GEOLOGICAL SURVEY OF NEW JERSEY

ANNUAL REPORT

OF THE

STATE GEOLOGIST

FOR THE YEAR

1893

TRENTON NEW JERSEY
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1894

NEW JERSEY GEOLOGICAL SURVEY

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VIII. CONGRESSIONAL DISTRICT.

HENRY AITKEN..Elizabeth.
WENDELL P. GARRISON...............................Orange.

* Deceased August 15th, 1894.

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To His Excellency George T. Werts, Governor of the State of New Jersey and ex-officio President of the Board of Managers of the Geological Survey of New Jersey:

SIR—I beg leave to present herewith the Annual Report of the Geological Survey for 1893.

Respectfully submitted,

JOHN C. SMOCK,
State Geologist.

TRENTON, N. J., January 16th, 1893.

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REPORT.

The Geological Survey for the year 1893 has been engaged in the continuation of the work on the surface formations of the State, on the greensand marl beds and the associated beds of the Cretaceous and Tertiary ages, on the study of stream-flow and the general questions of water-supply and water-power and on the examination of the clays of the State. The collection of artesian or deep-bored well records has also been continued. The preparation of collections representing the geology and the mineral resources of the State for a State exhibit at the World's Columbian Exposition at Chicago and the installation of this exhibit in the Mines and Mining building, have taken a part of the year. The division of the work has been in accordance with these several lines of investigation or study, and the chief or head of each department or division has directed the work in its details, following the general plan approved by the State Geologist. In this way the results have been reported, passing over the details of methods of work. Following this introductory and administrative report there are—

Part I. Surface Geology—Report of Progress.
Part II. Cretaceous and Tertiary Geology—Report of Progress.
Part III. Report on Archean Geology.
Part IV. Water-Supply and Water-Power.
Part V. Artesian Wells in Southern New Jersey.
Part VI. Minerals of New Jersey, with Notes on Mineral Localities.

SURFACE GEOLOGY

Professor Rollin D. Salisbury, of the University of Chicago, has been retained as geologist in charge of this division of the surface formations or surface geology. He was in the field five months and

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had five assistants during a part of the season. The State has had the advantage of the employment of Professor Salisbury and this corps of assistants trained by him for the work, at comparatively small cost, on account of his ability to give to it the vacation from his university duties, which was practically the whole of the field season. The allotment for this division is $3,000, which covers both field expenses and services while engaged in the preparation of the maps and reports.

This study of the surface geology was begun by Professor Salisbury in 1891 and reports of progress were published in the annual reports for 1891 and 1892. The mapping of the surface formations was begun the first season, and was continued last year. During 1893 it has been pushed vigorously and great progress has been made. The greater part of the work of the last field season was in the northern and central parts of the State, including considerable parts of the areas covered by the sheets Nos. 2, 3, 5, 6, 7, 8 and 9 of the topographic atlas. According to county lines the areas already mapped cover about one-half of Warren county, nearly all of Morris and Passaic counties, all of Bergen, Hudson, Essex, Union, Somerset and Hunterdon counties, nearly all of Middlesex and Mercer counties, and about one-half of Monmouth county. Some reconnoissance work has been done in the southern part of the State, preparatory to the detailed mapping. As was said in the report of last year, the great variation in the nature of the surface within short distances and the gradations from one type to another in these surface beds make it difficult to separate them, and determine their limits of outcrop and their relation to one another. The most casual observer of the surface can appreciate this fact of variation in the surface and the work to make a map of all of the varieties. The farmer looks upon them as soils and subsoils. The geologist is obliged to take into account the deeper beds also, including the soil as the weathered part. While the surface formations are the basis for a classification of soils they are not simply the soils in all their endless variety, but they are generic, embracing the latter as species.

The preparation of geological maps of the surface formations, separate from that of the underlying strata or solid beds, is new in our country, and New Jersey is again in the advance in beginning the publication of such maps. The topographic sheets are the basis for these new geological maps, which may be said to make a new series,

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distinct from the topographic by their geology and from the older geological maps in the absence of any representation of the older and underlying rock formations, except so far as the latter crop out and make the surface. They show the nature of the soils and subsoils in general, and the deposits of sands, gravels, peat, shell marls, and other earthy beds and also the bowlder-covered areas of the glacial drift. Sheet No. 6 of the atlas has been prepared for publication, and the edition has been ordered printed, as the first one to be issued. The other sheets are to be published as fast as they can be gotten ready.

One of the applications of these maps will be in the study of the soils and their proper classification according to origin rather than differences of physical constitution or texture, which are somewhat wide in variation and not clearly defined in classes or groups. The reference to origin in classification is scientific as well as practical.

The relation of the surface to forestry is another direction in which the work is of practical application. Wherever the ground is encumbered with bowlder drift, where the soil and subsoil are gravelly and open, or where the residuary formations of rock are unfitted on account of the thin earth covering to make a deep soil, the land is, perhaps, more productive in the cropping of wood than in tillage or even pasturage. The surface geology teaches us approximately the areas thus unsuited to profitable agriculture and better reserved for timber. Reference to this point was made in the report of last year. The renewed interest in the subject of forestry calls for the repetition of this particular application.

The description and maps of the peat or muck deposits, of the beds of clay, sand and gravel, and the broken-rock or talus areas, give information of value concerning the location and extent of valuable economic materials.

The discoveries of the probable outlet of the Upper Passaic valley and the old drainage lines previous to the coming of the glacier and the rise of the Lake Passaic may also have some important bearing upon the natural lines along which the reclamation of these undrained lands to agriculture may yet be accomplished with entire success.

Professor Salisbury has given on pages 325–328 some economic considerations in the last part of the section on Lake Passaic.

The general features of the glacial drift were outlined in the annual report for 1880, and the existence of a glacial lake (Passaic)

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was indicated. The extra-morainic drift was in part referred to as "transported glacial drift," and the yellow sand and gravel were designated as "pre-glacial drift." Professor Salisbury has studied thoroughly these several groups of glacial and pre-glacial formations, and has presented a clear and full report which corrects some of the earlier descriptions and adds largely to the details as to localities. He has succeeded in proving the extension of the ice beyond the line of the terminal moraine, and as far south as a line running from Somerville to Riegelsville, on the Delaware. The line of the terminal moraine is now accurately located on the State map accompanying the report, as also the localities where the extra-morainic drift is found. Much of this drift is apparently older than the last ice epoch. The probable southern limit of the ice also is shown on this map. Particular attention is called to this map as a most graphic illustration of the report and representative of the most careful and thorough detailed study of all that complex group of deposits heretofore termed glacial drift. It is desirable that this map should replace those of earlier reports, and also that the later names given to the several subdivisions should now be used. The solution of the problems regarding the extension of the ice, and the glacial character of much of the drift, and the determination of its relation to that of the terminal moraine, marks a great advance in geological investigation in the State, and is a contribution to the science of geology. The history of these ice invasions of our territory is interesting as deciphered in these deposits, aside from the practical results.

The existence of the glacial Lake Passaic has been fully made out, and the old shore-line has been surveyed and mapped. It is shown in detail on atlas sheet No. 6. The features of the old shore-line and its deposits of water-worn gravel, the wave-cut terraces and the deltas or deposits in the lake from the old shore drainage are shown. The northeastern limit, where the glacier, as a dam, shut in the waters of the lake, also is indicated. The islands, now parts of Long hill, Hook mountain, Riker hill, Preakness mountain and some of the high ground near Convent, and the long peninsulas of the New Vernon hills and the Basking ridge, are prominent features of the map. Probably no fact in our present geography is better attested than that of this lake, and the evidence is fully stated in connection with the description. The geological history here given will be the more fully appreciated as the drainage works of the valley are completed and

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the adjacent hill country is more fully occupied as residential territory by the inhabitants of our cities.

The study of the yellow gravels of the central and southern parts of the State has resulted in resolving this complex and hitherto perplexing group or series into clearly defined and characteristic members. Their relations to one another are traced out, and their earlier age demonstrated, although not yet correlated with entire certainty. The names Beacon hill, Pensauken and Jamesburg are taken from typical localities. The work of tracing the limits of these several formations is now ready to be done, and it can be carried forward with steady progress over a large part of southern New Jersey. This work on the yellow gravel is justly regarded as one of great importance in the domain of what may be called surface geology, and capable of wide application. The problem had been given much time, and the efforts of earlier years to solve it were unsuccessful, and the work on it was felt to be a failure. The success of Professor Salisbury is, therefore, recognized as worthy of this particular reference, and as one which throws a flood of light upon the geology of the southern part of the State. The elevations and submergences of the geologic age antedating that of the glacier or ice invasion, indicated by these several gravel and sand formations, are apparently part of a series of movements in our coastal region which are recognized as continuing in our times.

CRETACEOUS AND TERTIARY FORMATIONS.

The work in the greensand marl belt and in the newer formations of Tertiary age overlying the marl beds has been continued, and in co-operation with the United States Geological Survey. It is in charge of Prof. William B. Clark, of Johns Hopkins University, Baltimore. The Geological map published in last year's report, on the base of the United States Geological Survey sheets, shows the extent of outcrop of these marl beds in eastern Monmouth county. No attempt is made in this survey of the marl beds to show the limits of the later surface formations. The work already done on three sheets of the United States Geological Survey series is valuable for a new geological map of the State in a revised form and in much greater detail than that of the map published in 1868, and later on a State map on a smaller scale in 1888. The progress in the work has

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been steady although not as rapid as it might have been under more favorable conditions of larger appropriation and more help. The recent revival in the greensand marl trade in some parts of the State and the return to the use of this natural fertilizer, characteristic of the southern part of the State, so widely distributed and so accessible for extraction, suggest the importance of continuing the survey of the marl belt.

The investigation of the fertilizing action of the marls and the methods of application to the soil in order to the best results from their use has been suggested as important although not strictly in the line of geological studies. It may follow the completion of the map as an application of geologic science to agriculture.

The areal work of the year has covered 235 square miles, and the country between the Lakewood meridian on the east and that of New Egypt on the west. The limits north and south are the parallels of Freehold and Manchester, respectively. It is represented by the Cassville sheet of the United States Geological Survey. On account of the more recent surface formations concealing the Cretaceous beds over large areas, the determination of the geological boundaries was much more difficult than it was in the eastern part of Monmouth county, where the topography favored the work. By means of boring, the upper marl bed has been discovered at points hitherto unknown, thus proving the continuity of that bed further southwest.

Surveys were made of five section lines crossing the marl belt in a northwest-southeast direction and in the line of the dip of the beds.

The results appear to corroborate the statements of previous surveys of the marl belt as to the more important and more general facts of dip, thickness and the order of succession of the beds, but they do not give any additional information upon the variation in strike and in the thickness of beds, nor do they indicate any further subdivision, referred to in the earlier reports of the Survey. The topographic maps were used without the help of a detailed instrumental survey, essential to the accurate determination of the position of the beds in their relation to the topography.

Following the methods of the United States Geological Survey place names have been given to the large subdivisions. They are regarded as provisional. The old names, taken from the position of the beds and their mineralogical characters, have been used so long and have become so well known and familiar to the people living in

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this part of the State that it seems unwise to replace them by names which are not altogether representative of typical localities. An exhaustive survey, aided by instrumental observations, is necessary to determine the characteristic subdivisions of the beds as now known. These minor subdivisions were described in the earlier reports of the Survey and were recognized in the later studies of the marl beds.* Other subdivisions, particularly of the complex member of the series, known as "clay marls," are highly probable. The geologic units as accepted in this report are too large and are complex in character. Their subdivision must precede the adoption of any system of names. For the use of the farmers, the old names were practical and readily learned. They answer present needs. Therefore the proposed names are not here accepted as final, but as temporary and to be replaced by others, after a more thorough survey shall have been made of the whole Cretaceous and Tertiary series of formations—from the plastic clays to the upper marl bed and the later clays, sands and gravels. The present popular names may then give way to names representative of the several subdivisions in their typical localities.

ARCHEAN GEOLOGY.

The survey of the crystalline rocks of the Highlands has been carried forward by the United States Geological Survey, and has been in charge of Dr. J. E. Wolff, of Harvard University, Cambridge, Massachusetts. He was in the field through the summer and a part of the autumn. The work of mapping the several kinds of crystalline rocks is done on two sheets of the United States Survey, which are known as the Hopatcong and the Morristown sheets, or an area of about 450 square miles, although a part of the country covered by these sheets is of later age and not properly included in the limits of this survey. The topographic maps afford base for platting all field observations and the areal work done in detail gives an accurate representation of all the rock outcrops or exposures in their proper relations to one another. The earlier work of the State Survey in the crystalline-rock region of the Highlands lacked maps for the accurate delineation of results, and was therefore, of necessity, limited to attempts at generalizations on the division of the whole

*Geology of New Jersey 1868, pp. 241, *et seq.*
Annual Report State Geologist, 1886, pp. 157, 167, 172, 173, 175, 176, 181, 182.

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into well-marked belts or districts characterized by predominant rock species and types, or on the establishment of different horizons of gneissic rocks by stratigraphic work.

Dr. Wolff has prepared a paper on the geological structure in the vicinity of Hibernia in Morris county and its relations to the iron-ore deposits, which is published by permission of the director of the United States Survey, as Part III. of this annual report. The paper has a short reference to opinions on the occurrence and origin of these rocks given in previous publications of the Survey. A general description of the Hibernia region follows, with some details of the kinds of rock occurring there. The geological structure is considered, particularly in reference to the iron-ore deposits and their probable extension beyond the mine limits. The results of the detailed survey of this Hibernia mine district are discussed in their relations to the crystalline schists of the Highland region and the conclusions reached are clearly and succinctly stated.

The studies of Dr. Wolff bring out clearly the pitch structure and its relation to the foliation and the mineralogical constitution of the rocks. It is shown that pitch and foliation replace one another and that they are the results of compressing forces which acted contemporaneously with the metamorphosing agents. It is proper here to refer to the work done by Dr. Cook in his studies of the structural relations of the iron-ore beds.* The importance of a recognition of this type of structure was appreciated by the practical managers of the iron-mining companies and their mine superintendents.

Another important conclusion is that the whole series of rocks is of sedimentary origin and of Algonkian age. That they were once stratified and were subsequently altered to their crystalline structure and were not eruptive masses, corroborates the opinions and published statements of Dr. Cook on the sedimentary origin and bedded structure of the iron ores and the associated rocks, as opposed to the earlier views held by Prof. Henry D. Rogers and other writers.† The theory that these deposits of iron ore were once beds in shallow basins and of comparatively limited extent which afterwards were covered by deposits of earthy materials, not unlike formations now in progress,

* Geology of New Jersey, 1868, pp. 55, 333.
Ann. Rep. State Geologist, 1883, pp. 54-57.
Ann. Rep. State Geologist, 1886, pp. 95-97.

† Geology of New Jersey, 1868, pp. 331, 332, 532-534.

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is certainly consistent with facts of occurrence and analogous to what is going on at the present time.

The work of Dr. Wolff suggests as a practical lesson the search for the extension of the Hibernia ore-bed in a northwest direction, following the trend of the rock horizons above the ore which are traceable to the northwest. It also suggests the extension of this detailed survey over the whole territory of the Highlands and the careful study of its structure.

WATER-SUPPLY AND WATER-POWER.

The subjects of water-supply and water-power have been further investigated and studied by Mr. C. C. Vermeule, consulting engineer and topographer of the Survey. The results of his studies and surveys have been published in part in the annual reports for 1890, 1891 and 1892. During the year the collection and tabulation of data for the volume on water-supply have been carried steadily forward. Gaugings have been continued on the Raritan, Passaic, Delaware and Great Egg Harbor rivers. A series, seventeen years in length, has been computed for the Passaic, a most important contribution to the available statistics of stream-flow. The data collected for the report on water-supply have been of value in answering the questions on the character and extent of the flood-flows on the Passaic river in connection with the drainage works now being executed on that stream, and Mr. Vermeule has given some time to the investigation of these flood-flows for the use of the committee of the Board of Managers of the Survey appointed to examine the condition of the Passaic Drainage works.

Mr. Vermeule has prepared for this report a map of the State, showing the various water-sheds which are utilized for public water systems and those which are still available. The high water-sheds whence a gravity flow may be had are also indicated. It is a graphic illustration of the tabulated statement of the public water systems of the State as given on pages 378 and 379 of this report.

So much has been said in the various reports of the Survey on the subject of water-supply for the cities and towns of the State, that any additional statements might be regarded as unnecessary were it not that the importance of abundant supplies of wholesome water for the needs of the cities which are so fast covering the territory between

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the Hudson and the Watchung or First mountain is so great as to justify a repetition of what has been given in previous reports. The gathering-grounds in the Highlands are valuable on account of their sparse population and the large part of the territory which is in forest. The red sandstone country southeast of the Highlands is more cleared up and also more or less densely populated. And the population is advancing toward the hill-country of the Highlands, and, in places, towns, as Pompton, Boonton and Morristown, are spreading over the adjacent hills. The available sources of supply from the red sandstone are therefore destined soon to be in danger of pollution from the density of population. Besides, the water of its streams is more apt to be turbid by the material washed from the surface in heavy rainstorms. Hence the necessity of the cities to find their supplies in the streams flowing out of the hills. The height of the water-sheds of the Highlands also is in their favor, affording gravity supplies.

For the purity and healthfulness of the water of the streams in the Highlands, it is important that they be not exposed to the danger of pollution from the sewage of villages and towns, and also that the country which they drain be kept in forest. Tillage, with its ploughed fields and bared surfaces, tends to the more rapid delivery of the rains and the carrying away of the finer earthy materials in the soil, thereby loading the streams with matter in suspension. The more rapid discharge of the surface-waters means also the contamination of the stream-water by whatever noxious matters may occur in the soil. The multitudinous rootlets, the mass of fallen tree limbs and branchlets, the matted growth of lowly plant forms and the carpet of leaves, which mark the forested lands, hold back the waters and allow of their more equable discharge into the streams. They cover and protect the soil and prevent the steady degradation which is so characteristic of all bare lands. The difference in the degree of clearness or in the turbidity of the waters of streams flowing from woodland and from cleared, farm-land is well known to all careful observers. The Highlands of northern New Jersey are remarkable for the large part of their area in wood and so near to the great centers of population. The beauty of the scenery also makes it valuable as a great natural park, and as such it is an ideal territory in which to gather good water for the supply of our cities. The natural drainage toward the southeast seems to point to it as the district to which to look for this supply.

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It is important for the conservation of an equable flow of water that the country be kept in forest. Deforestation carried to the ultimate limit would make the streams draining this part of the State torrential in the wet seasons, and dry water-courses in the summer, and the amount of matter carried from the soil would be increased greatly. Such a condition is not anticipated, nor is it probable, but it is well to arrest the movement in that direction when it can be done easily and without much opposition. It may not be practicable for the State to acquire exclusive control by ownership in all or even a part of the Highlands, but it seems to be within its sphere to pass such enactments as shall protect and insure the continuance of a good supply of wholesome water for one-half of its population, and soon to become the much larger part. The clearing of the forest, and its conversion to farms, is not essential to the cause of agriculture, when there are so many unimproved tracts with greater capacity of production in the State and nearer to the great markets, hence it would not retard the development of the State to stop the work of clearing and the encroachment upon the forests of the Highlands, particularly wherever the surface is steeply sloping and liable to be exposed to the wash of heavy rains. Provision for stopping the work of clearing is not necessarily opposed to that of utilizing the timber resources. In all of this hill country the wood grows fast and the young growth soon becomes a forest covering to the hillsides, and protecting the surface. By means of a careful control and comprehensive management it would be possible to leave in forest a fair percentage of the whole area, and yet afford to agriculture the full equivalent of what is now in farms. The difference would be in the distribution of the woodland.

The large consumption of water by cities, and the rate of increase, viewed in the light of the prospective population of the part of the State near New York, is suggestive of demands which will eventually absorb the supply from the Highlands. The upper Delaware, above the Water Gap, may be needed for the cities on that stream. Mr. Vermeule has given in a tabular statement the consumption of the cities and towns of the State which have public water systems. The rapid increase in the number of localities and in the aggregate population which is thus supplied, is evidence of the importance of the question of water-supply, and seems to justify some more comprehensive treatment and that by the State. The Geological Survey has

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by its maps and reports indicated the location of the available watersheds and their capacity of delivery. Some facts as to the quality have also been given. It is about to prepare maps showing the territory in forest and the relations of the forests to these sources of supply. The limit of its investigation seems to be reached, and the further study of the relation of hydrographic basins to each particular city or point of reception appears to belong to the province of a more specialized bureau or State commission. A State water board would be able to make a practical use of these facts and provide a comprehensive and economic plan embracing all of the localities and the population wanting such supply.

The dangers in the use of some of our river-waters, which are in dry seasons polluted by sewage, are referred to in Mr. Vermeule's report. Such waters are offensive to one's *sense* of cleanliness if not threatening to public health.

The subject of water-power has received some attention in connection with the study of stream-flow. Electric transmission of power to distances greater than heretofore practicable, makes it possible to utilize water-power where it has not been of value, and attention is called to the many idle or unused mill-sites in the State which may thus be again set to work. A list of all these sites, as nearly complete as possible, is to be given in the forthcoming volume on water-supply and water-power.

ARTESIAN WELLS.

The report on this subject will be noted on pages 387–421 of the report. Mr. Woolman has continued to collect the records of wells put down in the southern part of the State. His diligence and enthusiasm in the work deserve a word of commendation, as it is so largely a labor of love. His report contains, in addition to the later records received, an interesting historical notice of wells in the southern part of the State and important generalizations on the water-bearing beds or horizons.

The specimens collected in the progress of this work during several years have been all arranged and labeled by Mr. Woolman and placed in the museum-room of the Survey, where they may be examined and studied in their proper relation to one another. The collection already contains about 500 specimens and is one of the most interesting and valuable in the possession of the Survey.

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These well-borings give vertical sections of the beds passed through and are valuable corroborative evidence of the geologic structure which is gathered from careful surveys of surface-sections. Their confirmation of the succession of the beds of the greensand marl series has been referred to in previous reports. Recently collected data from well-borings in Salem county show that the lime-sand of the middle marl bed is there 100 feet thick. Another notable discovery is the coarse gravel bed at the base of the Cretaceous beds in Camden county, near the Delaware river. Its correlation with the Potomac formation is referred to in Mr. Woolman's paper. The greater thickness of the clay series or Raritan formation also is indicated by some of the well records. Further studies, and aided by additional records, will no doubt modify to some extent our scheme of the Cretaceous and Tertiary formations in New Jersey.

The importance of artesian wells as sources of water-supply for domestic uses and for manufacturing establishments in certain isolated localities is growing as the population of our coastal belt increases and as new sites are laid out for improvement. Well-to-do farmers and their more wealthy neighbors who have country homes are putting down artesian wells for their home use. Wherever a deep-water supply is wanted to replace a shallow surface one which may be exposed to danger of pollution or is otherwise objectionable, the recourse is to these deep-bored or artesian wells.

The well sections have shown the existence of several well-defined water horizons, but there is still much to be learned, particularly in the clay-marl and the plastic clay series in the central and southern-central parts of the State, from the red sandstone country south and southeast to the marl belt. There are sandy beds in these formations which when pierced by wells should yield an abundant flow of water. It seems entirely reasonable to believe that they will yet be proven to be as truly water-bearing as the sand bed, which is at the top of the clay-marls and under the lower marl bed.

In the more rocky and the northern part of the State there are comparatively few deep-bored wells. They are nearly all in the red sandstone belt. The thick masses of drift in some of the valleys, as that of the Upper Passaic and others in the Highlands, ought to afford ground for artesian wells.

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DRAINAGE.

The Geological Survey is entrusted by law with the work of making surveys and plans for the drainage of lands "subject to overflow from freshets, or which are in a low, marshy, boggy or wet condition," whenever application is received from at least five owners of separate lots of land included in such wet tracts.* Under the provisions of the several drainage acts the work of draining the Great Meadows in the Pequest valley, Warren county, has been completed and has demonstrated the practicability of such drainage works. The Passaic drainage is still unfinished and the progress of the work has not gone far enough to afford much relief in times of flood and show what may be expected when completed. No work has been done on the Drowned Lands of the Wallkill. These three large tracts of wet lands were surveyed in 1869–71, and the reports and maps of the surveys were printed in the annual reports for those years.† The success on the Great Meadows of the Pequest continues to be shown by the profitable cultivation of the land formerly more or less flooded, and the large crops of celery, onions and potatoes. A part of the tract is still unimproved although dry enough for farming. Here as everywhere in the improvement of these wet lands, it is necessary to have open ditches, and to keep them cleared of any obstruction, so that the water in heavy rains may not accumulate in stagnant pools on the surface. The flatness of all of these tracts makes this care of the minor canals and ditches almost as important as the lowering and clearing of the main stream or channel. Since the work was done there has been some obstruction to the rapid flow by the trailing branches of the willows which border the stream below the bridge at Danville. The new railroad bridge, placed obliquely to the direction of the current, also tends to constrict the channel-way and slacken the flow. Further down some obstructions in shape of logs and stones have been noted. These accidental, and perhaps unavoidable occurrences, seem to call for some continued oversight or properly constituted authority to remove obstructions and to maintain a clear channel for the rapid

* See Ann. Rep. State Geologist for 1888, pp, 49-60.

† Ann. Rep. State Geologist for 1869, pp. 41–46. Passaic river wet lands.
Ann. Rep. State Geologist for 1870, pp. 65–67.
Ann. Rep. State Geologist for 1870, pp. 69-73. Pequest wet lands.
Ann. Rep. State Geologist for 1871, pp. 15-20. Drowned Lands of the Wallkill.

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delivery of the flood-waters as planned in the drainage works. According to the drainage laws there is no remedy except the appointment of a new commission. The following extract from last year's report is more pertinent now than it was at that time: "It would seem as if there should continue in force some commission of drainage works or joint supervision by a representative body from the several land-holders. The interest of the land-owners in any drainage scheme and in its continued success should be the basis for any provisions made for continued supervision, and be in harmony with our common views of republican form of government. The representatives of the people of the locality, that is, the owners in question, are entitled to authority. Some amendment of the general drainage laws of the State is wanted to give authority to the representatives of the associated land-owners who may wish to have the benefits of a drainage project continued after the work has been done and the commission has ceased from its authority. The Pequest drainage needs it, and the delay in clearing obstructions, which may increase in the future, is threatening the permanence of the improvement. It is not necessary to refer to failures in the case of smaller experiments or projects for drainage, to enforce the argument for continued watchfulness on the part of some authorized representative of the owners in the case of the Great Meadows tract or other tracts which may hereafter be improved. Abandonment means loss of property and discouragement to others contemplating such improvements."

A history of the work was given in the annual report of the State Geologist for 1884, and the need of some supervision to be continued was then noted by Dr. Cook.*

Work on the Passaic drainage has been suspended on account of the financial stringency of the times and the difficulty in securing the funds necessary for the additional outlay. The question of the style of gates to be put in at Little Falls, is under consideration by a committee of the Board of Managers.

The wet lands of this Upper Passaic valley are interesting geologically, as they represent the lower and imperfectly drained bottom of an extinct glacial lake (Passaic), which has been described at length in this report (see pages 225–328), and whose limits are shown on the map accompanying the report.

The Drowned Lands of the Wallkill, in Sussex county, and in

*See Ann. Rep. 1884, pp. 119, 120.

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Orange county, New York, await further improvement and relief from flooding. The outlet ditch at Denton carries all of the water of the Wallkill. The continuation of the work of lowering the stream and the cutting of side canals and lateral ditches is necessary. This tract is not so near to market as those on the Passaic, but it has excellent meadow lands on its border, and the soil of the whole tract is susceptible of a high state of cultivation. It ought to be improved.

The Paulinskill meadows, near Newton, in Sussex county, also need to be drained. There are several other wet tracts in the State which might be drained profitably, but which cannot be improved except by associated effort or by the direction of a commission, as provided for in the laws upon the subject and under plans indicated by the Geological Survey.

The improvement of wet lands adds to the arable territory of the State, and increases the productiveness in a greater degree, inasmuch as these improved tracts are on the average more fertile than the upland or adjacent hill land, and they are more easily tilled. They are not so seriously affected by droughts, being more like lands which are irrigated. Their reclamation is important in the general State economy, in that they add to the area of producing land and allow of the reversion of the more stony hillsides and mountain slopes to forest. If a part of the farm population, which is now struggling to earn a scanty subsistence on the bowlder-covered, thin soils of some of the mountain sides, could be transferred to these rich, black, loamy soils of the Great Meadows of the Pequest, or of the Drowned Lands of the Wallkill and the Passaic valley, with their drainage works completed, the gain to the State in the total production and in the total valuation would be large enough to meet the expenses of these drainage improvements. The advantages from a sanitary point of view alone seem to be enough to justify the cost of draining, aside from the indirect benefits from the general improvement in the public health.

RECLAMATION OF TIDE-MARSH LANDS.

The reclamation of the tide-marsh lands is allied closely with drainage improvements, although the tidal marshes are not included in the wet tracts which come under the provisions of the drainage laws. The work done in the southern part of the State has not been extended over the whole of these strips of marsh, but over the more

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favorably situated tracts, and where the soil was a more solid mud or clay loam. The depression in the prices of farm products and the lower valuation of all farm land have tended to contract the limits and stop the extension of the system. The results have, however, been such as to show that these lands were profitable farm lands. The first cost and the expenses of maintaining the embankments have deterred farmers from adding to their banked-meadow tracts, and in some cases have allowed them to return to their original condition of tide meadows.

In the eastern part of the State there have been very few individual experiments in reclaiming these meadows. The failure on the Hackensack meadows has hindered further associated efforts, and there are no examples for the encouragement of capitalists or land-owners to follow in the work. The last report referred to the subject, and a part of the report was devoted to the description of the methods practiced in the Netherlands and their application to New Jersey.* This paper has not produced any results in the way of experiments in reclaiming any of the vast stretches of tidal marsh which fringe the upland on the Atlantic side of the State nor of the more accessible and advantageously situated Hackensack and Newark meadows. Attention is again asked to these tracts and their value as reclaimed lands for the production of all market-garden crops.

NATURAL PARKS AND FOREST RESERVATIONS.

Reference was made in the last annual report to this subject. The situation of the State, so near to New York and Philadelphia, the topographic features of the northern part, and the climatic advantages and general healthfulness, favor the establishment of reservations for the benefit of the residents of these cities and of the cities and towns within the State. The accessible and attractive localities and districts near New York, in the northeastern part of the State, have been appreciated and have afforded sites for many beautiful country homes. The suburban residential districts are remarkable for their natural beauty, and the improvements due to the landscape architect. There is, however, a large aggregate area in these suburban districts which is still awaiting the touch of the artist hand. The resources of the

*Ann. Rep. State Geologist, 1892, pp. 331-353.

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State in these hills and valleys, and in the features of its topography, which are capable of artistic improvement, are as substantial and as important as its mineral and farm lands, and their prospective value beyond our most sanguine expectation. The large share of the annual appropriation given to the study of the surface geology makes it particularly pertinent to direct attention not only to the geologic features of the surface, but also to the intimate relation between them and the elements of natural scenery which make the country attractive. The characteristic features of the hills, valleys and plains are owing to the agency of geologic forces, and the later shape given to the surface is all explained by the survey of the surface formations. Some of the more striking and characteristic features deserve preservation for their educational value. They are historic tablets of geology for the use of students in the future as well as of those to-day.

In a utilitarian aspect these physical features have an importance worthy of attention. The opportunities and facilities for an outing, so near our large towns and cities, offered by them, are not yet so well known as they should be nor so thoroughly appreciated even by those familiar with them. The Palisade range, overlooking New York City and harbor and the adjacent country for miles away, the bold trap-rock ranges of Watchung mountains, with their high points and wide views over the Passaic and Hackensack valleys and the plain country to the south, and the more distant Highlands afford sites where the advantages of healthfulness are united with those of scenic beauty of the bolder kind, while the valleys with their lakes offer more restricted views but more quiet elements of landscape beauty. The appreciation of these country charms is not, however, within the range of the masses of our city population. The educational and moral value of an outing where man can touch as it were nature is well known, and the provision for this teaching of nature should be at least considered by all who are interested or engaged in the uplifting of the less favored classes, who live crowded together in our cities. To discover the localities easily accessible and valuable because of their characteristic features of surface it is necessary to survey the country with this object in view. The topographic maps of the Survey show the shape; the forthcoming geological maps will show the nature of the surface and point to the later geologic changes which have fashioned it and given it character. There remains the

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examination of the forest and of the peculiar features which may give value for reservations or natural parks.

Reference has been made under the head of Water-Supply to the Highlands and to the importance of keeping a part in forest. The creation of a great park like that of the Adirondacks in New York or the Algonkian in Ontario, Canada, is not possible and yet the great value of the more mountainous and uncultivated areas in which rise the streams that are to supply our cities with water, as gathering-ground, is suggestive of some kind of public or State protection. The reservation of these lands for water-supply is consistent with the proposition of a natural park, accessible under proper regulations to the public. It is connected also with the subject of forestry control, and its maintenence is possible by a judicious and economic forest administration. The details as to localities cannot be given here. They are to be presented in a future report on our forests, and in particular the forests on the water-sheds of the Highlands.

The attention of our cities to the subject of parks near or within their limits has been aroused, and the Survey has been asked for information for their help in locating them to advantage. It is proposed to show by maps the more desirable tracts of woodland or unimproved lands near populous centers which are advantageous for such public parks.

The example of the Metropolitan Park Commission of Massachusetts, which has for its object the consideration and selection of valuable open spaces in the vicinity of towns near Boston, is worthy of careful study by the inhabitants of the group of cities which are growing toward one another in the country between the Hudson river and the Watchung or Orange mountain. Magnificent sites remain on the hills near these cities, but there is a remarkable absence of open spaces in the cities of Paterson, Newark and Jersey City.

MINERALS AND MINERAL LOCALITIES.

The last part of this report, pp. 423–442, is devoted to a list of the useful minerals and mineral substances which occur naturally in the State, and to notes on the localities and modes of occurrence. It is necessarily incomplete because of change in the arts, so that what are now comparatively valueless or of no economic importance may become of use in the extension of the field of applied science. Again,

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improved methods widen the range whence materials are drawn and utilize what may have had no value. Our ignorance as to the location of ores and deposits of mineral substances and their extent also makes our list wanting in many particulars. The discoveries of the future alone can fill these unknown or scarcely recognized gaps.

In the arrangement of the list there is no division into "mined" and "not mined" minerals, as is done in the volumes on "Mineral Resources of the United States," issued by the United States Geological Survey, but reference is made in the notes to use or active conditions. The metallic minerals, or what may be termed metallic ores, are given first; then the non-metallic, which include all the other minerals of economic importance. The order is in general in conformity to that of Dana's System of Mineralogy. Where there are many localities, as in the case of iron ores, copper ores and others, the districts or belts of territory in which they occur are stated instead of an enumeration of localities, mines or quarries. The more common minerals are represented by the localities where they occur to a workable extent, although it is not to be assumed that they are present in all these places in quantity for profitable working, but rather as deserving of further examination and thorough exploration, and nearly all of the localities are those which have been worked to a greater or less extent, although in many cases not developed into producing mines or quarries.

The materials which are used in construction and in agriculture are generally composite mineral substances and cannot be grouped under the simple mineral species. The structural materials include building stones, roofing slates, flagging stones, clays, sands and limestones for limes and cements. They are rocks and not simple minerals, although included under the general head of minerals. The marls, peats and limes under the head of fertilizers also are composite in mineralogical constitution. These groups follow the simple minerals. Road-making materials are at the end of the list.

The notes have been made as short as possible and at same time convey needed general information. Specific data about localities was impossible, and, in order to furnish some help to those using the list, references to the reports of the Survey were appended, wherein descriptions of occurrence, of extent of working, development and history are to be found. Other references and to publications outside of the Survey are not given, although there are many articles

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in the scientific journals which contain valuable information particularly on the geological and mineralogical relations of the ore deposits of the State. A list of all of the mineral localities, with references to all publications bearing upon them, would be too large for an annual report. The present one is tentative and preparatory to such a larger and more nearly complete list. It is designed as a guide to the various mineral districts or divisions of the State, and in some degree to localities of occurrence, and to be a help to both the capitalist seeking new avenues of investment and the prospector or explorer in search of particular ores or minerals of use in the arts. The republication of the list in an enlarged form in another annual report is dependent upon the value of the help which this one is found to afford.

WORK OF THE UNITED STATES GEOLOGICAL SURVEY IN THE STATE.

The United States Geological Survey has continued its field-work in the Highlands, in the study of the crystalline rocks, and in mapping the areas occupied by them. Dr. J. E. Wolff, of Harvard University, has had charge of it. The allotment for the work has not been adequate to the employment of any assistants, and has not been sufficient to keep Dr. Wolff in the field throughout the whole field-season. Important results have, however, been reached in the survey of the crystalline schists, and some of the more practical applications are given in the report communicated through the permission of the director of the United States Survey.

The co-operative work in the southern part of the State has been continued under the immediate direction of Dr. William B. Clark, of Johns Hopkins University. He has had the assistance of R. M. Bagg for a part of the season. The expenses of this division of the work have been borne conjointly by the Federal and the State Surveys. The appropriation by the State has been limited by the small amount of funds available for this part of our work. The whole amount allotted to it has not been sufficient to make such detailed surveys of the section lines as are necessary to a thorough study of the geologic structure of the greensand marl beds and the later formations associated with them, and at the same time carry forward the work of mapping these several formations. A larger appropriation is needed to do this work and to make progress commensurate with what is done in the

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division of surface geology. The work on the geological maps might be suspended without any serious disadvantage to the practical interests of the State, and the whole appropriation be put on the study and survey of such sections as are so situated as to yield the most valuable stratigraphic results, were it not required on the part of the Federal Survey to produce geological maps as illustrative of work done.

It is to be hoped that the allotment by the State may be made considerably larger after the survey of the surface formations shall have been completed.

GEOLOGICAL SURVEY EXHIBIT AT THE WORLD'S COLUMBIAN EXPOSITION.

The material for the State exhibit in the division of Mines and Mining at the Exposition in Chicago was in part collected in 1892. In the northern part of the State, Harry Landes, an assistant of Dr. J. E. Wolff, of the U. S. Geological Survey, collected representative specimens from the various geological formations and from the active quarries, and other economic products. This collection was made in the latter part of the season. In the southern part of the State, Henry L. Gane, assistant to Prof. William B. Clark, spent a large part of the summer and autumn of 1892 in collecting work. The iron ores from the mines then worked had been collected in 1890 by Frank L. Nason, of the Survey staff.

Early in the year Mr. Nason was engaged to take charge of the preparation and installation of the exhibit. The collections brought in during the preceding year were opened, and from them and the material remaining from the State museum, representative and choice specimens were selected. It was found necessary to collect additional material, in order to a complete exhibit, particularly of the economics, and a part of the early spring was devoted to the work of obtaining suites from the zinc mines of Sussex county, the quarries in the red sandstone and the clay district of Middlesex county. A collection of minerals of the Sussex zinc mines also was secured by him for the use of the Survey at the Exposition. After the preparation of the material, and in April, the exhibit was shipped and the work of installation was begun in the Mines and Mining building. The interval of time after its arrival and the opening date was short, and it

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was only through great effort that it was ready for exhibition at that time. The unforeseen contingencies connected with the preparation and installation of the exhibit, and circumstances over which Mr. Nason had no control, made his labor severe as well as trying, and his success in getting all in presentable form was highly creditable to him.

The State exhibit consisted of representative specimens of the various geological formations, of the ores of iron, zinc, copper and lead, and some of the associated rocks, of limestone, slates, building stones, clays, marls, sands and of other natural products of economic importance. A small and carefully selected collection of the minerals of the State was also in the exhibit. The maps and other publications were included in it, and two mine models. One of the latter, a model of the Washington iron mine, Morris county, was loaned to the Survey by Mr. Frederick A. Canfield, of Dover, a member of the State Commission. The central piece in the space alotted for the State exhibit was occupied by the relief map of the State on the scale of the maps of the topographic survey. It was prepared from designs by the consulting engineer and topographer, C. C. Vermeule, and under his direction, at his office in New York City. In accuracy of representation of topographic detail it was the best State relief map in the Exposition, and it called out much favorable comment as well as some criticism on the disparity of scale. The construction of this map was found to be a much greater piece of work than was expected at the outset, and it was not completed until nearly a month after the opening of the Exposition. There was a lack of surface finish due to this want of time, and on this account it failed to attract the general attention which it deserved. Its late arrival was also a disturbing element in the orderly arrangement of the whole exhibit.

No attempt was made to get specimens of extraordinary size for the exhibit on account of the great expense incidental to the collecting and transportation and the want of room in the exhibition space, and therefore it was perhaps not so impressive or striking as those of other States. The aim was to make it instructive and comprehensive in illustration of the geology and the natural resources of the State.

The location of the State exhibit was on the ground floor of the Mines and Mining building. To Hon S. J. Meeker, President, and Mr. Walter S. Lenox, Secretary, of the New Jersey State Commission, credit is due for the favorable location of the exhibit, as

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well as for their constant effort in seeking to make it worthy of the State. The construction of the booth was under their supervision and from designs selected by them.

The painstaking labor and enthusiastic devotion of Mr. Nason in the work of installation won for the exhibit a general expression of admiration for the neatness of arrangement and beauty of display of the material at his command. The collections were under his care until the 1st of July, when he returned to New Jersey. Unfortunately the Survey was not able to retain Mr. Nason throughout the season in order to attend to the inquiries of visitors to such an exhibit. During the remainder of the Exposition, Prof. S. R. Morse, of the State school exhibit, gave some time to the general oversight of the attendant in care of the cases and their cleaning.

At the close of the Exposition the collections were packed by Hatfield Smith, general assistant, who had assisted in the installation work. They were stored, at the request of the Commission, in the Fidelity Warehouse and Cold-Storage Company's warehouse in Trenton. It is hoped that they can be released soon and can be incorporated in the collections of the Survey in the rooms in the State House, or form a part of a larger collection in what might be known as a State Museum. The various exhibits of the State made at the Exposition would form a valuable nucleus for a museum at the Capitol, to which there would be a constant influx of interesting historic and educational material representative of what there is in the State in natural products capable of development, as well as of what has been done by the forefathers and what is being done in the education of the children.

GEOLOGICAL ROOMS.

The room on the third floor of the old library extension part of the State House, given last year to the Geological Survey by the State House authorities for the exhibition of its collections, has been in part furnished with the old cases which were in use at the Centennial Exposition in 1876, and later in the museum of the Survey. They have been placed on the floor so as to form an alcove-like arrangement and have been used for the exhibition of rocks, minerals, ores, clays and other geological specimens. Several cases of drawers belonging to the Survey, which had been stored in the basement rooms, have also been placed against the walls of the room for holding

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collections not necessary for general exhibition. Duplicate material also is placed temporarily in these drawer-cases. On one side of the entrance, shelving has been built against the wall for the collection of woods of New Jersey. For the iron ores a large case has been set up at the corner of the room. Little space is left for additional cases excepting in the center of the room, and it is reserved for the relief map of the State. A large and beautiful relief map of the United States on a spherical projection, from E. E. Howell, of Washington, D. C., has been added to the collections in the room. It has been well mounted and has attracted much attention and afforded a great deal of graphic instruction in the geography of our country. The relief map of the State, when placed on the floor by it will make another excellent geographic illustration and in more detail of surface configuration and hydrography.

Mr. Harry Landes, formerly assistant to Dr. J. E. Wolff, of the United States Geological Survey, and collector for the State Survey in 1892, was engaged about December 1st to unpack and arrange the various collections of the Survey which had been in part stored in the basement. The work at the time of this writing is nearly done and the cases are nearly all filled with the material thus stored, and exclusive of that which was sent to the Columbian Exposition. The old collections made by the Geological Survey under Dr. William Kitchell in 1854–6, and which were stored in drawers in the old museum, were examined carefully in order to identify them by locality, but on account of the loss of some of the labels and the carbonization of many more of them in the State House fire in 1885, comparatively few of the specimens were with certainty identified and incorporated in the collection on exhibition. The remainder of this collection was repacked and stored in the basement, and marked "Kitchell collection." The large mass of material which had accumulated during the long superintendence of the Survey work by the late Dr. Cook was also examined carefully, and a selection was made of all the specimens which were suitable for exhibition or which were valuable for reference. Many of them are types of descriptions or of analyses in the reports. Localities were represented in all cases, so far as any specimens could be found. Variations in the character also were illustrated as far as possible. Those of historic importance, as in the development of mines, quarries, clay banks, marl pits, &c., were also retained in the reference collections. The comparatively

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small part of unimportant and practically worthless material in these old collections was thrown out, in order to economy of storage space for what had to be deposited in boxes in the basement. Mr. Landes has thus examined all of the old stock of the Survey, excepting a few boxes of paleontological specimens and the collections of the State exhibit at Chicago. New labels have been written for all, care being taken to retain the old ones. The duplicate specimens and those illustrating localities of occurrence and not otherwise notable have been classified and arranged by localities under their several heads: geological specimens, rocks, minerals, ores, clays, marls, sands, &c. They are in the old drawer cases, and are easily accessible to those in pursuit of particular information as regards locality or mode of occurrence. The old museum exhibition cases, sixteen in number, are filled as follows: Two at the right hand on entering the room have a small synoptic collection, showing representative rocks of the various geologic formations; two are devoted to minerals; four are occupied by a collection of the characteristic fossil forms from the Cretaceous and Tertiary beds. On the left side two are filled with clays, fire-sands and other refractory materials; two have specimens of economic geology, and four contain a series of the rocks of the State. The iron ores have all been arranged by mines and by counties in a large case at the corner of the room. For want of drawer room many of the clays and all of the marls and soils and other earthy specimens in glass boxes and show boxes have been placed on the shelving above wall cases. The large collection of specimens from artesian wells are stored in drawers awaiting new cases for holding them.

The collection of crystalline rocks from the Highlands, made by Mr. Nason while on the Survey staff, is for the present kept intact in drawer cases.

The present arrangement of cases leaves little more space than is desirable for ease of access and movement of visitors about the room. The introduction of the Exposition cases and the addition of the State exhibit from the Exposition will leave exceedingly narrow aisles and floor room for circulation about the cases and crowd to an extent which is unfavorable to an instructive and pleasing exhibition.

The Geological room has been open a part of the time each week and a curator has been appointed by the Superintendent of the State House, to have the care of it and to attend to visitors. The number

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of visitors has increased, although the work of arrangement has interfered with seeing, and has made the room at times unsightly and disappointing. As the work nears completion there is apparently greater interest shown by a more careful examination and by larger attendance.

CHEMICAL LABORATORY.

In accordance with a resolution of the Board of Managers, passed at the meeting in June, Professor A. H. Chester, of Rutgers College, was engaged to direct the chemical investigations and analytical work needed by the Survey. The leading object in making this engagement was to get the clays of the State analyzed and tested, for use in the forthcoming report on the clays and clay beds. Professor Chester's report shows what has been done since the opening of the laboratory late in September:

"January 10th, 1894.

"*Prof. J. C. Smock:*

"DEAR SIR—In response to your inquiry I would say that chemical work for the Geological Survey of New Jersey is constantly in progress here, Mr. Myers spending more than half of his time on such work under my immediate direction. He is now engaged on the examination of a mineral from Franklin Furnace, which appears to differ from any found there before, and perhaps from any previously found in this country. It is one of the alteration products of biotite, and its investigation will perhaps throw some light on the genesis of our important zinc and manganese deposits. Work on clay samples is also in progress, with a view to a fuller investigation than has hitherto been made of the chemical composition of these most valuable deposits. Several samples of limestone have been completely analyzed and reported upon, and also two samples of drift gravel, with the view of ascertaining their relative age.

"Work here will be pushed as fast as is consistent with accuracy.

"Respectfully yours,

"ALBERT H. CHESTER."

OFFICE WORK.

The general direction of the several divisions of work which are carried on by the Survey, the superintendence of the arranging of the collections in the rooms in the State House and the official correspondence, have taken a large part of the time of the State Geologist. The answers of an official character demanded by the numerous in-

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quiries relating to the State and its geology, physical geography and natural resources have been greater than ever before. They continue to have a wide range and in many cases call for chemical examination of specimens. The want of a laboratory where analyses and tests can be made, has been in part filled by the arrangement made with Professor Chester, of Rutgers College. It is believed that the information which is thus given specifically in answer to requests has a practical value as important as that which is published in the reports, and care is taken to answer as fully as possible all questions which appear to have any bearing upon the development of the resources of the State.

The demand for the publications of the Survey continues large and their distribution takes some time on the part of the office. The calls for reports have been larger than in any previous year, particularly from educational institutions. The reports are all distributed from the office. The maps of the atlas of New Jersey for the public schools of the State, are also sent out from here. The distribution of the topographic maps is made from New Brunswick, and is in charge of Mr. Upson.

PUBLICATIONS.

The publications of the Survey have been increased during the year only by the annual report. It is expected that the volume on the water-supply and the water-power of the State in the series of the final report will be ready for publication in the course of a few months.

There is still a large demand for individual sheets of the topographical atlas, and new editions of two of the sheets have been published.

STAFF OF THE SURVEY.

Prof. Rollin D. Salisbury is in charge of the survey of the surface formations. He has H. B. Kümmel, Charles E. Peet and G. N. Knapp as assistants.

Clarkson C. Vermeule, consulting engineer and topographer of the Survey, has continued his studies of the questions of water-supply and water-power preparatory to a report on the subject.

Irving S. Upson has charge of the sale of topographic maps from New Brunswick. He is also the disbursing officer of the Survey.

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In co-operation with the United States Geological Survey, Prof. WILLIAM B. CLARK, of Johns Hopkins University, Baltimore, was in the field a part of the season, studying the Cretaceous and Tertiary formations. He was assisted by R. M. BAGG.

In the Highlands the survey of the crystalline rocks was under the direction of Dr. J. E. WOLFF, of Harvard University, and of the United States Geological Survey.

ALFRED A. CANNON is clerical assistant to Mr. UPSON, at New Brunswick.

HATFIELD SMITH remains as general assistant at Trenton.

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UNITED STATES COAST AND GEODETIC SURVEY OF NEW JERSEY, 1893.

BY EDWARD A. BOWSER.

In the month of June an observing tower 32 feet high was built at Pine Hill to enable us to see over the tall timber to Mt. Holly, Berlin, Williamstown and Taylors. From June 28th to July 5th the observing signals at Williamstown, Taylors, Lippincott, Mt. Holly and Berlin were re-adjusted, and a vista was opened at Mt. Holly on the line to Pine Hill. On July 6th the measurement of the horizontal angles at Pine Hill was begun and completed on August 2d

On August 4th the instruments were moved to Lippincott, where an observing tower 32 feet high was built to enable us to see over the tall timber to Burden and Taylors. On August 12th, 14th and 15th observing signals were erected at Colsons and Burden, and the one at Taylors re-adjusted. On August 16th the measurement of the horizontal angles at Lippincott was begun. On September 5th a granite monument was set at Burden. This monument is 4.5 feet long, dressed 6 inches square at one end for a length of 6 inches, with the letters U. S. cut in each of the four sides and a triangle on the top. It was set in hydraulic cement to within 6 inches of the top, and a full description, with sketch, was made of it. In digging the hole for the monument we found two pieces of the cone which had been set in 1843. On September 12th the measurement of the angles at Burden was completed, and on the next day the instruments were moved to New Brunswick.

In November the latitudes and longitudes were computed of the two primary stations, Pine Hill and Lippincott, and the nine tertiary

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points, Williamstown Church, Atco, Glassboro, City Hall in Philadelphia, Clarksboro, Swedesboro, Chester, Salem and Port Penn Light.

The next stations to be occupied are Burden and Bridgeton, requiring observing towers 64 feet high, and probably vistas will have to be opened through the tree-tops on the lines Burden-Bridgeton and Burden-Pine Mount.

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PART I.

SURFACE GEOLOGY.

REPORT OF PROGRESS

BY

ROLLIN D. SALISBURY.

NEW JERSEY GEOLOGICAL SURVEY

SURFACE GEOLOGY—REPORT OF PROGRESS.

1893.

BY ROLLIN D. SALISBURY.

PREFACE.

During the summer of 1893 I spent about five months in the field. During portions of that time I had the assistance of Messrs. H. B. Kümmel, C. E. Peet, A. R. Whitson, G. N. Knapp and J. A. Bownocker. Mr. Bownocker was a volunteer assistant and was in the field three months. Messrs. Knapp and Whitson were there for the same length of time, and Messrs. Peet and Kümmel for a somewhat longer period. Work was carried on in several different regions, and involved the study of various problems connected with the surface geology of the State. Glacial studies were prosecuted in the northern part of the State, chiefly in the regions covered by sheets 2, 3 and 7. The study of extra-glacial surface formations was also prosecuted, chiefly in the areas included within the limits of sheets 5, 8 and 9. The mapping of the area covered by sheet 5 is essentially completed. Relatively little remains to be done on sheet 2, and sheets 3, 7, 8 and 9 are well advanced.

During the season additional light was thrown on several of the questions which had been referred to, or discussed in a preliminary way, in previous reports. In the last annual report I indicated that a sufficient body of evidence had been found to put beyond doubt the fact of the former existence of the glacial Lake Passaic, reference to which had been earlier made by Professor Cook. The general nature of this evidence was briefly discussed. During the later part of the past summer (1893), Mr. Kümmel devoted several weeks to the more detailed study of this lake, this portion of his work being

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done without compensation. The results of his study, together with some further observations of my own, are embodied in our joint report.

The peculiar and significant relations and position of the Palisade ridge, with reference to the direction of ice movement, as well as its proximity to the great center of population, made it seem desirable, both from the geological and economic standpoints, to study its drift phenomena with much care. During the later part of the summer Mr. Peet made a somewhat detailed study of the surface features of this ridge and gathered many interesting facts. Some of these results, together with the results of some studies on my own part, are embodied in the joint paper by Mr. Peet and myself. (See section on Palisades mountain.)

Further attention has been given to the extra-morainic drift in the western part of the State, first mentioned in a paper read before the Geological Society of America, in August, 1891,* and referred to later in my report for 1891. The glacial origin of this drift was soon afterward called into question by the Professors Wright, who maintained that much of the so-called drift was not drift at all.† In the last annual report I discussed somewhat more fully the question of the origin of this drift, because of the differences of opinion which had arisen concerning it. I there showed that it was impossible to refer it to local rock decay, as had been suggested by the Professors Wright. There can no longer be any doubt concerning the glacial character of much of the extra-morainic drift, since even those who disputed its glacial origin subsequently satisfied themselves that it is glacial. The southern limit of extra-morainic drift which is believed to be glacial has been accurately determined for the western part of the State, and every area where it occurs or where, in the present condition of surface, its existence can be determined, has been seen and studied. All localities in the western half of the State where it occurs in considerable quantity, as well as the line marking its extreme southern limit, are indicated on the map accompanying this report. I am not ready to affirm the distinctly glacial origin of the drift in

* Bulletin Geological Society of America, Vol. 3, page 113, August, 1891.

† Their published statements on this point have appeared in various places, among which may be mentioned, 1°, G. F. Wright, Proceedings Acad. Nat. Sci. of Philadelphia, December, 1892; 2°, American Journal Sci., Vol. 44, 1892, page 351; 3°, A. A. Wright, American Geologist, 1892.

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each one of the localities designated on the map, though the larger part of it is believed to be due directly to glacier ice. Some of it, and just how much can perhaps not be determined certainly, was probably deposited by water, in connection with ice. The chapter on the extra-morainic drift presents some data in addition to those which have already been published. This report is based in part upon the work of Messrs. Kümmel, Peet and Whitson. While data are at hand for a fuller discussion of this subject than appears in this report, it has been thought best to reserve it for a subsequent report.

In connection with the study of the glacial drift of the latest ice invasion, some points of interest are developing in the northwestern part of the State. Among these may be mentioned the important influence locally exerted by stagnant ice, in determining the character and disposition of the deposits of drift. Reference is made to some of the peculiar phenomena to which the stagnant ice gave rise, further on in this report.

In the same region the existence of a subordinate terminal moraine, a moraine of recession, has been discovered, though its limits have not been determined. Balesville, four miles north of Newton, marks one point in its course. Thence it runs eastward to Ogdensburg, beyond which point it has not been followed.

The mapping of the terminal moraine has been completed and is represented on the accompanying map. Upon comparison, it will be seen that its course corresponds closely with that published long since. The apparent changes in position, where such occur, are due to differentiations which have been made since the original mapping rather than to errors in that mapping. Some of the drift which is regarded as the work of water beyond the edge of the ice was then included within the moraine itself. It will be remembered, too, that the original mapping attempted to give only the outer limit of the moraine, and did not in any way purport to represent its width. A brief sketch of the moraine and its relations is given in another section of this report.

The problem of the yellow gravels which has always seemed a difficult one, and which has until now remained unsolved, seems to be gradually untangling itself. I now have reason to hope that the history of this formation can be worked out with reasonable fullness and with approximate accuracy. While many data are in hand concerning it, the limits of this report make it impossible to do more

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than indicate, in a brief way, the conclusions to which our study seems to be leading. The history of the formation appears to be very complex. The statements concerning this formation are based in considerable part on the work of Mr. Knapp.

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SECTION I.

THE YELLOW GRAVEL.

It was indicated in the last annual report that the history of the "Yellow Gravel" formation was likely to prove very complex. The work of the past summer has tended not only to confirm this conclusion, but to indicate that the history of the formation is even more complex than was then thought, and that the sands and gravels which have passed under a single name, were deposited at very different times and under very different conditions. Instead of three more or less distinct historical stages in this formation, as was suggested in the report for 1892, it seems probable that four are to be recognized. All present conclusions, however, are subject to change in the light of further study. It is hoped that when the whole area covered by this formation, or by these formations, shall have been studied, conclusions will have been reached which can be relied upon with confidence.

As now interpreted, the oldest phase of this formation is represented in various localities, and in various topographic relations. Towards its northern limit, it occurs in isolated areas of small extent, and considerable, though unequal, altitude. Further south it covers larger areas which are less widely separated, and which lie at lower altitudes. Still further south the formation becomes continuous, if present interpretations be correct.

Isolated areas.—1°. The gravel reaches its maximum elevation on the tops of some of the Mount Pleasant hills, south and southeast of Matawan. It is especially well developed on Crawford's hill, and on Telegraph and Beacon hills. On the highest of these, its upper surface reaches a maximum altitude of nearly 400 feet *A. T.* The altitude of the base of the formation cannot be determined here with accuracy, but it is probably not far from 360 feet.

2°. On the tops of the highest Sand hills, a few miles north of Monmouth Junction, there are, at a few points, traces of gravel, amounting to no more than scattering pebbles, which are regarded as the remnant of the oldest division of the "Yellow Gravel," and which are therefore correlated with the gravel on the Mount Pleasant

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hills. It is not determined whether or not the sand of the Sand hills, or any part of it, is to be correlated with the same formation. The traces of gravel on the Sand hills cannot represent a horizon higher than the very base of the gravel, since no more than the merest traces remain. The highest point of the Sand hills is a little less than 300 feet, or about 100 feet lower than the top of the gravel which caps the highest of the Mount Pleasant hills, and about fifty or sixty feet below its base, as nearly as can be determined.

3°. Four or five miles west of the Sand hills there is an area of gravel at a maximum elevation of 321 feet, which is to be correlated with that of the Mount Pleasant hills. This remnant of gravel is much more considerable than that on the Sand hills. Its base is slightly higher than the highest point of the Sand hills.

4°. The gravel capping of the Navesink Highlands, with a maximum altitude of about 300 feet, is to be correlated with that of the other localities mentioned. The formation here embraces all the sand and gravel which lie above the Middle Marl. The sand and gravel together have here a maximum thickness of about 100 feet, so that the base of the formation is considerably lower in the Navesink Highlands than in the Mount Pleasant hills. It is a fact of significance also that the base of the formation is lower at the east end of the highlands than at the west, and lower along the south side than along the north. At the east end of the highlands its base has an altitude of no more than 180 feet, and is therefore about 180 feet lower than the corresponding horizon in the Mount Pleasant hills.

5°. The gravel capping many of the higher hills in the vicinity of Perrineville and Clarksburg, eight or ten miles southeast of Hightstown, is believed to be the equivalent of that on the Mount Pleasant hills. The upper surface here reaches a maximum altitude of 378 feet. In the northern hills of this area, the bottom of the formation is at least 100 feet lower than its summit, and its base is nearly or quite 100 feet below the corresponding horizon at Beacon and Crawford's hills. A little further south, between Clarksburg and Prospertown, the lower surface of the formation declines to about 200 feet.

6°. Southwest of the Perrineville-Clarksburg hills, equivalent gravel and sand caps many of the higher hills and ridges of the area extending from Ellisdale and Hornerstown on the northeast to Fountain Green on the southwest. None of these areas rise much above

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200 feet, and the base of the gravel and accompanying sand steadily declines in this direction.

7°. The Juliustown ridge and Arney's Mount, north of Pemberton, are heavily capped with sand and gravel, which is to be correlated with that of the localities already mentioned. The sand and gravel here are largely cemented into sandstone and conglomerate. The highest point of Arney's Mount is 230 feet, but the base of the sand and gravel formation in the Juliustown ridge may be seen to be low, certainly not more than 120 feet above sea-level, and it may be as low as 100 feet, so far as is now known.

8°. The same formation caps Mount Holly at the village of the same name.

9°. The summit of Mount Laurel (173 feet), four miles southwest of Moorestown, has an undetermined thickness of gravel and conglomerate which is to be correlated with that of the foregoing localities.

10°. The Hominy hills, north of Farmingdale, are made up principally of sand and gravel, which is believed to correspond in age with the sand and gravel of the localities already mentioned. If this be true, the formation has here a much greater thickness than at any of the other places. The highest of the Hominy hills has an elevation of 308 feet. The base of the formation here has not been accurately fixed, but so far as present knowledge goes it may be as low as 125 feet. This would give the formation a thickness of nearly 200 feet at this place. If this be true, the sand and gravel of the Hominy hills is barely isolated from the corresponding formation of other areas near at hand.

The foregoing are the principal localities where the oldest phase of the "Yellow Gravel" occurs in isolated areas.

Constitution of the sand and gravel.—The sand and gravel of the several areas enumerated is far from uniform in character. Indeed its lithological diversity is so great that the foregoing correlation was slow in suggesting itself. There may be said to be three more or less distinct types of material embraced within the limits of the formation which is here considered as a unit. There are (1°) *coarse gravel*, whose constituent pebbles are predominantly more than an inch in diameter; (2°) *fine gravel* with a matrix of sand, the constituent pebbles being mainly less than one-fourth of an inch in diameter and almost wholly of white or transparent quartz; and (3°) sand.

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The coarse gravel is well shown on Beacon hill, on Crawford's hill and at certain points on the Navesink Highlands, in the Hominy hills and in the Perrineville-Clarksburg hills. The pebbles are of white, whitish or yellowish quartz, of chert, flint and sandstone.

The quartz pebbles are of various types and were derived from various formations. Some of them appear to have come from the vein quartz of the crystalline rocks to the north. Others were derived from the quartz veins of the Hudson river sandstone. Such pebbles have a characteristic columnar structure which prevents them from becoming well rounded. The chert is frequently soft, the result of chemical changes undergone since its deposition. Silicified fossils, derived from Paleozoic formations, are present, though they do not usually constitute any considerable proportion of the formation. The color of the sandstone fragments which enter into the formation is always light.

The pebbles often range up to three inches in diameter, and in the case of the sandstone they are frequently still larger. Cobble stones of this material are not rare, and masses one and even two feet in diameter are not unknown. These large pieces are rarely or never round. They are slab-like masses, but their angles and fracture faces are always somewhat water-worn. The coarse gravel sometimes has a sandy matrix, and sometimes a matrix which contains much earthy material.

The fine gravel, or conglomerate, is well shown on the Juliustown ridge, on Arney's Mount, on Mount Laurel, on Stony hill, near Ellisdale; on many of the hills about Perrineville and Clarksburg, at certain points in the Navesink Highlands and in the Hominy hills. Exact localities where this gravel is well exposed are the following: (*a*) On Arney's Mount, where the gravel is partly cemented and has been quarried; (*b*) in the road cut across the east end of Stony hill, near Ellisdale, where the gravel is not cemented; (*c*) in the cut along the east-west road across the 302-foot hill, a mile southwest of Perrineville (see topographic map); (*d*) on the east slope of Pine hill, two miles east of Perrineville, at an elevation of 240 feet, where numerous blocks of conglomerate occur, though no vertical exposure.

The pebbles of this type of gravel are mainly of quartz, which is almost uniformly white or transparent. The pebbles may be well rounded or angular. Chert is sometimes found, but is much less abundant than in the coarse gravel. The matrix of this fine gravel

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is sand, and the two constituents are combined in varying proportions. About the grains of sand, and about the tiny pebbles imbedded in it, there are frequently films of clayey matter, which is white, or sometimes pinkish. If the sand or gravel be handled, this clayey matter stains the fingers just as plastic clay does when handled.

In connection with the composition of the gravel, certain negative considerations are as significant as positive ones. The formation is almost as well characterized by what it does not contain as by what it does contain. The underlying Cretaceous beds contain abundant iron oxide concretions, as well as thicker and thinner beds of sand or marl, firmly cemented by iron oxide. But no single piece of ferruginous conglomerate or sandstone, and no single iron oxide concretion, except such as have been formed *in situ*, has ever been found in the formation under discussion. That is, the Cretaceous formation made little or no contribution to the overlying sand and gravel formation. This it would certainly have done had the surface of the Cretaceous been roughened by erosion when the sand and gravel beds were deposited upon it. No trace of material of Cretaceous origin anywhere enters into the sand and gravel formation, except at its very base. The relationship of the two is just what it would have been had the latter formation been deposited on the even surface of the former. Furthermore, no single pebble or fragment of limestone, shale of any sort, granite, gneiss, trap, gabbro, or Triassic sandstone, has anywhere been seen in the formation. In one or two instances pieces of quartz schist, containing a little mica or talc, have been seen, but these are extremely rare.

The third phase of the formation is sand, which is often white, but which frequently has a pinkish or yellowish tinge. The pinkish sand may be seen at numerous points about Clarksburg, while the white sand is conspicuous in the Hominy hills. The sand is almost wholly of quartz.

Many localities may be found where these three phases of the formation seem very distinct from each other, judged from the standpoint of physical constitution. At first, too, there seems to be some stratigraphical ground for their separation. In places the sand seems to underlie the fine gravel, and the fine gravel appears frequently to underlie the coarse. The possibility of a threefold division of the formation was long entertained, the division to be based both on stratigraphical and lithological grounds; but detailed study has

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developed the fact that there is every mixture of the three types. There are numerous places where materials corresponding to those of the coarse gravel are mingled with tiny quartz pebbles, which are identical with those of the fine. When the fine gravel is studied in detail, it is found that its matrix sometimes predominates over the pebbles to such an extent that only an occasional pebble remains. That is, the fine gravel often becomes sand, by the exclusion of the pebbles.

The mixture of types is not confined to combinations of the coarsest with the intermediate, or of the intermediate with the finest. The coarsest is often mingled with the finest. There are many places where the sand has been cemented, and the sandstone may be seen to contain large pebbles indistinguishable from those of the coarsest gravel, while no small pebbles are present. Sand which is not cemented may likewise contain a few large pebbles, where no small ones are present. Still again, sand which is either cemented or not may contain either few or many large or small pebbles, associated with each other in any proportion whatsoever. From the physical standpoint, therefore, there is no sharp line of division between the three types. They are simply the middle and extreme terms of a series which ranges from coarse gravel to fine sand.

The types are not only mixed, but they also intergrade to such a degree that between the coarse and the fine types there are all possible grades. A similar relationship also exists between the fine gravel and the sand. This is well shown in the Navesink Highlands at many points.

If these gradations existed in a vertical sense only, there might still be a threefold division on stratigraphical grounds. But this is not the case. The gradations are horizontal as well as vertical. Furthermore, there are not wanting many localities where the coarse material occurs in beds below the sand and the fine gravel, as well as above them. Locally it occurs at the base of the formation, and may occur at any horizon between the base and the summit, as well as at the summit itself. This may be seen at many points in the Navesink Highlands, in the Hominy hills and in the Clarksburg area. In spite of this, it still remains true that on the whole coarse gravel seems to be most abundant at the surface. and that the fine material predominates beneath; but the significance of this is liable to misinterpretation. In many cases at least, the apparent abundance of the

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coarse material at the surface is the result of erosion. From the hill-crests, the fine material has been carried away, while the coarse, being beyond the power of surface-drainage to handle, remains, protecting the surface against further degradation.

It should be stated that the relations here sketched are in part matters of inference. The coarse material may be seen above the fine at most points where the formation occurs, but there are few sections where the coarse can be seen to underlie the fine. Nevertheless, the coarse and the fine may be seen in such relationships at many points as to make it certain that they are variously interbedded vertically, and that the one may give place to the other laterally. Thus, near the south extremity of the Navesink Highlands, coarse gravel may be seen to exist considerably below the summits of some of the hills, where pits have been opened in it, while the tops of the same hills are of sand and sandstone, altogether free from gravel. The same relationship may be seen on the hill (267 feet) a few miles southwest of Red Valley. In the Hominy hills the same relationship is more fully illustrated. Thus, a 308-foot hill is heavily capped with gravel, while a 264-foot hill, a quarter of a mile further north, is covered with sand only, and a crest at 245 feet, but a few rods east of the latter, is heavily capped with gravel. In the same immediate vicinity a 220-foot crest is altogether free from gravel, while a crest at 190 feet is heavily covered with it. Two or three miles further east, a 244-foot crest has no gravel, while a bench on the side of the same hill, at an elevation of 190 to 200 feet, has a heavy bed of gravel upon its surface.

The only possible inference from these facts seems to be that in the Hominy hills region gravel existed at various levels before the area was cut up into hills by erosion. Those hills whose summits correspond to an original gravel horizon have gravel upon them; those hills whose summits do not correspond to such a horizon, have none. It is probable, too, that the gravel horizon is not always continuous for great distances horizontally. This may account for some of the above facts in connection with the distribution of gravel, but it does not at all militate against the general conclusion that coarse gravel occurs at various levels from base to summit of the formation here under consideration.

If the correlation here suggested be correct, there are several points of significance in connection with the distribution of the gravel and accompanying sand.

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1°. In most of the foregoing localities, it caps the summits of isolated elevations, which, in all cases save one, stand very much above their surroundings. This point is of significance in that it indicates the great amount of erosion which has taken place in this area since the gravel was deposited.

2°. In a group of elevations, such as the Mount Pleasant hills, the gravel is less abundant, or sometimes altogether wanting on the lower hills, even though they fall but little below the level of the highest. Thus, Crawford's hill, at an elevation of 391 feet, is heavily capped with gravel (estimated at forty feet), while Beers' hill, by its side, at an elevation of 347 feet, has but the merest trace of gravel upon it. This phenomenon, repeated many times in several different localities, shows that the bed on which the gravel was deposited, was substantially plane.

3°. The gravel attains its highest altitude, so far as concerns both base and summit, in the Mount Pleasant hills. From this point it declines to the northeast, to the Navesink Highlands, and to the southwest, to Mount Holly and beyond, along the strike of the formation. This suggests that the underlying Cretaceous beds were deformed after the deposition of the gravel, and that they were uplifted more in the Mount Pleasant region and less to the northeast and southwest.

4°. Along the belt of isolated areas of the gravel under consideration, that is, on the Navesink Highlands, the Mount Pleasant hills, the Perrineville-Clarksburg hills, and all the hills mentioned, southwest to Mount Holly and Mount Laurel, the formation rests on Middle Marl. Conversely throughout this belt from Navesink to Mount Holly, there is not a hill in which anything like the full thickness of the Middle Marl is present which is not capped with the gravel and sand. When these two facts are duly considered, the facts (*a*) that within the area specified no hill without Middle Marl has gravel, and (*b*) that no hill within this area in which the Middle Marl is present in any thickness is without gravel, it is clear that *the gravel of this belt was deposited while the Middle Marl still formed a continuous bed over it.* The thickness of the Middle Marl is often no more than twenty-five or thirty feet, and its greatest recorded thickness is, we believe, less than fifty feet.* It follows, then, that the gravel was deposited before the Middle Marl was eroded to any con-

*Clark, Annual Report New Jersey Survey, 1892, page 203.

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siderable extent, and since the Middle Marl is so thin a formation, it follows that the gravel was deposited before the Cretaceous surface of this belt had suffered much erosion. This is the same conclusion to which the point first suggested (1° above) led, and it is further not only consistent with another inference already suggested, viz., that the gravel was deposited before the deformation of the Cretaceous beds (3° above), but, in a measure, corroborates it. All these considerations, each of which increases the weight of the others, indicate that the age of the gravel is very great.

5°. The altitude of the base of the formation becomes less and less to the southeast, in the direction of the dip of the underlying formations, indicating that this formation, as well as the Cretaceous, dips in that direction.

6°. The degree of dip of this formation, where determined, is approximately the same as that of the underlying Cretaceous; but from the fact that it overlies different formations in different areas, the dips of the two formations cannot be strictly coincident.

Name.—This formation is well developed and well exposed on the summit of Beacon hill, three miles south of Matawan, and in this report the formation will be known as the Beacon hill sand and gravel.

Where the formation attains great thickness, sand predominates over the gravel; where it is thin, gravel is the more conspicuous element. Even where the sand constitutes the body of the formation, the gravel is often the more conspicuous element at the surface, for reasons already indicated. The very existence of the hills in many cases depends upon the presence of the capping of sand and gravel.

Possible traces of Beacon hill gravel north of the Cretaceous belt.—The gravel referred to in the Sand hills, and the more considerable area west of the same, are north of the main Cretaceous area of the State, but not beyond the northernmost outliers of this formation. The considerable body of gravel which lies west of the Sand hills and east of Rocky hill (at 321 feet) rests on Raritan clay, thus departing from what is the general rule in the case of the isolated areas, that the gravel rests on Middle Marl; but there is no evidence that the Middle Marl ever extended so far north as to the Sand hills, so that the relationship here indicated cannot be interpreted as meaning that the Cretaceous surface was eroded before the gravel was deposited.

In the vicinity of Rocky hill there are numerous areas, large and

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small, which are much higher than the area of gravel referred to, but on none of these elevations about Rocky hill, or further north, is there any trace of the formation under discussion. Meager traces of gravel occur at various points along the south base of First mountain, but always considerably below the level of the gravel near Rocky hill. These traces of gravel are possibly, but not probably, to be correlated with the Beacon hill gravel. The yellowish sands about Basking Ridge may prove to be the equivalent of the oldest phase of the yellow gravel.* Their altitude is somewhat greater than that of the gravel at any of the points where the formation has been certainly identified, but their correlation is uncertain.

Certain traces of yellow gravel have been found in the drift on Palisade ridge, as far north as Weehawken, at an elevation of 160 or 170 feet. Possible traces of it have been found as far north as the latitude of Englewood, at an elevation of 360 feet. As heretofore indicated,† some evidence of its existence has been found north of Second mountain, in the vicinity of Union Village. Scattered pebbles, not to be distinguished from those of the yellow gravel have also been noted between Feltville and Washingtonville. In these latter positions, the traces found are so very meager as not to warrant very positive conclusions concerning them. These meager remnants, as well as the general topographic relations of the formation, are such that it is probable that the formation was once continuous far north of isolated areas heretofore mentioned.

Outside of New Jersey, yellow gravel occurs on Staten Island and at several points in Pennsylvania, especially west of Philadelphia, at Bryn Mawr and Media. The relation of the gravel in these places to the various phases of the formation in New Jersey, has not been especially studied.

Continuous and nearly continuous areas of Beacon hill gravel and sand.—From the north side of the Navesink Highlands to the south, the base of the Beacon hill gravel declines at a rate which is not very different from that at which the Cretaceous beds decline in the same direction. The gravel also occurs on the westward continuation of the Navesink Highlands, about Chapel hill. Here also the base of the gravel is found to be highest to the north, and to decline to the southeast, in the direction of the dip of the Cretaceous strata. Following

* Annual Report, 1892, page 153.

† Annual Report, 1892, page 152.

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southeastward in the direction of the dip, the gravel, and its sandy equivalent, is found on the hill east of Red Bank, where its base is no more than 130 to 140 feet above the sea-level. Between Chapel hill and the hill east of Red Bank, the base of the formation declines to the southeast at the rate of twenty-five to thirty feet per mile. At Crawford's hill, the base of the formation has an altitude of about 360 feet. Five and a half miles to the southeast, near Phalanx, the base of the formation has an elevation of about 170 feet. The lines connecting these two points are nearly at right-angles to the strike, and indicate a dip of nearly thirty-five feet per mile. Similar calculations, based on measurements in the Perrineville-Clarksburg area, indicate that the base of the formation declines to the southeastward, in that region, at a rate varying from twenty-five to thirty-five feet per mile. If the base of the formation continues to decline to the southeast at any such rate as this, for any considerable distance, it will be readily seen that at no great distance the base of the formation must cease to stand at any considerable elevation above the sea-level.

To the north, the formation occurs in isolated areas, because erosion has cut out the valleys between the hills. This was possible because the area had considerable elevation, and the base of the formation was far above sea-level. To the south, where the base of the formation is lower, and especially where it approaches or reaches the sea-level, the streams are incompetent to cut through it, and therefore to separate one part of it from another. The isolated areas of the Beacon hill sand and gravel are therefore necessarily restricted to that part of the formation the base of which was well above sea-level. South of the line where the streams have cut through the Beacon hill gravel, it should constitute a continuous formation.

When the area south of the region where the Cretaceous beds come to the surface is studied, sand and gravel are found, which it is believed are to be correlated with the sand and gravel of Beacon hill. They constitute a widespread and continuous formation over a very wide area.

If the base of the formation has an elevation of 360 feet at Crawford's hill, and if it declines steadily to the southeast at a rate of thirty feet per mile, it would reach sea-level at a point twelve miles distant, that is, in the vicinity of Green Grove, six miles northeast of Farmingdale. There are no exposures at this point by which the facts for this immediate locality can be determined. But three miles

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further south the formation is exposed at sea-level, and there is here nothing to indicate that it is the base of the formation which is seen.

How much further south it would be necessary to go, in order to find the point where the upper surface of the formation reaches sea-level, depends upon the thickness of the formation. This point has not been determined. Its thickness at various points is known, but at none of these points does the present thickness present the original thickness. The cappings on the isolated hills represent merely the remnants which have escaped destruction. The full thickness of the formation, if it anywhere exists, must be to the south, where the formation was never elevated enough to suffer degradation. If the formation continues to dip to the southeast, at the rate which has been observed along its northern border, it is possible that the original thickness of the formation is still preserved over a considerable area in the southeastern part of the State.

Summary.—According to the foregoing interpretation, the Beacon hill sand and gravel is a formation resting, along its northern border, upon the surface of the Cretaceous, dipping to the southeast at an angle which corresponds approximately, but not exactly, with the angle of dip of the Cretaceous. The lack of correspondence is indicated by the fact that the formation rests in one place on the Raritan clay, further south on Middle Marl, and still further south on Upper Marl. It was deposited on the surface of the Cretaceous before the latter was eroded to any considerable extent, and while it was still approximately level. Subsequent to this deposition, the Cretaceous surface on which it rests was uplifted, but uplifted unequally. The area about the Mount Pleasant hills was raised more than the area to the east, and the area about Clarksburg was raised much more than the area further southwest. The maximum elevation would seem to have been in the region of the Mount Pleasant hills.

Following this elevation, the surface of that part of the gravel which was raised to a considerable height was subjected to extensive erosion. Valleys were cut, not only in the sand and gravel, but quite through the same, through the Middle Marl on which the sand and gravel rested, through the Red Sand into the Lower Marl, and sometimes even into the Clay Marl, beneath the Lower Marl. By the excavation of such valleys, which were wide as well as deep, remnants of the Beacon hill gravel came to rest upon the tops of very considerable hills.

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Further to the south, where the elevation was less, the valleys cut themselves less deeply into the surface, and the areas retaining their cover of gravel and sand are less widely separated from each other. Still further southeast, where the elevation of the sand and gravel was still less, the streams were unable to cut through the same, and the formation remains to this day continuous. It does not, however, constitute the surface formation over a large part of New Jersey. Over much the larger part of the area south of the Cretaceous belt, the Beacon hill sand and gravel is covered by later formations.

If the present interpretation be correct, the Beacon hill gravel includes much that has been looked upon as Miocene, and much which has been looked upon as post-Miocene. But no sufficient reason seems to exist for the separation of that which has been regarded as Miocene from that which has been thought younger. No affirmation is here made concerning the age of the formation. This question will be best discussed later. It may here be said, however, in anticipation of the discussion, that at present there are no sufficient stratigraphic grounds for asserting either that the Beacon hill sand and gravel is Miocene or that it is not.

Erosion following the uplift of the Beacon hill formation.—A few words should be added with reference to the duration of the period of erosion which followed the deformation of the Cretaceous and Beacon hill beds. The history of this elevation as to time, rate and extent, has not been determined so precisely as could be wished; but it is certain that a very long period followed, during which erosion was in progress along the belt over which isolated areas of the Beacon hill gravel and sand are now scattered. It would seem that the erosion which followed the elevation was sufficient to allow of the reduction of the general surface of the land something like 200 to 250 feet in the region of the Mount Pleasant hills, and 150 to 200 feet in the Sand hills and Clarksburg regions. This does not mean merely that valleys 150 to 250 feet in depth were excavated in the gravel-covered tract, but that most of the area covered by gravel was cut down to some such extent, and that the valleys were cut to still greater depths. It is probable that the total elevation which succeeded the deposition of the Beacon hill gravel exceeded 250 feet in the Mount Pleasant region, for there seems to be good evidence that certain valleys were cut during this time to a depth much greater than would have been

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possible had the land surface been lifted no more than 250 feet. This elevation may have taken place slowly or intermittently.

It is probable that the valley now occupied by the Millstone river was excavated during this erosion interval, near Kingston, to a depth not less than 250 feet below the level of the gravel capping of Rocky hill, three or four miles to the north. Certain facts from other regions point to similar conclusions concerning the amount of elevation and erosion which followed the deposition of the Beacon hill gravel. If, after the deposition of the Beacon hill gravel, the same was elevated to such an extent that erosion lowered the general surface 150 to 250 feet, in the Mount Pleasant and Perrineville regions, leaving only isolated hills corresponding to the original surface, and if after this amount of erosion had taken place the surface was again elevated high enough and long enough for the excavation of valleys 100 feet or so deep in the surface which had already been cut down 150 to 200 feet, this course of events would seem to harmonize with present evidence.

THE SECOND STAGE OF THE YELLOW GRAVEL.

During the period of degradation following the uplift of the Beacon hill sand and gravel, much of the eroded material was carried from its original position, and deposited, either in the valleys of the streams, or in the sea into which they flowed. Some of it, too, was doubtless scattered over the slopes of the hills which were isolated by the development of valleys which started on the yellow gravel surface, but which soon found themselves in the underlying Cretaceous or Miocene. (?)

After some such amount of uplift and erosion as suggested above, it would seem that the eroded surface which the Beacon hill formation had covered and on the higher points of which it still remained, was depressed, so that areas which are now 150 to 200 feet above the sea, and 200 and 250 feet below the tops of the highest gravel-capped hills in the Mount Pleasant and Perrineville areas, were submerged. The Mount Pleasant and Perrineville hills, as well as most of the hills heretofore mentioned as capped by the Beacon hill gravel, are believed to have stood as islands in the sea, which encroached upon the low land between them. Further south the whole of the Beacon hill gravel was submerged. Indeed it is not at all certain that the Beacon hill formation in the southeastern part of the State was

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brought above sea-level at the time of the uplift of its northern edge. If it remained below the sea during the period of erosion first sketched, sedimentation must have been uninterrupted in the south-eastern part of the State, from the beginning of the deposition of the Beacon hill sand and gravel till the close of the second formation of yellow gravel.

At the bottom of the shallow sea, which occupied the area which had been a low land surface just before, there was more or less gravel, when the sea covered it. This had been subaërially deposited in the valleys during the period of emergence and degradation. With the loose gravel which had descended from the hills, there were associated more or less conglomerate and sandstone, derived from the cemented gravel and sand. These masses of conglomerate and sandstone were of various sizes, and were subjected to various degrees of wear. With the gravel derived from the Beacon hill formation, there was more or less material derived from the underlying Cretaceous beds. This consisted in part of loam, marl and sand, and in part of ferruginous sandstone, furnished by the cemented layers of Cretaceous sand and marl.

Constitution of the second yellow gravel formation.—Into the shallow sea, land drainage brought gravel from the few areas which were high enough to stand as islands above the sea, such as the Mount Pleasant and Clarksburg hills, the Sand hills, &c. Along with the gravel, the stream brought much more sand, marl and clay, derived from the Cretaceous beds beneath the gravel. Masses of the ferruginous conglomerate, large and small, were brought down with the loose gravel, and with the reworked Cretaceous material, so that the new deposit was more heterogenous in composition than the preceding. All these materials were deposited in the sea, on what had been, at an earlier stage, a land surface. The deposits in the sea buried such materials as had been subaërially deposited in the valleys, and on the gentler slopes at an earlier time.

In addition to the heterogeneity brought about as indicated above, there seems to have been a new supply of material introduced from some outside source. The gravel of this second epoch of deposition frequently contains pebbles or cobbles, or rarely even bowlders of various sorts of rock which do not, so far as known, exist in the Beacon hill gravel. Granite, gneiss, Triassic shale and sandstone, gabbro and trap although unknown in the Beacon hill gravel, occur,

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even if but sparingly, in the second phase of the yellow gravel complex. Quartzite, too, very unlike anything which occurs in the Beacon hill gravel, occurs in this second member of the yellow gravel series.

Except the quartzites, all these types of rock bear conclusive evidence of extensive decomposition since the deposition of the formation in which they occur. It is the rule, rather than the exception, that masses of these various sorts of rock, even when a foot or more in diameter, are so thoroughly decomposed that they can be cut with a trowel. In some places, even where they are abundant, not a pebble or a cobble of crystalline rock can be found which is not so far decomposed as to be unable to withstand the pressure which can be applied by the hand. In the case of large pieces, deeply buried beneath the surface, the central parts are sometimes firm and relatively fresh, though the outer portion, for some considerable distance from the surface, is thoroughly decomposed and sometimes so far altered as to make it altogether impossible to recognize the nature of the rock from its exterior. A conspicuous example of this was afforded by a large gabbro bowlder in the extensive excavations along the railway near Jamesburg.

The decomposed condition of the crystalline-rock constituents of the formation may be studied at the very coarse gravel pit at Kingston, where the base of the gravel referred to the stage here described, has a low altitude. The decomposed pieces of granitic material are here abundant. The same thing may be seen in the vicinity of South Amboy, where the bits of granitic material are smaller, but thoroughly decomposed. At this place, two bowlders of highly garnetiferous gneissic rock, more than two feet in diameter, were seen, quite unlike any rock which is known to occur *in situ* within the limits of the State. A single bowlder of coarse-grained gabbro, more than two feet in diameter, was found at Jamesburg. No rock of just this sort is known to occur *in situ* within the State. Indeed, a source whence the bowlder might have come is not known. The decomposed condition of the granitic and trappean material is well shown also in the fine section afforded by Hylton's pits, southwest of Palmyra. So widespread is the granitic and gneissic material in this phase of the yellow gravel, and so uniformly is it thoroughly softened through decomposition, that its presence and its condition become diagnostic marks of the formation.

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Many, if not all, of the quartzite bowlders which are found in this formation, are such as might have come from the Green Pond mountain conglomerate formation, but many of them are not distinctive.

It has been current belief that the absence of Triassic shale was a distinctive feature of the yellow gravel; but this is not the fact. The shale is by no means one of the principal constituents, but it is one of the most widespread. It is rarely so abundant as to make the appellation "Yellow Gravel" a misnomer, but it seems to be nearly co-extensive with the formation itself. As indicating something of its range, it may be stated that the red shale has been seen about South Amboy, at Jamesburg, near Allentown, at Hylton's pits near Palmyra, and east of Woodstown. It has been doubtfully recognized also near Bridgeton. No piece of Triassic sandstone or shale has ever been seen in the gravel which was not thoroughly softened by decomposition.

Sandstone, somewhat closely resembling the sandstone (approaching a quartzite) which is now found *in situ* in the vicinity of Succasunna, are found in this phase of the gravel formation. It is, however, not at all certain that they came from this region. In no single case has so much as a pebble of limestone been seen in the formation. The chert which it contains is frequently soft, readily crumbling to powder.

The bowlders of crystalline rock, presumably of northern origin, are much more abundant toward the northeast limit of the formation than elsewhere. They are very rare south and southeast of a line running from Cheesequake creek to Jamesburg. Along the Delaware they extend much further south. Their apparent absence south of the Cheesequake may be due in part to the less extensive exposures of this region, but it is certain that this cannot account for the full measure of the apparent difference.

Something has already been said concerning the size of the bowlders of this formation. Some of them are two, three, and even four feet in diameter, and if the conglomerate masses from the earlier Beacon hill gravel be taken into account, even larger bowlders occur. The Triassic shale and sandstone masses, as well as some of the others, often have a slab-like form, rather than the rounded form and well-worn surfaces proper to bowlders. Even the bowlders of trap, gneiss, &c., where not so far decomposed as to have lost their original form, are quite likely to be somewhat angular, or at any rate not well worn.

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It is not easy to see how bowlders of such size, and from such distant sources, could have reached their present positions without the aid of ice. The constitution and structure of the sand and gravel in which they are imbedded give positive evidence that water was the principal agent concerned in their deposition. The inference, therefore, is that such ice as may have aided in the carriage of the bowlders, was floating ice. The existence of bowlders suggests a possible connection with the earlier epochs of glaciation, though no single glaciated bowlder has been seen in the sand or gravel referred to this epoch. None, indeed, except the quartzites have sufficiently withstood the disintegrating effects of subsequent time to show striæ, even if they once existed in abundance. With increasing distance from the highlands, these coarse materials become less abundant, and the Cretaceous and the Beacon hill beds become the principal sources of material for the second stage of the gravel.

Distribution.—The material which is tentatively referred to the second yellow gravel formation, overspreads the higher areas about Hightstown, Dayton, Jamesburg, Dunham's Corners, South River and Old Bridge. It is known in the vicinity of Recklesstown, near Bustletown, and near Palmyra. It occurs to a limited extent north of Raritan bay. Throughout most of this area it is covered by a few feet of loam, which is believed to be of later origin. Further southeast this formation is doubtless widespread. As already noted, it is probable that much of the southeastern part of the State did not rise above the sea-level at the close of the Beacon hill epoch; and that from the beginning of that epoch to the end of the epoch during which the second stage of gravel was deposited, sedimentation was there uninterrupted. To the north two remnants of this formation are known, north of Raritan. The beds are here chiefly of sand, and furnish most of the sand which is used in Raritan and Somerville.

The upper surface of the second stage of the yellow gravel formation has a maximum elevation of 180 to 200 feet in the Perrineville region; 120 or 130 feet in the vicinity of Hightstown; 160 feet in the vicinity of Jamesburg; 150 to 160 feet at South Amboy and Old Bridge; 100 feet near Bustletown; and 80 to 90 feet south of Palmyra. It possibly reaches a greater elevation in the vicinity of the Mount Pleasant hills. It will be noticed that it is somewhat higher in the east-central part of the State than elsewhere, as if, in the course of the elevation which has taken place since it was formed, the

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eastern-central part had been elevated rather more than the western or the extreme eastern. Along the line of strike of the Cretaceous beds, however, its altitude is subject to less variation than that of the Beacon hill formation.

This formation is well exposed at many points, among which the following may be mentioned: At Bonhamtown, in the railway gravel pit; at South Amboy, on the sides of the highest hill (147 feet) in that place, and in the numerous railway cuts in the immediate vicinity; at Jamesburg, in the deep railway cut and pit; at the railway pit at Newtown, and at Hylton's pit, near Palmyra. The great bed of very coarse gravel at Kingston is probably to be correlated with it. At Bonhamtown, Jamesburg, Kingston, and at the mouth of the Pensauken creek, the surface portion of the exposed formations is believed to represent a later stage of the complex series with which we are dealing. The same is true of some of the exposures about South Amboy, though perhaps not of all.

Name.—Perhaps the best and most characteristic exposures of this formation occur near South Amboy, so that this locality might well give its name to the formation. But this name has been so long associated with the plastic clays, in one way and another, that it has seemed best to choose another, and Pensauken has been selected. This name is taken because of the good exposure of the formation at the mouth of the Pensauken creek, at Hylton's extensive pits. The portion of the section to which the name is given is the arkose, more or less stony layer, ten to twenty-five feet thick, which lies near the surface. It is covered by a thin layer of loam, of later origin, four feet or less in thickness. The largest hard quartzitic bowlders of the region belong to the uppermost layer, not to the Pensauken formation. The formation is largely worked for the coarse arkose sand, which is used by foundries.

It should not be lost sight of that the Pensauken gravel and sand beds are often not predominantly of gravel. In many places the formation is distinctly an arkose sand. In addition to the locality at the mouth of Pensauken creek, the arkose character may be well seen in and near South Amboy, at various points near Old Bridge, and at most places in the elevated flat region in the vicinity of South River, Old Bridge and Dunham's Corners, where there are exposures as much as six or eight feet in depth. The arkose element is less distinct in Bonhamtown than south of the bay, but may be distinctly recognized here. At Jamesburg the arkose element fails for the most

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part, but it is present at Hightstown, Newtown, Recklesstown and Bustletown.

The arkose character does not mark the immediate surface, which is loamy, or sometimes more or less gravelly, even when not covered by later loam. Along the eastern side of the State the arkose character does not persist.

At Jamesburg, and at many other points as well, the formation contains a little marl of Cretaceous origin. Small lumps of Cretaceous clay are present in some places, especially about South Amboy. "Fire Sand," apparently of Cretaceous derivation, also enters into its compositon at some points.

Summing up what has already been said concerning the greater heterogeneity of the Pensauken gravel and sand as compared with the Beacon hill formation, it may be said there enter into its composition the following elements: (1°) gravel and sand from the Beacon hill formation, some of it being in the form of conglomerate; (2°) clay, green sand, fire sand, and quartz sand from the Cretaceous (and possibly Miocene); some of this sand was cemented, and appears in the formation under consideration, either as bits or blocks of ferruginous sandstone or as concretions; (3°) an abundance of arkose material, not derived from the Cretaceous, or any later formation; (4°) bowlders, large and small, (*a*) from the Trias, including both sandstone and shale; (*b*) from trap formations, probably from the trap ridges of New Jersey; (*c*) from granitic and crystalline schist formations, some of the bowlders not being known to correspond with any formation of New Jersey; (*d*) from quartzite formations, or from conglomerate containing quartzite; and (*e*) from a formation of gabbro, the location of which is unknown. Some of these bowlders are as much as four feet in diameter, and they are, more commonly than otherwise, angular or subangular in form.

Conditions of formation.—The conditions under which this second yellow gravel formation (the Pensauken) was developed must have been such as to allow of somewhat wide transportation of coarse materials, while at the same time the great body of material in many places was derived close at hand. The structure of the formation, as best shown in the railway cuts near Jamesburg, at the Bonhamtown pit and at the mouth of the Pensauken creek, seems to indicate clearly that waves were concerned in its deposition. But for the more or less wide transportation of the bowlders some other agency must have been in operation, as already suggested.

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Thickness.—The thickness attained by the Pensauken gravel and sand is not easily estimated, and seems to be very inconstant. This is the natural consequence of its deposition on an eroded surface. At Kingston and at Bonhamtown the bottom of the gravel tentatively referred to this stage is not more than fifty or sixty feet above sea-level. At South Amboy its bottom is about ninety feet above tide, and at Jamesburg about the same. At these places its thickness varies from forty to sixty feet. These thicknesses are probably above the average, though they may not represent the maximum. During the deposition of the Pensauken gravel and sand, sedimentation seems to have continued so long that the pre-existing erosion surface on which the formation was laid down lost much of its relief by the filling of its erosion depressions. Only a few elevations, like the Mount Pleasant hills, stood well above the plain developed by its deposition.

Former extent.—The Pensauken gravel and sand formation must have extended far north of its present continuous body if the waters which deposited it stood at the level which we have supposed. The only escape from this conclusion would be the possibility of subsequent differential changes of level on a considerable scale. A mile and a half north of Kingston, on the steep slope, there are traces of gravel which may possibly represent the original upper limit of this formation. Their altitude is nearly 200 feet above tide. On the south face of First mountain there are similar traces of a similar gravel at a corresponding elevation. More considerable remnants of gravel, which are perhaps to be correlated with the Pensauken formation, occur two miles and less west of Franklin Park, at an altitude of about 150 feet. Isolated areas of the Pensauken formation occur a mile or so west of Raritan and three miles north of Somerville. If the formation once had such an extent as these remnants indicate, and it seems certain that it did, it is manifest that an enormous amount of erosion has subsequently taken place.

Elevation and erosion of the Pensauken formation.—Subsequent to the deposition of the Pensauken gravel and sand, the area over which it had been spread was elevated. As in the case of the elevation following the deposition of the Beacon hill gravel and sand, the elevation at this time was probably greater to the north than to the south, and probably greater in the east-central part of the State than further east or west. But the elevation was probably much less unequal in different areas than before. It is probable that most of the area of the State became dry land at this time. On the surface exposed by

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this elevation a new drainage system established itself, in a measure independent of pre-existing drainage lines. It is quite possible that the new generation of streams followed the old, so far as some of the principal valleys are concerned, throughout that part of the State where valleys had been developed subsequent to the Beacon hill deposition; but facts are not at hand to show either that most of the new generation of streams did or did not follow old drainage lines, but certain lines of evidence lead indirectly to the conclusion that at least some of the new streams were independent of the old in their courses.

The present drainage system of the region south of Lawrence brook, including the latter stream, is believed to be the descendant of the drainage system which established itself after the uplift of the Pensauken gravel and sand, though its history is not believed to be a simple one.

The elevation of the Pensauken gravel was probably sufficient to allow of the excavation of valleys comparable in depth to those which exist to-day in the central part of the State. Whether or not the southeastern part of the State was brought above the level of the sea is not known. If not, deposition continued there while the formation was undergoing erosion along its northern edge, in the areas above the sea. The duration of this elevation was sufficiently long to allow the drainage system to reach a mature stage of development. If the elevation which succeeded the deposition of the Pensauken gravel and sand was prompt and considerable, the period of erosion which followed need not have been exceedingly long in order to account for the amount of erosion which took place, even though this amount was great. The formation is of loose and easily-eroded materials. On the other hand, its porosity allowed the rainfall to sink beneath the surface readily, a condition which does not favor the rapid development of valleys.

If the elevation which followed the deposition of the Pensauken gravel and sand was slow, and at first slight, the interval during which it was exposed to erosion may have been long, since under such conditions erosion must have progressed slowly.

THE THIRD YELLOW GRAVEL FORMATION.

After a drainage system had been developed to maturity on the surface of the Pensauken gravel and sand beds, it is believed that the land again sank so as to submerge, for the second time since the

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Beacon hill epoch, considerable portions of the surface of the State. The amount of the subsidence which resulted in this submergence is not believed to have been so great as to allow the sea to reach a level, relative to the land, equal to that which it reached during the deposition of the Pensauken beds. It appears to have overspread the eroded surface until it reached an elevation which is now marked approximately by the 130-foot contour northeast of Trenton. The same contour seems to have marked approximately the limit reached by the sea along the whole of its northern border. This line does not depart widely from the southern border of the Triassic area from Trenton to New Brunswick, and beyond.

When the land sank beneath the sea, the water covered a surface which had suffered a considerable amount of erosion. The streams had in some places cut through the Pensauken gravel and sand, into the Cretaceous below. Along the valleys, and on the lower slopes, there was, doubtless, more or less gravel, sand, &c., which had been deposited along the streams while they were active. During the submergence, a thin mantle of commingled gravel, sand and loam was spread over the submerged area. The material was derived from the surface of all the adjacent land draining into the sea. In this formation, loam is perhaps the most abundant constituent. The stony material which entered into its composition is made up (1°) of such pebbles as entered into the formation of the Beacon hill gravel formation; (2°) of pieces of conglomerate which came from this formation directly; and (3°) of some of the pebbles of diverse sorts which entered into the Pensauken stage of the yellow gravel, but which were not present in the Beacon hill stage; (4°) of certain other constituents which were introduced at this stage for the first time into the complex yellow gravel series.

The granites, the gneisses and schists, the Triassic shales and sandstones, which have been referred to as characterizing the Pensauken formation, and which exist in it in a decomposed condition, are absent from the third stage of the yellow gravel (loam) formation, while the quartzites and other non-decomposable sorts of rock which enter into the Pensauken beds, but not into the Beacon hill gravel, re-appear in this third member of the complex series.

Along the northern border of the deposits referred to this stage, there was a new element introduced. The loam of this region is often distinctly reddish, and the color is such as to indicate clearly that the

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Triassic shale was its source. This redness characterizes much of the surface about Bonhamtown, above the levels which were reached by the waters of the last glacial epoch.

Besides the reddish color of the loam along the northern border of the formation, a still greater variety of stony material appears in this third formation than in its predecessor. The stones, too, are much larger. Bowlders are by no means rare over an area centering about Ernston, South River, Old Bridge and Fresh Ponds. Glaciated stones are not unknown, though they are rare. There are also occasional pieces of gneissic material, which, while showing the effects of weathering, are yet distinctly fresher than the corresponding materials of the Pensauken beds, and this in spite of the fact that they are nearer the surface, and so more favorably situated for decay. The loam and loamy gravel referred to this submergence is well exposed about Trenton and Trenton Junction, where it is extensively used for brick. It covers most of the surface below an altitude of 130 feet, north of the Delaware and Raritan canal, and appears to rise to somewhat greater heights over surfaces further south, as about Jamesburg. Northeast of New Brunswick it is less loamy than at Trenton. This formation is well exposed in the upper part of the railway excavation near Jamesburg. It is the upper, loamy part, above the sandy, gravelly part which is referred to the Pensauken division of the series. The distinction between the two sorts of material in this excavation is readily recognized by the workmen. The same formation overlies the Pensauken bed south of Palmyra, but is there poorly developed.

Name.—Perhaps the best development of this formation is in the vicinity of Trenton. That city would be entitled to give its name to it but for the fact that it has already been appropriated for a formation for which it is much less appropriate. The next best locality furnishing a convenient name is Jamesburg. Cuts near that place, along the railway running to Monmouth Junction, expose the formation in its full thickness. This is no more than eight to twelve feet at this point, and this is greater than its average thickness. It here constitutes the surface bed, and rests on the Pensauken formation below.

So shallow a mantle spread over an erosion surface was altogether insufficient to obliterate the valleys which had been excavated during the preceding erosion interval. The extent of the deposition was

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therefore much less than during the Pensauken epoch, and the duration of the depression was presumably of correspondingly less duration.

The deposits made during this epoch of submergence were, however, sufficient to modify the valleys. In many places deposits were made in such wise as to interfere with ready drainage through the old valleys. It is believed that the prevalent marshiness of many of the rivers south of a line from Trenton to New Brunswick is due to the partial obstruction of drainage caused by the deposits made at this time. It is probable that the peculiar non-erosion topography which affects much of the country between South River and Trenton, and to which reference was made in the annual report for 1891,* was developed at this time, and that the condition of its development was the submergence of an erosion surface, the materials of which were incoherent sand, gravel and loam. In some places it appears that the topography, which seems to be made up of moraine-like hummocks and hollows, is really made up of a tangle of low ridges, which surround and inclose undrained depressions.

This third stage of the formation, the Jamesburg, does not ordinarily show distinct structure of any sort. It is not distinctly stratified, though obscure indications of stratification are sometimes observable. Its constituents are not notably well assorted. It sometimes seems to be composed of very much such material as might have resulted from the decomposition of the underlying Pensauken beds, especially where the latter is arkose. On the other hand, its distribution seems to be somewhat different. In many places it appears to have a fixed upper limit in altitude, a limit which does not correspond with that of the Pensauken formation, and its upper limit appears to be in definite correspondence with certain phases of topography. Its surface, too, has suffered much less erosion than the Pensauken gravel has suffered.

At some points the Jamesburg loam appears to rest unconformably upon the Pensauken beds, but in such formations it is often difficult to be sure that an apparent unconformity is really such. Some of the best evidence in this line is found at Kingston and in the vicinity of Jamesburg. Figure 1 represents the condition of things seen at several places.

*Annual Report for 1891, page 107.

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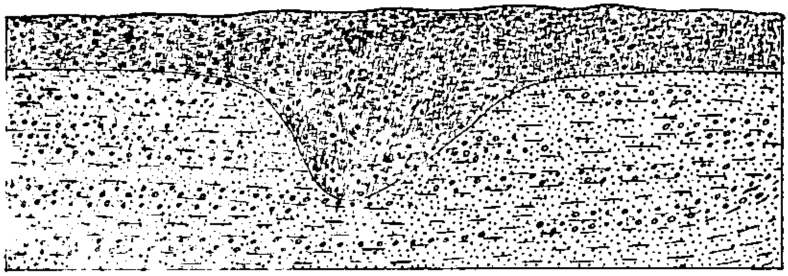

Fig. 1.

The upper part of the figure represents Jamesburg loam overlying older, Pensauken gravel. The section from which the figure was taken was seen near Jamesburg. The height of the section is eight feet.

After the deposition of the Jamesburg loam, sand and gravel, the surface was again uplifted, bringing most, if not all, of the present area of the State above the sea. If any portion of its area remained beneath the sea, it could have been only the low border lands, which now have an altitude of fifty feet or less. If the low coast border possessing this altitude was lifted above the sea at the close of the Jamesburg epoch, it was subsequently depressed.

After the uplift which followed the deposition of the Jamesburg loam, the surface drainage appropriated the pre-existing valleys which had not been obliterated, but only slightly obstructed. Drainage from that time to this has not been vigorous, and many of the valleys still remain marshy. The recovery from the depression may have been slow. It is not certain that the land reached its present altitude before the last glacial epoch came on, though it would seem that the Delaware had cut a considerable valley after the Jamesburg loam was deposited, before the glacial waters brought down the Trenton gravel.

The amount of erosion which has been accomplished since the uplift which followed the deposition of the Jamesburg beds, is not great. The flat tract northeast of New Brunswick, where the tributaries of the Raritan have made but little headway, is an instructive example. The flat surface, often undrained, in the vicinity of Trenton, and all along the stretches of country just below the 130-foot contour from Trenton to New Brunswick, is a further illustration of the small amount of erosion which has been effected since the deposition of the Jamesburg loam. There seems to have been considerable erosion of the James-

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burg beds only along the immediate valleys of considerable streams, like the Delaware.

Since the amount of erosion subsequent to the deposition of the Jamesburg formation has been so slight, it would be expected that the old shore line at 130 feet should be found. Its absence, or at any rate its indistinctness, is one of the difficulties in the sequence here sketched. Certain features, which may have been developed along shore, do exist at several points, notably at an elevation of 130 feet, between Ewingville and Lawrenceville, but they are much less decisive than could be desired.

The material of the Jamesburg formation is often very like that of the Pensauken. In some places the weathering of the latter might have given rise to the overlying bed, which is here classed as Jamesburg. The basis of separation is not so much in the unlikeness of the material of the two formations, as in certain topographical features. Without going into details, it seems certain that after the development of a drainage system, very much like the present, on the surface of the Pensauken gravel and sand, the area possessing this drainage system was submerged for a brief period, long enough to mask, but not to obliterate, the old valleys.

THE FOURTH YELLOW GRAVEL FORMATION.

A more or less distinct stage of deposition subsequent to the deposition of the Jamesburg loam is indicated about the borders of various portions of the State, where the present surface from the sea up to an altitude of forty to forty-five feet is very much younger than that which lies at a higher altitude. This constitutes the fourth stage of deposition within what has been known as the yellow gravel formation. It is not altogether certain that this last phase marks anything more than a halting stage in the rise of the land, although more probably it represents a slight subsidence, preceded by an elevation equal to the present. This stage represented in the eastern, southern and southwestern parts of the State by the low, terrace-like border along the sea, at elevations varying from twenty-five to forty-five feet, may have been contemporaneous with the last glacial epoch, or perhaps even subsequent to it.

The relative duration of the several historical stages, since the beginning of the yellow gravel series, cannot be fixed with great

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accuracy, though some suggestions as to their relative importance can be given. The amount of erosion which was accomplished after the deposition of the Beacon hill formation, and before the deposition of the Pensauken, was much greater than all that has been accomplished since. During that time, it would appear that the northern part of the surface which the Beacon hill gravel overspread, was, after elevation, cut down something like 200 to 250 feet, bringing the surface to a peneplain, with only isolated hills, somewhat widely separated from each other, to mark the minimum altitude of the original surface. Below the peneplain, still deeper valleys were cut. Further south where the elevation was less, the erosion was less. For so considerable an amount of erosion, and especially for the development of so advanced a stage of erosion, a very considerable interval of time is demanded. The character of the formation is not such as to especially facilitate rapid degradation. Although the formation is mainly of loose, incoherent material, it is also very porous, allowing water to sink beneath the surface readily, instead of forcing it to flow off over it.

That the elevation was great, at least during some part of the erosion interval which followed the uplift of the Beacon hill formation, is indicated by the fact that the deposit of the Pensauken gravel, if we interpret rightly, is sometimes found at levels fully 300 feet below the bottom of the Beacon hill yellow gravel.

The duration of the second phase of deposition, the Pensauken, may have been equal to the first, so far as now known. The duration of the second erosion interval, that which followed the uplift of the Pensauken, was probably not one-fourth that of the preceding erosion interval, and may not have been one-tenth if conditions were equally favorable for erosion. Indeed, it was probably considerably less than the former, even if the conditions were such as not to allow of a rate of erosion more than one-half that which had preceded. During this time, the drainage system is believed to have developed to something like advanced youth or early maturity.

The duration of deposition in the Jamesburg epoch was probably less than during either of the preceding stages, as indicated by the slight thickness of the formation, and the relatively slight modification of the topography which it effected.

The erosion which was accomplished on the Jamesburg surface after its emergence and before the last glacial epoch was slight. Indeed, except along considerable valleys, the third stage of the yel-

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low gravel formation, that which reached up to 130 feet in the vicinity of Trenton and New Brunswick, and probably to a somewhat greater elevation further southeast, has suffered but little erosion to this day.

The youngest stage of the yellow gravel complex which is tentatively differentiated, the area standing at an elevation of about forty-five feet above the sea, along the north part of the Atlantic coast, is still younger, and has suffered still less degradation. This may be as late as the last glacial epoch or possibly even later.

From this it would seem that the time which elapsed between the first formation of yellow gravel and the second was probably much longer than all the time which has elapsed since the second; likewise that the time which elapsed between the second and third stages was probably longer than all which has elapsed since the third. Along with these statements it should be remembered that quantitative estimates of time, based on relative amounts of erosion, when the conditions which affect the rate of erosion are not accurately known, may be wide of the truth.

The age of the yellow gravel formations.—It is not yet possible to state with great confidence what relations the several formations herein mentioned sustain to known formations elsewhere. Their relations to each other in time are believed not to be open to question. The series as a whole has been sometimes regarded as of Pleistocene age. It has often been thought, or parts of it at least have been thought, to antedate the Pleistocene. Unfortunately the data which bear upon the question of the age of the various formations are not such as to put the conclusion beyond doubt. Nevertheless several conclusions which have a bearing on the age of the several formations seem warranted.

The Jamesburg formation, the third of the foregoing series, is found at several points up the Delaware valley, much beyond the continuous body of the formation to the south. It is found near Washington's Crossing, near Titusville, and still further north, near Raven Rock. Its constitution and its disposition at these points seem to connect it with the extreme outer portion of the glacial drift, which lies further north. This glacial drift, as has been indicated in earlier reports, is believed to antedate, by a very considerable period, the formation of the terminal moraine at Belvidere and eastward. This formation is what has been known heretofore as the Columbia formation. The Jamesburg is, therefore, but a local name for the Columbia formation, or for a part of it.

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The Jamesburg formation, further south, frequently contains glacially-striated bowlders. This again seems to connect it with the glacial period. It should be understood, however, that the Jamesburg formation in the southern part of the State was deposited by water, and that such glacial bowlders as it may contain are believed to have been dropped in it by floating ice.

In general, the Jamesburg formation does not extend far enough north to meet the glacial drift; this, at least, is true in all of the central and western parts of the State, and the relations between the glacial formations and the Jamesburg are not clear in the eastern part, where they may come in contact. Meager as the basis for correlation is, the phenomena of the Delaware valley and the constitution of the Jamesburg formation seem to indicate the connection of the Jamesburg formation with the maximum extension of the ice.

If the maximum extension of the ice occurred in the first glacial epoch, it follows that the Jamesburg formation is the time equivalent of the oldest glacial drift. If the oldest glacial drift marks the beginning of the Pleistocene, the Jamesburg formation would represent the earliest Pleistocene deposit south of the limit of the ice. In this event, the second yellow gravel formation, the Pensauken, must antedate the Pleistocene.

Another line of evidence leads to the same conclusion. The Pensauken formation, or its existing remnants, does not in general extend so far north as to meet the glacial drift; but this it does at several points, and at one of these its relationship to the glacial drift is most significant. This is near Raritan and Somerville. About two miles north by northeast of the latter place, the extreme border of the older glacial drift overlies a remnant of the Pensauken formation. Again, a mile or so northwest of Raritan, the Jamesburg formation, which is believed to be the time equivalent of the glacial drift which overlies the Pensauken formation north of Somerville, overlies sand and gravel of Pensauken age. At no other points within the State has the older glacial drift, or its equivalent, been seen to overlie the Pensauken formation. The older glacial drift is present at many other points northwest of Raritan and Somerville, over a very considerable area, but nowhere else is the Pensauken formation beneath it.

The relationship of the earlier glacial drift, and its time equivalent, the Jamesburg formation, to the Pensauken, as shown at these localities, is such as to suggest that the latter had been so extensively

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eroded that only remnants of it still existed along its northern edge at the time of the deposition of the southernmost glacial drift. Stated in other terms, the outermost glacial drift appears to overlie the Pensauken formation unconformably. If this inference be correct, the Pensauken formation antedates that glacial period during which the ice reached the southernmost extension. If this outermost drift represents the first glacial epoch, and therefore the beginning of the Pleistocene period, we reach the same conclusion as before, viz., that the Pensauken formation must be pre-Pleistocene. The formation next earlier than the Pleistocene on the Atlantic slope, so far as heretofore recognized, is the Lafayette formation, and the Lafayette formation as described by McGee * possesses many characteristics which correspond with those of the Pensauken formation.

On the other hand, it may be true that there was a minor glacial epoch, or perhaps more than one, earlier than that in which the ice reached its maximum extension. It is possible, therefore, to think of the Pensauken formation as the time equivalent of a glacial epoch earlier than that during which the known extra-morainic glacial drift of New Jersey was deposited. This suggestion is in general agreement with the sequence published some time since by Professor James Geikie.† If this suggestion be true, we shall have to look to the south, or at least to territory outside the limit of glaciation, for evidence of the first glacial epoch.

The strongest argument for connecting the Pensauken formation with any ice epoch, is the presence of large, somewhat widely transported bowlders, but so far as this point is concerned, it would apply equally well to the Lafayette formation.

Until the time of the Pensauken formation can be fixed with certainty, that is, until it can be decided whether it is Pleistocene, or whether it is Lafayette (Pliocene), or whether it falls between the Lafayette and the Pleistocene, it will be impossible to fix with accuracy the age of the Beacon hill formation. If the Pensauken formation be Lafayette, the Beacon hill is certainly much older than Lafayette. It has already been indicated that the Beacon hill formation, so far as can now be seen, includes much that has been regarded as Miocene.

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* Twelfth Annual Report, United States Geological Survey.

† On the Glacial Succession in Europe, by Professor James Geikie, Transactions of the Royal Society of Edinburg, Vol. 37, 1892, pages 127–149.

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Conclusive stratigraphic reasons cannot at present be adduced to show that the Beacon hill formation is not Miocene; on the other hand, this conclusion does not at present seem to be a necessary one. If the Pensauken formation be Pleistocene, the Beacon hill formation may be Lafayette, or may be a formation heretofore unrecognized, between the Pleistocene and the Lafayette. In this connection it is to be remembered that the Beacon hill formation was deposited on the Cretaceous surface, before the latter was much eroded, at least throughout the main portion of the Cretaceous belt of New Jersey. Its relationship is such as to suggest the Miocene age of the whole formation. On the other hand, there is at its base, in many places, what has been regarded as Miocene, and it is still regarded as possible that the lower part of what is here classed as the Beacon hill formation should be separated from the upper. In this division, the lower part only may be Miocene, or the lower part may be earlier Miocene, and the upper later Miocene.*

If the Pensauken formation is Pleistocene, it is clear that we have two formations representing the time equivalent between the beginning of the Pleistocene and the last glacial epoch. These two formations are the Pensauken and the Jamesburg.

Later than the Jamesburg there are in New Jersey, along the Delaware and other valleys which served as avenues of drainage during the last glacial epoch, extensive deposits of gravel of later origin than the Jamesburg formation. Along the eastern and southern coasts of New Jersey, as well as along the Delaware bay, and along the lower course of the Delaware river, there are deposits of loam, sand, or in some places of gravel, which represent a period of deposition much later than the Jamesburg epoch. Whether or not they are the time equivalent of the glacial gravel in the Delaware and other valleys has not been determined with certainty, but they are probably little or no earlier than this formation.

This fourth phase of the yellow gravel formation generally forms a gently-sloping plain, but it sometimes appears in a more or less terrace-like form. This plain may mark a stage in the uplift of the surface after the Jamesburg deposition.

The later limit of the Columbia has never been very sharply defined. The question as to whether the late glacial gravels, that is, those con-

*On the basis of fragmentary fossils, Mr. Arthur Hollick thinks the sand and gravel of the Navesink highlands (Beacon hill) cannot be so old as Miocene.

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temporaneous with the terminal moraine at Belvidere, should be classed as Columbia, has, so far as is known to the writer, never been discussed. No formations have been recognized in the south later than the Columbia, but there is the best of reason, both topographic and genetic, for separating the gravel of the Delaware and other valleys from the Columbia of the same region. They were made at a later time; they were deposited in valleys excavated or re-excavated after the Jamesburg epoch of deposition, and the gravels have an origin very different from that of the Jamesburg materials. We are disposed to regard the glacial gravels of the last glacial epoch, and of contemporaneous deposits south of the limit of glaciation, as post-Columbia. On this basis the fourth stage of the yellow gravel, covering the low areas, varying from sea-level up to an elevation of twenty-five feet in some places, and up to an elevation of forty-five to fifty feet in others, is likewise regarded as post-Columbia.

Further south, the Columbia formation has been referred to as in some sense bifold. It has been described under the names of High and Low Level Columbia,* though it is not clear that these two names have been regarded as representing distinct formations. It is impossible at present to say whether the High Level Columbia and the Low Level Columbia further south, are the equivalents of the Pensauken and Jamesburg formations, or whether they are the equivalents of the Jamesburg formation and of the formation that is here referred to as post-Columbia. It cannot even be affirmed that they are the equivalent of any two members of the series here described.

Conclusion as to age.—In conclusion it may be said (1) that (on stratigraphic grounds) so far as is now known, the Beacon hill gravel may be either Miocene or Lafayette or something between; (2) that if the Beacon hill formation be Lafayette, the Pensauken and Jamesburg formations may be Pleistocene, the former corresponding to a heretofore-unknown (so far as the east is concerned) glacial epoch which antedates the epoch of maximum ice extension, or the Pensauken may be post-Lafayette and pre-Pleistocene; and (3) that the post-Columbia formation corresponds approximately with the last glacial epoch. In any case it seems to be perfectly clear that the Beacon hill gravel is pre-Pleistocene. Until conclusions are more certain than they now are, it seems best not to use the terms Lafayette,

* McGee and Darton.

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Columbia, &c., in connection with these formations, but to apply to them local names. When their correlation is certainly worked out it may be necessary to change these names, so as to bring the nomenclature of the formations into harmony with that of other regions where names have already been given. It should be remembered, however, that Trenton and Trenton Junction, where the loam (the Jamesburg) is extensively used for brick, has been regarded as one of the typical localities of the Columbia formation.

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SECTION II.

EXTRA-MORAINIC DRIFT.

The extra-morainic surface materials of New Jersey which have at one time or another been referred to as "drift" are believed to have been deposited in part by glacier ice; in part by streams contemporaneous with the ice; in part by streams during intervals of deglaciation, subsequent to the beginning and before the end of the glacial period; in part by the waters of the sea at the time the ice first encroached upon the territory of the State, and in part by oceanic water since that time.

The present chapter will concern itself primarily with those phases of the drift which owe their origin to glacier ice directly, or to streams associated with it, or to streams which subsequently modified their deposits. Between these phases of the drift it is not always easy to distinguish.

Both the geographic and topographic distribution of the extra-morainic drift which is believed to have been deposited by ice, or to have been connected directly with it, are instructive. The line marking the southern boundary of the drift, which is believed to be of glacial origin, has been carefully traced from the Delaware to the Watchung mountains. The eastward continuation of this line is difficult of determination. It is probable that it can never be located with accuracy, since the low land in the eastern part of the State has probably been submerged since the deposition of the drift of which the line referred to marks the limit. The constitution of the surface and sub-surface formations is also more unfavorable for accurate determination of the drift limit in the eastern part of the State than in the western, since in the former area, the sub-surface formation is loose, heterogeneous gravel and sand, and in the latter more or less homogeneous indurated rock.

Southern limit.—The southern limit of drift, which is looked upon as of glacial origin, so far as it has yet been possible to determine it, is shown on the State map accompanying this report. Commencing at the Delaware, it runs through Hunterdon, Somerset and Middlesex counties. At the Delaware, the line begins opposite Monroe, a little

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more than a mile south of Riegelsville. From this point it bears a little to the northeast for two or three miles, then turns nearly due east through Spring Mills, bears slightly south through Pittstown, beyond which point it extends in a direction slightly south of east for two or three miles. Thence it turns to the northeast, reaching the South branch of the Raritan river near Lansdowne. From this point it runs through Allerville, where it bends to the northeast and continues in this direction nearly to the Central Railroad of New Jersey between Lebanon and Annandale, rather nearer the latter place than the former. Thence it curves around the north side of Cushetunk mountain, near the line of the railway. At the east base of the mountain it bends south again to a point just west of Drea Hook, and thence southeast to Readington. A short distance southeast of Readington it crosses the county line between Hunterdon and Somerset counties, and at this point reaches its southernmost limit between the Delaware and Somerville, in latitude 40° 34′. The line is continued eastward in Somerset county to the junction of the North and South branches of the Raritan. Thence its course is in a general northeasterly direction, running a little north of Raritan, and reaching First mountain two miles north of Somerville. Between this line and the moraine, it is not asserted that all the drift is of glacial origin, though it is believed that glacier ice reached, approximately, the limit indicated.

Discontinuity of the extra-morainic drift.—At various points between the above line and the moraine to the north, glacial drift is found, though it is very far from constituting a continuous sheet. Indeed, much the larger part of the surface within the area specified has only meager traces of drift. These traces are most commonly in the form of scattered bowlders, which came from formations much farther north. In places there are thin beds of drift, no more than two or three feet in depth, while in other localities the drift is in beds of considerable thickness.

The lack of continuity of drift in this region is in striking contrast to the condition of things north of the moraine, where drift in greater or less thickness is essentially continuous. It is true that there are frequent outcrops of rock north of the moraine. It is true that there are, here and there, areas of some size where the drift is very thin. But the areas north of the moraine, where drift is very thin, are much less extensive than the areas where the drift is thin

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south of the moraine and north of the outer limit of the drift. The relationship may be expressed in some such terms as the following: North of the moraine four-fifths of the surface is so deeply covered with drift as to effectually conceal the native rock and its products; south of the moraine and north of the drift limit as here outlined, four-fifths of the surface is nearly free from drift. Just as the one-fifth north of the moraine has occasional bowlders and small patches of drift, so the four-fifths of the area south of the moraine and between it and the drift limit has occasional bowlders and small amounts of drift in other forms. The amount of drift per square mile on the four-fifths to the south is probably less than the amount on the one-fifth to the north.

Geographic distribution.—The drift which is regarded as glacial in origin reaches its most southerly point just east of Readington, near the western line of Somerset county, in latitude 40° 34′. The limit of the drift is, here, about twenty-two miles south of the outer border of the moraine on the same meridian. Near the west line of the State, in Hunterdon county, the outer limit of the drift lies about fifteen miles below the southern line of the moraine at Oxford Church, just east of Belvidere.

Within the area of the extra-morainic drift the drift cannot be said to be notably more abundant in one part of the area than in another. There are somewhat larger areas of it in western Hunterdon and central Morris counties than elsewhere, but there are also very considerable patches of it in Somerset county and in eastern Hunterdon county near the extreme southern limit. On the whole, it is more abundant near the moraine than further from it, although many of the largest bowlders are near the outermost limit.

It will be most instructive to describe the extra-morainic drift in connection with the underlying formations, since in this wise some of the peculiarities of its topographic distribution are best brought out. To appreciate fully the significance of the position of the drift here described, reference should be made to the topographic maps. The areas of drift, shown on the map accompanying this report, can be located without difficulty on the contour sheets.

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A. DRIFT ON THE TRIASSIC (NEWARK) FORMATION.

The extra-morainic drift which is regarded as of glacial origin, and which overlies the Triassic formation, is found in both Somerset and Hunterdon counties. It is found most abundantly in the western part of the former and the eastern part of the latter.

In the following pages, describing or referring to areas of drift on the Triassic formation, the several areas will be referred to in somewhat arbitrary order, passing in general, however, from west to east:

1°. *Little York area.*—Just north of Little York, three miles north by northeast of Milford, there is a drift-covered knoll of red shale which has an altitude of a little more than 400 feet. The drift has a maximum observed thickness of about six feet, though the bottom of the drift was not seen at this point. A considerable variety of stony material exists here, including gneiss, sandstone which is probably Potsdam, Oneida and Medina sandstone, flints and some small pieces of shale and slate, such as might have come from the Hudson river formation. No stones were found which were well striated. Some of the quartzite bowlders have smooth faces, as if they had been planed, but nothing was seen which could be asserted to be glaciation. Taken by itself it would not be possible to affirm that the drift of this area is glacier drift, on the strength of exposures seen. The limits of the area are not very sharply defined. The drift referred to is not to be confused with the inner drift about the forks of the streams near by.

2°. *Pattenburg area.*—There is a considerable area of drift, very irregular in shape, just east of Pattenburg. The underlying rock is seen only at the railway cut east of the village, but if the location of the contact of the Trias with the crystalline schist area on the geological map be accurate, the drift is partly on shale and partly north of it. At the railway cut the underlying rock is shale. The maximum depth which can be seen is in the railway cut, and is about thirty feet. Where this depth is seen the bottom is not exposed. In general, however, the thickness of the drift is much less. It is mainly of material derived from the crystalline schist area. There are bowlders four feet in diameter, though smaller ones are much more numerous. There are pieces of grayish shale, more or less slaty, in smaller proportion. The large pieces of the shale are often firm, and many of them are faceted and striated. Indeed, no better

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examples of striated stone are to be found anywhere within the drift area of New Jersey than have been found at Pattenburg. There is a conspicuous absence of the local red shale in the drift. This is not strange when it is remembered that the drift here lies on the extreme northern border of the Trias. Quartzite and sandstone bowlders are present, also occasional black flints. A single piece of igneous rock was found, not unlike some of the dark rocks associated with the gneiss. Many of the gneiss bowlders are deeply weathered and decayed. This is particularly true of the coarse-grained types, less so of the finer-grained ones, which contain less feldspar.

The matrix in which the bowlders are imbedded is gritty clay, very compact. The bowlders are imbedded in it without arrangement. The matrix is of such a color as to indicate a high degree of oxidation. It is very similar to earths which have arisen from the decay of the crystalline schist, but contains the notable and significant admixture of foreign material. The drift here rises to an elevation of something more than 480 feet, and does not, as in many of the following cases, lie upon a summit, but rather upon the slope of the gneiss area, which lies to the north. It spreads out upon the red shale south of the creek, rising something like 100 feet above it southeast of Pattenburg.

3°. There is another small area of drift on the red shale one and a half miles south of Pattenburg. The limits of the area are hard to define. Instead of stopping abruptly at a traceable line, the drift becomes thinner and thinner, until only scattering bowlders or pebbles are to be seen. The area is of small extent and does not present any features different from those already mentioned. The exposures are not such as to show much of its constitution.

4°. *Hensfoot area.*—Near Hensfoot, on the road from Everittstown to Perryville, about one and a half miles southwest of the latter place, there is a small area covered by a considerable bed of drift. Bowlders three or four feet in diameter occur, though not commonly. A beautiful example of glacially-striated grey shale, probably from the Hudson river formation, was found here. Flints are very abundant.

5°. *Potterstown area.*—The drift here occupies the summit and uppermost slopes of an elevated area, which is more or less isolated by erosion. The highest point of the area is 326 feet, and the drift does not constitute a bed more than seventy-five feet below the sum-

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mit. The area of the drift is about a mile square. Drift was observed to have a depth of eight feet at one point, and it may be much thicker in places where it is not exposed. It is largely composed of material derived from the crystalline schist region. Between this area and the next the surface is thickly strewn with pebbles and cobbles, but the fine material of the drift, if it ever existed over this area, has been entirely removed.

6°. Between the North and South branches of the Rockaway creek, north-northwest of White House station, there is another drift-covered area. Here, likewise, the drift occupies a high, isolated area, running up to a maximum altitude of 261 feet and down the slopes for a short distance below the summit. The matrix of the drift is composed almost wholly of reddish clay, derived principally from the red shale. The clay is stiff and gritty, and erodes in sharp little ridges, similar to those developed in the erosion of lacustrine clay. In the northern part of the area, stony material is rather abundant on the surface. South of the summit the clayey texture is more prominent. Pebbles which may have come from the Medina sandstone were found, but they could not be certainly identified. The largest bowlders are all of crystalline schist, and are mostly angular. Among the gneiss bowlders but a single one was seen which appeared to be distinctly worn. The variety of stony material is essentially the same as that of the other areas in this vicinity, some of which are described more in detail. The border of the area has the same general character as elsewhere. The drift "frays out" on the upper slopes.

7°. There is a small area covered with a bed of drift a little more than a mile northwest of White House station. This area lies between the railroad on the south and the Rockaway creek on the north, and is included between the two arms of the very considerable northward bend of the Rockaway creek at this point. The area is about a mile long and a half mile wide. The drift occupies the summit, with a maximum altitude of 226 feet. It is not abundant below 160 feet. Descending toward this level the drift thins out, and little but scattered erratics occur below. The drift is thickest on the flat portions of the summits of the hill. The greatest depth actually observed is four feet.

The matrix in which the stony material of the drift is here imbedded is largely of red shale origin. The stony material is like

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that of the other areas in this vicinity, except that black flint is much more abundant. No bowlders larger than five feet are to be found, though bowlders approaching this size are not rare. Crystalline schist bowlders are somewhat less abundant here than in many of the other areas near by, although this area is nearer a source of such material than many of the others. Like the other areas of drift in this vicinity, this is separated by topographic barriers in the form of valleys and high elevations from all sources of crystalline schist.

8°. *Drea Hook area.*—This area lies in Hunterdon county, about a mile south of White House station. The drift occupies the top of the spur of high land projecting eastward from the base of Cushetunk mountain and constituting the divide between Rockaway creek and Chambers brook on the north and Hollands brook on the south. The drift approaches an altitude of 300 feet and does not descend on the slope as a distinct bed below an altitude of about 200 feet. The area is about three miles long, and varies in width from a few rods to a mile. The drift is thickest on the highest part of the divide. It is made up of a clayey, gravelly matrix, with an abundance of stony material similar to that found east of Readington (described below), with the addition of an element of trap, derived, apparently, from Cushetunk mountain. The drift of this area is well exposed in a road cut a little more than a mile south-southwest of White House station on the road to Drea Hook, where ten feet of it may be seen. Its contact with the shale below is sharp, and there is no loose shale along the junction of the two. The material is not stratified, but in places seems to be foliated. The matrix is sometimes slightly arkose, indicating the presence of a much-decomposed gneiss. A few striæ were found on the shale bits, though none of them were strikingly good examples of glaciation. The shale bits are usually rather small.

Stony material is particularly abundant at the southern end of the area, one and a half miles southeast of Drea Hook. The greatest diameter of any bowlder found in this area is twelve feet, but bowlders four to six feet in diameter are not rare, and in places those of smaller size may be said to be abundant. The larger ones, and many of those of smaller size, are of quartzose gneiss or schist. These bowlders of schist or gneiss are not so far from their possible source as those east of Readington. But they are separated from such source by the same valleys in the one direction, and by the same trap mountain in the

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other, so that the conclusions concerning the origin of the drift of the other areas apply with equal force to this.

9°. *East of Readington.*—The drift here occupies the high land between Hollands brook on the southwest and the North branch of the Raritan on the northeast. It covers an area about two miles long and a quarter of a mile to a mile in width. Its summit reaches 227 feet. It will be noticed that this is the highest land in the immediate vicinity, and that its upper surface is rather flat. Drift covers the slope down to an altitude of about 180 feet. The maximum observed thickness of the drift in this area is about six feet, but exposures showing the full section of the drift are infrequent, and it is not to be supposed that its greatest depth is exposed. As a general fact, it is thickest on the highest parts of the area, and thins out down the slope.

The drift consists of stones, large and small, imbedded in a matrix of a gritty, gravelly, clayey nature. The variety of stony material is not very great. Gneiss, quartzite, sandstone of two or three types, gray shale and black flint are the only varieties which were noted. These sorts of rock are so unlike the underlying rock that the drift is very distinct. In size the stones of the drift vary greatly. A single bowlder of gneiss, fifteen feet in diameter, was observed. This is the largest of the bowlders, and occurs about a mile northeast of the Readington church. In spite of its great size it has already been reduced by blasting. Two or three other bowlders, eight to ten feet in diameter, lie near it, while others from four to six feet in greatest diameter are also present. Most of these large bowlders are rather angular. They are between seven and eight miles from the nearest beds from which they could have come. They are separated from these sources to the north by considerable valleys, and from the corresponding beds to the northwest by Cushetunk mountain, so that they cannot be referred to any sort of subaërial transportation other than that of glacier ice.

Much of the quartzite is of material which might have come from the conglomerate which lies at the junction of the Trias with the crystalline schist, and which is classed with the former. Some of the sandstone bowlders are of the type which is very widespread throughout the State, and which appear to correspond lithologically with the quartzite and sandstone found *in situ* at a few points in the State, as near Succasunna. These are well worn. A few pebbles of sandstone

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which appear to correspond with the Medina formation were found, but their identification is not beyond question. The gray shale, which is present in small quantities, is believed to have come from the Hudson river formation. On the whole, quartzite is much the most abundant constituent, and gneiss is the second in importance. Locally it predominates over the quartzite. Nowhere in this area were stones found showing certain glacial striæ. Most of the bowlders seen are surface bowlders, which could hardly have preserved their striæ had they existed originally.

Much of the gneiss is considerably decomposed, though this is not true of all of it. In general, it may be said that such gneiss as contains a large proportion of feldspar has undergone much disintegration, while that which is highly quartzose is much firmer and does not differ notably from comparable masses of loose gneiss scattered about the surface of the crystalline schist area, where no drift is present.

10°. *Mechanicsville area.*—East of White House station and northeast of the area last mentioned, there is a third area of drift of greater size than any thus far mentioned, lying partly in Somerset and partly in Hunterdon counties. Here also the drift occupies a divide, namely, that between Rockaway creek on the north and Chambers brook on the south. The altitude of the drift, which is thick enough to constitute a bed, varies from a maximum of 243 feet to a minimum of about 160 feet.

The drift is here somewhat unlike that of the localities farther south, in that there is much less stony material over most of the area, and, locally at least, the material is much more sandy. The sandiness, which is by no means universal, is particularly observable near Mechanicsville, where there is sand at least eight feet in depth, containing very little stony material and no indication of stratification. Such stony material as exists in this area is very like that of the other areas. In the drift of this area a number of trap fragments were found, and also a few pieces of limestone conglomerate such as occurs in the Triassic (Newark) formation near Apgar's Corner. The largest bowlders are of gneiss, about one and a half miles east-southeast of White House station. The largest is nine feet in diameter. In some parts of the area, especially to the east, the finer material of the drift seems to have been largely removed, only the coarser constituents being present. As in the other areas mentioned, the greatest thickness of drift occurs on the higher and flatter portions

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of the divide, and only scatterings of drift are found below a level of 160 or 170 feet. At the edges of the area, where the drift thins out, the material which remains is coarse, the fine having been washed away.

11°. *Areas between the North branch of Rockaway creek and Lamington river.*—Several small areas of drift occur within this area, always in topographic situations similar to those already described. That is, the drift occupies the summits of more or less distinctly-isolated elevations, running up to altitudes of something more than 200 feet. The most southerly of these regions is a little more than two and a half miles due northeast of White House station. Its maximum altitude is 243 feet. From this altitude a considerable body of drift descends the slope to about 200 feet. The drift is composed largely of sand.

Less than a mile to the northwest, across the branch railroad running up to Gladstone, there is another small patch of drift, with a maximum altitude of 253 feet. The drift here is much more clayey than that of the locality last mentioned. Stony material is abundant and like that of other adjacent areas in all essential respects. Considerable depths of drift are not exposed in this area.

A mile or so west of Lamington there is another small area of drift at an elevation of a little more than 200 feet. The drift shows no stratification, but it does not show distinctly glacial marks. Bowlders are abundant toward the lower part of the area, while much more fine material is found near the summit. Trap is a constituent of the drift, and much of it shows a high degree of decomposition. Although deep sections were not seen, it is reported that a well on the summit of the area was sunk through twenty feet of the drift, beneath which is red shale. The thickness of the drift diminishes as the slope is descended.

Just south of New Germantown, and reaching northwest of that village, there is an elongated bed of drift running in a northwest-southeast direction. At its north end this bed approaches the crystalline schist region. It is well exposed in a road cut three-fourths of a mile south of New Germantown, where a bed of material, mainly of gneissic origin, and four to six feet in depth, is shown. No stratification exists. Most of the stony material came from the crystalline schist, but sandstone and quartzite, such as might have come from the Triassic conglomerate, are also present. Black flints and shale, probably from the Hudson river formation, are present. A piece of

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Hudson river shale about ten inches long was found, showing remarkably distinct glacial striæ. Bowlders of gneiss, which have the appearance of having been planed on one or more surfaces, and subsequently roughened by weathering, are to be seen.

12°. *Areas of drift between the Lamington and North branch of the Raritan.*—Several areas of drift occur on the flat-topped hills of this region. The drift is similar in composition to that already described, but it has in general a more clayey matrix and a larger proportion of quartzite among its stony material. At some places, however, gneiss is very abundant. This is particularly noticeable on the hill a mile northwest of Greater Cross Roads. The summit of the elevation, which here rises to 252 feet, is covered with drift, but the drift does not descend very much below the summit.

The most extensive area of drift in this region is that which lies between the Lamington river and Middle brook. The drift here reaches an altitude of about 375 feet. It contains trap, although the area is several miles from trap ledges both to the east and west. Furthermore, the area is separated from the trap to the west by the valley of the Lamington, and from the trap to the east by the valleys of Middle brook and the North branch of the Raritan. The geological map indicates the existence of a small area of trap a little west of Pottersville, about four miles north of the drift, but this also is separated from this drift area by the valley of the Lamington.

13°. *North of Raritan.*—North of Raritan there is a small area, including the crests of the two hills which on the topographic map are marked as having altitudes of 176 and 169 feet, which has a little drift upon it. Beneath the drift is a bed of yellow sand,* with more or less gravel. This drift is less stony than that of most of the other areas, but there are occasional bowlders two or three feet in diameter and many smaller cobbles. The drift at this point does not give any distinctive evidence of having originated at the hands of glacier ice directly. A single piece of glacially-striated shale, however, was found. There is a fringe of stony material around the area which can be said to be covered by anything like a bed of drift, and its limits are not at all well marked.

14°. *The Somerville area.*—The Somerville area of drift extends from a point two miles north of Somerville to a point one mile south of Pluckamin. Its upper limit is very difficult of definition, since it

* The Pensauken formation. See *ante*.

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is concealed by trap talus, which has descended from the upper part of the ridge, burying it in places to a depth of several feet. As nearly as it can be determined, the upper limit of the drift has an altitude of about 280 feet. The lower limit is at about 160 feet, though it seems to descend a little lower than this at one or two points. The drift consists of stiff, gritty clay, in places becoming sandy, and carrying, in general, an abundance of stony material. The clay is reddish in color, and is composed principally of red shale material. It is very compact. When exposed in ravines and gullies it sometimes stands, with nearly perpendicular faces, ten or fifteen feet high. The stony material is composed largely of gneiss and trap, but much quartzite is present, mostly of the vitreous sort, such as is found in the Triassic conglomerate. There are also abundant masses of red shale and sandstone, in the form of small bowlders. The feldspathic rocks are much decomposed, though all but the small ones have firm cores. On the average, the stony material is not conspicuously well rounded, though not a few of the bowlders bear distinct marks of wear. In some exposures, planed and striated pieces of rock are absent. In other exposures they are very abundant. In a single gully exposure, between the Pluckamin-Somerville road and the trap ridge, a score or more of stones, up to two feet in diameter, with glaciated surfaces, may be seen.

The east end of this bed of drift, a little more than two miles north of Somerville and a little east, overlies a bed of yellow sand of unknown depth, but which has been seen exposed to a depth of eight feet, at an altitude of about 160 feet. The exposure is on the north side of the road, running northwest and southeast, at the base of the trap ridge.

15°. Closely associated with the last is a bed of drift just north of the west end of First mountain and east of Pluckamin. It appears to have been pushed into its present position from the northwest. In character, it is like the drift described under 14°.

16°. *Liberty Corner area.*—A mile or more west of Liberty Corner there is an area of drift fully two miles long and nearly a mile wide. It reaches an elevation of about 430 feet, nearly due west from Liberty Corner. Much of the drift of this area lies below the level of Lake Passaic, the surface of which stood at a level of about 356 feet in this region. Below this level there are bowlders in abundance, some of which were pretty certainly floated in by icebergs during the

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existence of the lake. It would appear that a good deal of the drift below the lake level had such an origin, but all of it did not. Beneath the drift there is, at one point, a considerable bed of sand, at an elevation of about 400 feet. This is exposed in a pit by the roadside, about two miles west of Liberty Corner. Stony material is abundant, the same types of rock being represented as in other areas already described. The drift, as shown in the few shallow exposures, is often sandy, and often distinctly till-like.

17°. South of Basking Ridge, and north of Madisonville, there are other areas of drift on the Triassic formation. But they are at levels below that of the lake, and do not occur in situations which are especially significant. A part of the drift is believed to have come to its present position by the help of the lake and icebergs, when the moraine at Madison was making.

Besides the drift of the foregoing localities, there is much extramorainic drift within the area specified, in two classes of situations—first, in the valley of such streams as served as avenues of discharge for the waters of the last glacial epoch, and second, within the area of Lake Passaic. This drift is not here referred to, as its origin is believed to have been much later than that of the drift under discussion.

SCATTERED BOWLDERS.

Besides the beds of drift of more or less extent that have been referred to as lying upon the Triassic (Newark) formation, scattered bowlders are found in greater or less abundance over most of the area of shale and sandstone which lies between the crystalline schist area on the north and the drift boundary on the south. In some places the bowlders are very abundant, and in some places they are very rare. The small crosses on the map between the areas of drift show something of their distribution. Near the crystalline schist, the underlying Trias is in places a conglomerate, made up of a great variety of rock constituents, such as quartzite, limestone and gneiss. In such places it is very difficult to distinguish between drift and bowlders which may have come from the conglomerate. In some cases certain discriminations cannot be made. There is probably not an area a square mile in extent anywhere north of the line marking the outer limit of the drift where bowlders may not be found, but there are some square miles where they are so scarce as to be very hard to find.

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On the other hand, over more of the area there are very many to the square mile.

Bowlders are abundant about the borders of almost all the drift areas which have been specified above. Where the drift occurs on summits they are found on the slopes below, and to some exent in the valleys at the bases of the slopes. Their occurrence in such positions strongly suggests that they are erosion remnants, and that the imbedding matrix has been carried away since they were deposited.

Resumé.—A review of the foregoing facts shows that in almost all the areas where extra-morainic and extra-valley drift lies on red shale, it is found capping isolated and more or less flat-topped hills. There are some exceptions to this rule, but they do not in any way diminish its significance. The exceptions are—1°. Certain areas which lie at altitudes considerably above the others, as at Hensfoot; 2°. Certain areas where the drift is banked against a considerable elevation, as north of Somerville. Those parts of the drift areas near Liberty Corner and Basking Ridge, which lie above the level of Lake Passaic, fall in one or the other of the above categories. The following facts are significant:

1°. Outside the highland region, and outside Lake Passaic, every area of extra-morainic and extra-valley drift over red shale occupies the summit of an isolated hill or ridge. The isolation is the work of stream erosion. 2°. Outside the highland region and Lake Passaic, every drift-covered hill or ridge but one has its crest more than 200 feet high. The exception is made by 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 (see page 82). 3°. North of the limit of drift nearly every red shale hill which rises to an altitude as great as 220 feet has a drift covering. 4°. The summits of the isolated drift-capped hills have a vertical range of only eighty feet. 5°. Except along certain valleys where it is of later origin, no body of drift occurs below an altitude of 160 feet, although there are extensive tracts of land at this and lower levels adjacent to the areas enumerated above. 6°. The drift occurs down to 160 feet, and, indeed, below 200 feet, only where connected with drift-capped summits, which rise to a height of more than 200 feet, the Raritan area being excepted. 7°. The drift thins out promptly on descending the slopes from the summits of the drift-capped elevations. 8°. The whole

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relationship of the drift to topography indicates that the drift on the slopes has largely if not wholly descended from the summits.

From these facts we seem to be shut up to the conclusion that the isolation of the drift-covered hills in the vicinity of White House station took place *after the drift was deposited.* Since hills (the hill north of Raritan being excepted) whose summits are below 200 feet and few whose summits are below 225 feet are drift-capped, it is rational to infer that the surface of this region was not lower than 200 to 225 feet when the drift was deposited. It is possible that narrow valleys may have existed below this level, but certainly no considerable areas. The limited vertical range of the drift implies that the surface was no more than gently undulating, and that its general level corresponded approximately with the surface which is now about 225 to 275 feet above the sea. From New Germantown on the north to Readington on the south, and from a point two miles northwest of White House on the west to Somerville on the east, the general altitude of the surface did not rise greatly above or fall greatly below these limits. It is to be noticed further than an extensive area, similar in altitude and topography to that where the drift occurs, stretches off to the south beyond the limit of the drift. Since the topography and topographic relations of this driftless tract, south of Hollands brook, lying partly in Hunterdon county and partly in Somerset, appear to be identical, in all essential respects, with the corresponding drift-spotted country to the north, the conclusion is inevitable that the drift never extended further south than the above brook. Since it did not, the drift cannot be referred to the sea, or to any other body of water, for any sea which could have deposited the drift which centers about White House, must also have covered the areas at equal and less altitudes to the south and east, and would have left some signs of its presence here, as well as further north, in corresponding situations.

The drift consists of a matrix, varying from fine sand to a rather tough clay, and stony material varying from the smallest pebbles to bowlders fifteen feet in diameter. The matrix is always thoroughly oxidized. It is nowhere calcareous. It generally lacks all indication of structure, though slight foliation is observed in some of the deeper exposures. The stony material is made up principally of gneiss and quartzite, with lesser quantities of black flint, yellow-brown sandstone, which is quartzitic on the exterior, bluish or grayish shale and

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trap. In many cases most of the decomposable elements have been disintegrated. The gneiss which remains firm generally contains but a small amount of feldspar. At some points, however, as north of Somerville and southeast of White House, many of the gneiss bowlders remain firm. The few trap pieces found have a deeply-oxidized layer on the outside. The whole aspect of the drift is that of age. Limestone has nowhere been found in the extra-morainic glacial drift which lies on the red shale.

The stony material is predominantly angular, and the whole physical condition of the drift joins with its topographical distribution in indicating that the length of time which has elapsed since its deposition is long.

Glaciated bowlders are not abundant. Good specimens have been found a mile southwest of White House station, a mile south of New Germantown, and on the lower slopes of First mountain, three miles east of North Branch. At the latter place, striated stones and bowlders are numerous. In its constitution, and in the relations of its constituents, the drift corresponds with glacial till.

The material of the drift, so far as it is not strictly local, came from the highland region to the north. The crystalline schist, the Triassic conglomerate between the schist and the red shale, the Hudson river sandstones and shale, the Cambrian or Silurian sandstones, and probably the Oneida and Medina sandstones, made their several contributions.

Considering the sources of the material which is here classed as drift, its physical and lithological heterogeneity, its structure, the occasional striation of its component bowlders and stones, and its topographic distribution and relations, we have no option but to conclude that it is of glacial origin.

Erosion since the drift was deposited.—The larger streams of this area now flow at levels more than 100 feet below the levels of the lowest summits on which the drift occurs. Two miles east of White House the Rockaway creek has an altitude of 100 feet. A mile northwest of Pluckamin the North branch of the Raritan has the same altitude. Near Readington the bed of Hollands brook has the same altitude, while the junction of the two branches of the Raritan is below 50 feet. In the same region the drift is mainly above 200 feet.

It is not merely that streams have valleys so much below the level

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of the drift summits. These valleys are by no means narrow or gorge-like. Their slopes are gentle, and the valleys between the summits are wide. The drainage system is well advanced. The area of the surface which is below the drift level is several times as great as the area which rises to it. This will convey to the geologist some definite idea concerning the amount of erosion which has been accomplished in the region since the drift was deposited. Careful study of the topographic map (sheet 5) in connection with the map accompanying this report will emphasize, as words cannot, the point here made.

In forming a judgment as to the length of time necessary for accomplishing this amount of erosion, it is necessary to remember that the region is twenty to thirty miles from the sea, and that its altitude is not great. The rock in which the valleys have been excavated is shale, and shale which is, on the whole, easily eroded. But even an easily-eroded rock cannot be eroded rapidly, unless the streams which do the eroding have steep gradients. The forms of the valleys prove conclusively that their excavation has been a slow process, in spite of the fact that the rock is not resistant.

It should perhaps be repeated that bowlders, and other traces of drift, are not wanting on the slopes below the summit areas, or even in the valleys, as near Flemington Junction. But the bowlders on slopes below summits are believed to have descended from the summits, and the drift in the valleys is clearly of later origin than that on the hills.

Nowhere within the moraine, or within the area covered by drift contemporaneous with the moraine, is any such amount of erosion known to have been accomplished, *under similar conditions*, since the ice retracted. After a careful study of much of the drift of the State, the writer has no hesitation in saying that, in his judgment, no area of the moraine, and no area north of it, so situated as to be comparable to the drift area about White House, *has suffered any considerable fraction of the erosion that this area has*, since the drift was deposited.

With erosion as a measure, the drift described above must be *very much* older than that of the moraine. The physical and chemical constitution of the drift leads independently to the same conclusion.

There is another standpoint from which to place limits upon the antiquity of this drift. Ten or twelve miles southeast of the drift

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area east of Readington, there is an area of gravel at an elevation of 321 feet. This is believed to be equivalent to the traces of gravel found on the summits of the Sand hills, on Beacon hill, Telegraph hill, &c. This gravel is described in this volume under the name "Beacon hill gravel" (see page 47).

When this gravel was deposited by the sea, for such is believed to have been its origin, the same sea must have covered the area about White House, if relative levels were the same then as now. It is of course possible that relative levels were not the same as now, but we have no evidence that such was the case. If the sea covered the Readington-White House area, it must have left gravel or some equivalent deposit upon it. Since the gravel maintained so great a degree of uniformity from the Mount Pleasant hills to Clarksburg, and from there to the Sand hills and west, it would be strange if the character of an equivalent deposit at Readington should have been essentially different. If such a deposit was ever made, *it appears to have been completely removed before the drift was deposited,* for no trace of yellow gravel appears in the drift, or anywhere in the area north of Hollands brook or west of the North branch of the Raritan.

Not only this, but the Pensauken formation, which followed the Beacon hill formation after a long period of erosion, and which once covered the region northwest of Somerville up to the elevation of 180 to 200 feet, appears to have been mainly cut away before the outermost glacial drift was deposited, for, as already stated, the outermost drift appears to overlie these beds of Pensauken sand and gravel uncomformably. It is a fact not without significance in this connection that the gneissic and granitic material of the outermost glacial drift is less thoroughly decomposed than the corresponding material of the Pensauken formation (see *ante*). This is not only harmonious with the foregoing conclusion, but corroborative of it.

If this inference be correct, the drift at the Readington-White House vicinity is not only very much older than that of the moraine, but it is very much younger not only than the Beacon hill gravel, but than the Pensauken. The difference in time between this drift and the Beacon hill formation would seem to be clearly greater than between this drift and the moraine.

Pre-morainic drift in the valleys of the extra-morainic Triassic area.—Within the area of the extra-morainic drift on the Trias of the western part of the State, there is, in addition to that on the highlands

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already described, a considerable amount in certain of the valleys. This may be divided into two classes—1°, that which is in the valleys outside the glacial drift limit; 2°, that which is in the valleys within the drift limit.

Concerning the first class it may be said that there is no valley drift, except such as is strictly local, in any of the valleys except those which head north of the drift limit. Specifically all the drift in extra-morainic valleys occurs in the valley of the South branch of the Raritan. It forms a nearly continuous bed in this valley from Lansdowne to Three Bridges, though there is a considerable interruption near Stanton station. From Three Bridges to the village of South Branch the drift in the valley is present in patches only. At Lansdowne its elevation is about 180 feet; at South Branch about 70 feet. The fall of the river in the same stretch is from an altitude of 160 feet to 60 feet.

The valley drift of the South branch of the Raritan reaches a maximum height of about thirty-five feet above the stream at Flemington Junction, and extends down to the flood plain, as shown at various points in the same region. The depth of this valley drift is not readily determinable. Near Flemington Junction it has a known thickness of twenty feet.

At several points this drift is disposed in the form of more or less clearly-defined terraces. This disposition may be seen at Flemington Junction, where the terrace-like bench is twenty-five feet above the stream; at Woodfern, where it is fifteen feet above the river; and west of South Branch village, where it has a height of about fifteen feet.

In composition this drift may be characterized as a clayey gravel. Its stony constituents range up to six and eight inches is diameter. They are mainly of gneiss, with some sandstone, quartzite and shale, which is not Triassic. Triassic shale is also present, frequently in considerable quantity.

The matrix of the drift is sometimes stiff clay, and sometimes more or less arkose. It appears to have been derived largely from gneissic material, but with a considerable mixture of clay from the red shale at some points. It was nowhere observed to be distinctly stratified, though there are few good exposures. The best are to be seen at Sunnyside, Flemington Junction and Woodfern.

It is to be noted that the small valleys between Hollands brook and

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the South branch of the Raritan contain no drift. They lie beyond the outer limit of the drift.

The second class of valley drift, namely, that within the glaciated area, is best shown along the valley of the North branch of the Raritan. It forms a low and tolerably continuous plain, fifteen to twenty feet above the river, from the vicinity of Bedminster to Milltown. Its altitude in the former place is about 150 feet, and at the latter 60 to 70. The drift of this valley is more or less terrace-like, the terraces being occasionally well defined, as at North Branch village and north of Burnt Mill.

Comparable phenomena exist along the valleys of the Lamington river and Rockaway creek. On the whole, the valley drift of these localities is more clayey than that along the North branch. The drift in these minor valleys also sometimes takes on a terrace form, as may be seen in the Rockaway creek valley, northeast of White House.

The upper limit of the valley drift is not sharply defined. It does not rise to a certain distinct and readily-traceable level, and there stop. Rather, it grows thinner towards its upper limit and seems to "fray out." Above the valley drift, scattered stones and bowlders may be found, even to the summits of the elevation on which the beds of drift already described occur.

It is believed that this valley drift was deposited by the present streams long after the glacier had left this region. It is believed to be made up in part of the glacial drift, which was brought down to the valleys and deposited in them after they had been excavated to essentially their present level. As already indicated, it is believed that the amount of erosion which was accomplished after the upland drift of this region was deposited, and before the valleys reached their present level, was very considerable (see page 87). The connection of the upland drift with the valley drift by scattered bowlders and stones on the slopes between, seems to corroborate this conclusion concerning the origin of the valley drift.

It will be readily seen that if this be the correct interpretation of the valley drift, it is significant of slight crustal movements, its accumulation in the valley seeming to point to a time when drainage was sluggish, after a time when it was more rapid.

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B. DRIFT NORTH OF THE TRIASSIC AREA.

On Musconetcong mountain.—The extra-morainic drift on the crystalline schist and associated formations will be described in less detail, partly because data concerning it are less well in hand. While its areal distribution is known, and all available facts concerning it are collected, there are some questions of interpretation which need further study.

On Musconetcong mountain there are at least two well-defined areas of drift, though both are small. The first of these occurs a little more than a mile north of Spring Mills and four miles northeast of Riegelsville. There are roadside exposures three to five feet in depth, which show at least this amount of drift. In color the drift is reddish brown. It is non-calcareous, and contains stony material of the various sorts common to the extra-morainic drift of this region. Of these materials gneiss is the most abundant. The shale bits sometimes show distinct striation, though this is not the rule. Some of the harder stones possess surfaces which seem to have been planed by ice wear, but it is possible that they were otherwise developed. Owing to the lack of exposures, and owing to the similarity of the matrix of the drift at this point to the decomposition products of the gneiss, the exact limits of the area of drift are difficult of definition. Its position, as well as it can be defined, is shown on the map. Its altitude is about 640 feet.

The second small area is about one and a half miles northwest of Little York and nearly two miles east by northeast of the area just mentioned, and about two miles south of Bloomsbury. A gully exposes the drift to a depth of three or four feet, where it contains the same sorts of material as other patches of drift in the vicinity. Stones from the Medina and Oneida formations may both be recognized here. Bowlders from these formations are sometimes two and a half feet in diameter.

About Swinesburg, three miles southeast of Bloomsbury, and at a point about two miles east of Riegelsville, bowlders are very abundant at the surface, and it is possible that there are here greater quantities of drift than are revealed. The absence of exposures in both these situations makes it impossible to affirm that there is any considerable bed of drift present. In the former of these two situations the bowlders have an altitude of something like 940 feet. In the latter, they

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are between 600 and 700 feet above the sea. Throughout this area remnants of drift—bowlders, &c.—are rather likely to be found, and to be found in greatest abundance, in cols and on level upland surfaces. They are very generally absent from the steeper slopes and sharp summits. Scattered bowlders occur on Musconetcong mountain, where drift in greater quantities is not present. They are more likely to occur on areas of considerable elevation, and in cols, than elsewhere. They are especially likely to be abundant about the borders of drift areas in such situations. There is probably not an area a mile square on the mountain which is free from them.

Although not on Musconetcong mountain, mention may best be made at this point of two or three areas of drift on the crystalline schist area, not far from those already described. Two of these are near High Bridge, and have been heretofore described.* Here the drift has a range in altitude from 460 feet down to 200, and the latter elevation is no more than twenty-five feet above the bed of the South branch of the Raritan, near at hand.

The other areas north of Lebanon cover an area varying in altitude from 500 feet to less than 300, and reach nearly to the level of the valleys. The drift here lies partly on crystalline schist and partly on Triassic conglomerate. It is closely associated with the drift areas on the Trias, west of White House, already described.

On Schooley's mountain.—On the northeastern continuation of Musconetcong mountain there are isolated areas where beds of drift occur. Two of these are near Newport. One of them is a mile southwest of this place. Here the drift is two to five feet in thickness, and there is no rarity of striated shale fragments three or four inches in diameter and a considerable variety of stony material. The drift is distinctly unlike the gneiss residuary which lies beneath, apparently undisturbed. Just south of Newport there is another small area where a similar condition of things may be found. The elevation of the drift at these points is less than at many others, being between 600 and 700 feet. In both situations the drift is on a slope well down towards the bottom of the little valley.

Another small area of drift occurs just north of Pleasant Grove. It is exposed to a maximum depth of about four feet. The drift here lies upon a rather gentle slope at an elevation of about 900 feet.

Further east, a much more considerable body of drift is found,

* Annual Report for 1891, page 103. Ditto 1892, page 64.

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extending from the village of Schooley's Mountain to a point four miles further northeast, with an average width of about three-quarters of a mile. It is mainly above an elevation of 1,000 feet, and runs up to 1,080 feet. It covers the surface of a rather flat-topped upland area. The drift has an even surface and comparatively few bowlders. Gneiss bowlders are much less abundant than in other drift areas on the crystalline schist, and the sandstone and quartzite bowlders are correspondingly more abundant. Several varieties of sandstone and quartzite are represented, including possible representatives of the Oneida and Medina. Black flints occur, and a single piece of limestone was seen. Hudson river shale and sandstone fragments are also present. The bowlders are sometimes two or three feet in diameter. They are distinctly worn, except the bowlders of gneiss, which are generally rather angular. Striated stones are found now and then, but not in abundance. Depths of more than ten feet of drift occur, and at that depth, in one place at least, its bottom is not reached. In several places large, unworn slabs of sandstone occur in such relations as to suggest that sandstone once formerly existed over the gneiss, or, more likely, interfolded with it, and that these slabs are erosion remnants of it. There are no exposures, so far as known, to give confirmation to this suggestion. The same thing is suggested at other points.

Separated from the area of drift just mentioned, there is another more extensive area, also on Schooley's mountain, about two miles east of Hackettstown and west of Budds lake. Roughly speaking, it reaches from Drakestown on the south to the moraine north of Budds lake on the north, having an area of six or seven square miles. Within this general area there are some summits which are free or nearly free from drift. While at its north edge the extra-morainic drift of this area reaches the moraine at two points, it is separated from it most of the way by a narrow belt which has no more than traces of drift. The drift occupies the rather flat tract just north of Drakestown, at an elevation of nearly 1,100 feet. Its greatest altitude is 1,180 feet. From these altitudes it reaches down the upper slopes to levels below 1,000 feet. Its highest point is not so high by about twenty-five feet as the highest point of the moraine to the north. The drift has the general constitution of till. The matrix is more highly colored than that of the moraine, its color being such as to indicate a higher state of oxidation. The stony material is made up of Hudson river shale and sandstone, sometimes showing striation, black flints, quartzites of various colors, conglomerates and sandstone

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of light, yellowish color. Striated stones are very rare. There are few exposures. The best occur a mile north of Drakestown, a mile northeast of the south end of Budds lake, and again along the road northwest of Budds lake.

A half mile east of Drakestown there is a gravel pit where the exposed drift is fresher in appearance than at most points. This is at an elevation of about 960 feet, or 60 feet above the lake. The drift exposed here is stratified, and in its color and in those other characteristics on which an estimate of age is based it is in contrast to the drift at other points in the area. The drift at this point is on the slope of a valley leading down to Budds lake. The moraine on the other side of the lake, three miles away, is at an elevation somewhat higher than that of the gravel.

South of Budds lake, a mile or so west of Mount Olive, there is another area of drift hardly separated from the last. Its altitude is about 1,040 feet. In its general make-up it is not unlike the rest of the drift on Schooley's mountain.

Two or three other patches of drift lying three to five miles east of the last are best spoken of in this connection. They are west of the valley of Drake's brook, on the highland which is virtually a continuation of Schooley's mountain.

One of these areas is a mile northwest of Flanders. The drift here occupies the summit and upper slopes of an area which reaches a maximum altitude of 1,116 feet just east of Salmon mine. It is only about a mile from the moraine and has about the same elevation. The stony materials are in considerable part like those of the moraine to the north, but the proportions of materials are different, and some constituents—certain varieties of quartzite—are found outside of the moraine and not in it. Deep exposures are not to be found. The shallow ones and the surface indicate a much higher degree of oxidation and weathering than the drift of the moraine close at hand.

Northeast of the last area there is a long (two and three-fourths miles), narrow (five-eighths of a mile) area of drift, occupying the flat summit of the ridge. It reaches a maximum altitude of 1,190 feet. Its north end reaches nearly to the moraine. In general, the matrix of the extra-morainic drift is more clayey and sticky than that of the moraine, a distinction which is of very general application.

The drift of this area is not well exposed. The best exposure seen was a temporary one, six feet in depth, about a mile north of Hilt-

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mine. Here the drift was mainly of a clayey nature, with a color indicating complete oxidation to the bottom of the exposure. The general appearance of the drift is in striking contrast to that of the moraine close by. The color of the latter is usually greyish three feet or so from the surface, a color which generally indicates the absence of leaching and oxidation when it occurs. This, however, depends upon the constitution of the material concerned. The sorts of rock in the extra-morainic drift are not markedly different from those of the moraine to the north. There appears to be a greater variety, however, in the extra-morainic drift, if varieties of gneiss and schist be excepted. This appears to be true in spite of the fact that the drift appearing to have the greater variety of stone is so much less well exposed than the other, so that its stony constituents are less easily seen.

There are two or three other small areas of extra-morainic drift in this vicinity. They differ in no important respects from those already noted. Scattered bowlders occur on Schooley's mountain in much the same abundance, and in much the same relations, as on Musconetcong.

Lower Pohatcong mountain.—No considerable body of drift was found on this mountain from Washington to the Delaware, but it is important to notice that a number of isolated bowlders and bowlderets are found along the crest of the mountain. The bowlders are here less common than in most other areas of equal size, between the moraine and the southern limit of the drift.

Upper Pohatcong mountain.—On Upper Pohatcong mountain there are small patches of drift at various points. One and a half miles northeast of Port Colden, on the summit of the highland plateau, at an elevation of 940 feet, there is a small area of drift characterized by a considerable abundance of stony material of foreign origin.

A mile northeast of Karrville, at an elevation of more than 1,000 feet, there is a small area, showing a considerable quantity of bowlders of various sorts, including Oriskany. There are no exposures.

On the same mountain, a mile north of Rockport, on the road from Beattystown to Danville, is also another small area of drift, reaching a maximum altitude of nearly 1,200 feet. A half mile to the northeast there is another small patch reaching an elevation fully as great. These areas are only a mile or so from the moraine, but are 150 to 300 feet higher than its outer edge. There is also a considerable area of drift at a somewhat lower level (820 to 1,000 feet),

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reaching northeastward from Mount Bethel, a mile and a-half north of west of Rockport. This drift occupies a shallow valley, the bottom of which is more than 800 feet above tide. The drift runs up on the slopes nearly 200 feet above the valley bottom. Scattered bowlders occur on Upper Pohatcong mountain, in numbers and relations comparable to those already noted in connection with Musconetcong and Scott's mountains.

Marble mountain.—On Marble mountain beds of drift are not known to occur. There are scattered bowlders at various points, especially in the pass between the main mountain and the smaller part northwest of it. They were not found on either of the narrow summits or on the steep slopes.

Scott's mountain.—Northeast of Lower Harmony there is an area of drift occupying a col (680 feet) and spreading downward from it both to the northeast and southwest. The drift is ill-exposed. Two miles or a little less northeast of Lower Harmony there is another small patch of drift just at the forks of the road. The drift is not deeply exposed, but its depth locally exceeds six feet. The range of foreign material is somewhat great, Potsdam, Oneida, Medina and Hudson river bowlders being present. Glacially-striated stones are present, but rare. The altitude varies from 730 to 640 feet, and reaches down nearly to the level of the little creek at this point.

Drift also occurs on Scott's mountain at various points in the vicinity of Montana. One mile north of this place there is an area of drift of irregular, winding form, frequently occupying cols between hills. Foreign bowlders are of rather common occurrence over it, though exposures are wanting. The drift here reaches a maximum elevation of 1,180 feet. A mile northwest of Montana there is another small area the surface of which indicates that drift is present in considerable quantity. This reaches an altitude of 1,180 feet, but does not reach the summit of the broad-topped hill at 1,199.

South and west of Oxford Furnace there is a large area two or three miles square where drift is very generally present. The tops of the hills which have narrow summits, and the steep slopes below their tops are free from drift, or have bowlders only upon them. The drift is exposed by the roadside near Little York and about Oxford Furnace. At the former place the material is frequently found to be striated, and has the same general character which marks most of the drift of the highland region outside the moraine. Very

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much of the drift about Oxford Furnace seems to possess the same characteristics, but at several points in this vicinity the drift is distinctly unlike most of that outside the moraine. It is unleached, is highly calcareous, and contains distinctly-striated limestone fragments. This new, fresh type of drift extends as far south as the north end of the railway tunnel southeast of Oxford Furnace. There can be not the least doubt that for a short distance south of the moraine, in the vicinity of Oxford Furnace, the drift is of essentially the same age as the moraine. It is probably a fact that drift of terminal moraine age lies just outside the latter at many points.

On that part of Scott's mountain which lies northeast of Oxford Furnace there are a few small areas where drift is sufficiently abundant to constitute well-defined beds. Such areas are—(*a*) a mile southeast of Oxford Furnace, on the Washington road, in a col at 800 feet; (*b*) two miles east of Oxford Furnace, likewise in a col, a small area at an altitude of 1,080 feet; (*c*) another small patch half a mile northeast of the last, ill-defined; (*d*) another col area a mile or so north of Karrville. The limits of these areas last mentioned cannot be fixed with accuracy. Exposures are wanting, and the surface is wooded, for the most part. The areas have been mapped as drift, on the strength of abundant surface bowlders. Scattered bowlders may be found on most parts of Scott's mountain, though they are sometimes so rare as to be very inconspicuous. Considerable stretches of road may sometimes be traversed without seeing them. The most abundant are Potsdam, Oneida and Medina.

On the highlands east of the valley of the South branch of the Raritan.—Drift in the form of scattered erratics, if nothing more, is found over the whole of the highland area south of the moraine at Dover, and west of the moraine at Morristown, down to the borders of Lake Passaic on the south. Over most of this area the drift consists of scattered bowlders only. These are distributed throughout the area without respect to topography, except that they are, on the whole, rather more likely to be present on elevated, flat-topped areas, and in cols, than at other points. The extra-morainic drift is more abundant, on the whole, near the moraine than at considerable distances from it, yet considerable beds of drift occur as far south as Bernardsville, on the extreme southern limit of the highland area.

The general constitution of the drift is the same throughout most of this area. Its stony material is made up of gneiss or crystalline

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schist, which is usually little or not at all worn, of quartzite and sandstone and conglomerate of various sorts, and of black flints. At no point east of the Black river has Hudson river sandstone or shale been identified, and at no place within the same area was limestone found in the drift. In its general features of distribution and constitution, it will be seen that the drift of this region is altogether similar to that further west, except that Oneida and Medina sandstone and conglomerate bowlders, as well as Hudson river sandstone and shale, are absent, and Green Pond mountain conglomerate is present.

East of Succasunna and south of the moraine at Dover and Rockaway, and west of the moraine from Denville to Morristown, drift is present in sufficient thickness to constitute beds over an aggregate area of about fourteen square miles. This is mainly near the moraine. Except on steep slopes and sharp peaks, there is a somewhat general covering of drift over a belt a mile or two wide, just outside the moraine, from a point midway between Tabor and Littleton, westward to the valley at Succasunna. Many of the highest points within this area are free from beds of drift, but even on these summits, and on the abrupt slopes, bowlders are frequently present. These have been found in such situations that it is safe to say that there is no part of this area too high to have bowlders, although it cannot be said that they are especially characteristic of the highest points. Indeed they are almost sure to be wanting on such points if the slopes are steep and the summits narrow.

Exposures.—The drift is well exposed at but few points. Exposures occur at Swedes mines, two miles southwest of Rockaway, also about two miles from Rockaway on the Mill Brook road, where the wagon road crosses the Delaware, Lackawanna and Western railway. Another exposure occurs about one and one-third miles south of Rockaway, in the railway cut. Other railway cuts in the vicinity expose ten feet or so of till. The drift is well exposed also at the railway cut south and west of Mount Tabor. The till here has an exposed thickness of about twenty feet. Various cuts also in the village of Tabor expose varying thicknesses of drift. There are other exposures one mile south of Tabor and two-thirds of a mile west of the railroad. There are shallow exposures both north and south of Greenwood. Other trivial exposures in road cuts to the depth of three to five feet are seen at two or three points north of Shongum.

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Throughout the whole of this area, the extra-morainic drift has a somewhat different aspect from that of the moraine itself, yet the difference in many cases is hard to define. Generally speaking, the material outside the moraine is much more highly oxidized than that of the moraine itself. The greyish color which characterizes the material of the moraine, and which is the color of pulverized gneiss, is for the most part absent from the extra-morainic drift. Its color is much more commonly reddish brown, indicating a higher state of oxidation of its constituents. The two types of drift may be profitably compared in the immediate vicinity of Dover. On the north lies the moraine in which there are exposures, some of them of considerable extent. South of the river lies the other phase of the drift.

Another point of difference beside the color is found in the relative abundance of striated material. Generally speaking, it would fall within the limits of truth to say that the striated stony material is several times as abundant in the moraine as outside it, but there are places where the material outside the moraine is not poor in striated stone, and there are places in the moraine itself where striated stone is not especially abundant.

The stony material of the extra-morainic drift cannot be said to be markedly unlike that of the moraine from the standpoint of lithology. It is often true that materials are found in the extra-morainic drift which are not found in the moraine near at hand, but it is also true that no variety of stony material is found in the extra-morainic drift that is not found at some point in the moraine or north of it. On the other hand, it is true that all the sorts of stony materials of the moraine are found at some point outside it.

In general the proportions of material are not the same in the moraine and outside it. Limestone is frequently found in the moraine, but at no point east of the Black river valley was it found in the drift outside the moraine. In the extra-morainic drift quartzite forms a much larger proportion of the stony material than in the moraine. The gneissic and granitic rocks occur in greater variety in the moraine than outside. There is also a contrast, in many places very marked, in the amount of wear which the gneissic bowlders in the moraine have suffered, as compared with the wear shown by corresponding bowlders outside.

It is true, too, that at a number of points the extra-morainic drift of this region does not bear such distinctive evidence of age as in

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some other parts of the State. This is especially true of the drift very near the moraine. Thus the railway cut west of Tabor and the exposure near Mill Brook do not look so markedly unlike the drift of the moraine that it need be supposed that they are far separated in time of origin. We entertain the idea that the ice which made the moraine may have advanced somewhat beyond the position of the moraine, perhaps shortly before the latter was formed, and that some of the extra-morainic drift is the product of such advance. A specific bit of evidence bearing in this direction is found in the form of a gravel hill two and a third miles southwest of Rockaway. This gravel hill is almost kame-like in form, and rises up about forty feet above the gravel plain of the Rockaway. This gravel has the appearance of being late glacial gravel. We are inclined to believe that the ice reached this point at least, during the epoch when the moraine was made.

Further south, in the vicinity of Mendham, there is a considerable patch of drift, a square mile or more, which lies at an elevation ranging from 500 to 600 feet. It is difficult to say how thick the drift may be, since exposures are wanting. A fresh excavation in the summer of 1892, just west of Mendham, showed a sandstone bowlder imbedded in a clayey matrix, five feet below the surface. At several other points there are shallow exposures which show that there is a considerable body of foreign material overlying the gneiss. The soil in the region, however, as shown in the fields and roadways, is not notably different from that of the gneiss hills which have no drift. The drift of this area, therefore, is by no means obtrusive and might easily be overlooked. Further west there is also a considerable body of drift at Roxiticus. This occupies at an altitude ranging from 400 to 600 feet. It lies well down in a valley, which appears to owe its existence quite as much to the fact that the underlying rock is limestone as to river erosion. The drift is best exposed at a limestone quarry just west of the railway.

Another interesting area of drift occurs at Bernardsville. It lies east of the village, extending both north and south of it, and covers the Basking Ridge hill. It reaches a maximum altitude of about 500 feet and a minimum of a little less than 400. The drift is well exposed in the eastern edge of the village, on the road leading from Bernardsville to Madisonville. It is also well exposed by the roadside a half mile south of Bernardsville, and at the railway cut north

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of Basking Ridge station. In the former place several feet of the drift has every appearance of till. It overlies a considerable bed of yellow sand, the bottom of which is not exposed.

The cut south of Bernardsville is of even greater interest than the one east of the village, because of the extreme decomposition of the stony materials. Hardly a stone was found in the freshly-exposed drift which is not thoroughly decomposed. Every feature betokens great age. The exposure south of Bernardsville is wholly of till. Whether there is sand beneath or not is uncertain, but a few rods to the east, at a slightly lower level, there are considerable sand pits, where the sand corresponds in character with that east of Bernardsville. This sand is identical with the sand of the hill at Basking Ridge, as shown at certain pits, but not in the railway cut. From its structure and its constitution, there seems to be no possible doubt that the drift exposed east and south of Bernardsville is till. Though rare, two beautifully-striated bowlders have been found in the cut east of the village. One of the singular features of the till at both the localities mentioned, but especially at the point a half mile south of the village, is a considerable amount of Triassic shale and sandstone. The altitude of the exposures is between 440 and 460 feet. There is no red shale in the region at any such elevations. There are two possibilities with reference to the method by which it reached its position; either it was carried up from the lower Triassic area to the northeast, or it was formed when the Triassic rock close at hand was at greater heights than now—that is, before the adjacent surface had been cut down to its present level. The former of these suppositions is the easier, and nothing can be said against it.

Reference was made to the sand beds of this locality in 1892.* No further light has been thrown on their origin. The sand is slightly arkose, and contains very little stony material. But there were found in it, especially in the pits west of Basking Ridge hill, several small bits of red shale, apparently of Triassic origin. The altitude of the pits is about 450 to 460 feet. If the sand is connected in time and in genesis with the till overlying it, and against this view no fatal objections are known, these bits of shale raise no new questions. If the sand is older than the drift, a view against which no fatal objections seem to stand, these shale bits possess especial significance. In this event, it would seem that the sand must have been deposited by water

*Annual Report for 1892, pages 67 and 153.

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at a time when red shale stood at some such level as that of the sand pit. Although the sand is derived mainly from the crystalline schist, the presence of the red shale bits may be accounted for if it were deposited before erosion had brought down the surface of the Trias below the sand level. This is so extraordinary a hypothesis that the other view, which makes the sand essentially contemporaneous with the till, is perhaps the more probable. Nevertheless, there are some difficulties in the way of its acceptance, though they are not conclusive. Their consideration, however, is deferred.

From Bernardsville to Mendhan bowlders are more rare than at any other point within the area which is believed to have been covered by ice. But they may be found here and there in favored situations. Those which can be recognized as erratics are almost all sandstone or quartzite. Many of them have the general appearance of the rock at the sandstone and quartzitic ledges near Succasunna. Some of them are reddish purple in color, not unlike some portions of the Green Pond mountain conglomerate, although they are not conglomeratic.

As will be seen from the accompanying map, there is a very considerable amount of drift in the capacious valleys in the northern part of Hunterdon and southern part of Warren counties. This drift is found notably in Pohatcong and Musconetcong valleys, and in the valley of the South branch of the Raritan. There is some of it also in the Black and Lopatcong valleys, and in the Delaware valley much further south.

Drift in the valley of the South branch of the Raritan and adjacent to it.—From a point a short distance south of Kenvil, drift is found in considerable abundance above the sand plain which was contemporaneous with the moraine. It extends south and southwest to Ironia and Flanders. It reaches a maximum elevation of 900 feet, the adjacent valleys having an elevation of about 700, so that it is not very strictly valley drift, although the area which it occupies is well below the high lands east and west. The considerable area of drift in this locality commences as a narrow ridge at its north end. It rises above the overwash plain which connects with the moraine a mile and a half to the north, and widens and rises southward until its maximum width is reached in the latitude of Flanders, where it covers the area from the immediate valley of Drakes brook to the valley of Black river. The drift does not rise to the summit of the

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high gneiss hills a mile and a half west of Ironia, but stops at an elevation of about 900 feet.

With one or two distinct exceptions, the drift of this locality has the appearance of being much older than that of the moraine. The oxidation and weathering, as seen at many of the exposures, is very considerable. This may be seen at the sand pit southeast of Carey's, where the full section of drift, about eight feet, bears the marks of great age.

Exposures.—At the exposure near Carey's just referred to, the color of the matrix of the drift is yellow to red. Stony materials consist of gneiss, Hudson river shale, quartzite of various types, sandstone and black flint. Flints were not noticed in the moraine northeast of this point, nor were the yellowish-brown quartzitic sandstones, which are especially abundant in the drift. Both these types of stony material, however, are present in the moraine at various points. No limestone was seen in the extra-morainic drift, though in the moraine to the northeast of this locality, limestone is by no means rare. If the ice which made the moraine advanced down the valley to the southwest, and deposited the material which is under consideration, it is difficult to see why limestone should have been absent.

Another exposure occurs a mile and a half northwest of Ironia, at an elevation of 880 feet. The drift at this point has a *distinctly fresh* appearance. The surface appears to be weathered to a depth of no more than two feet. The drift is gravelly, with a considerable variety of stony constituents not unlike those of the moraine to the north, with the addition of abundant stony material which could have been derived from sources between the moraine and this exposure. The drift between this point and Ironia is generally fresh-looking.

At the school-house between Succasunna and Drakesville, the drift is again exposed by the roadside. Here, again, the drift does not have the appearance of being extremely old, though it is more highly colored (oxidized) than the drift in the moraine.

Southwest of the above exposure, about a third of a mile, there is another excavation which shows eight feet of drift overlying the white sand. The drift is highly colored, except in its lower part, where it is mixed with white sand. The drift here is till, and shows foliation.

About a half mile north of Ironia, a railroad cut exposes a considerable body of till. The surface portion is oxidized to a very

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high color for a depth of two or three feet. Beneath this, the color still appears to be high, but it is so far concealed that little can be said of the deeper parts. Something like half the stony material in the cut is such as might have come from near Kenvil or Succasunna. Much of the stony material is little worn, though some of it is distinctly so, and striation is not very rare.

Drift between Flanders and Lower Valley.—From Flanders to Middle Valley, the drift is nearly continuous on the east side of the valley. North of Bartley, it is on the west side of the valley as well, but it everywhere keeps to the east of the valley of the South branch. The remarkable thing about the drift at this point is that while it overlies limestone it contains no material derived from it. There are good exposures just north of Flanders and at the railway cuts between Flanders and Bartley. Throughout the area the drift is made up of gneiss, black and yellow flints, yellow-brown quartzitic sandstone, and quartzite of various colors. Many of the latter may have come from the vicinity of Kenvil. There is a little drift in the valley between Middle Valley and Lower Valley, which seems to be a continuation of that from Flanders.

In this connection a small area of drift, comparable to that from Bartley to Middle Valley, may be mentioned. It lies one mile east of Gladstone. Here also the underlying formation is limestone. The matrix of the drift is rather loamy and has a pronounced yellow color and contains the usual variety of stony material.

Along the Black river valley above the overwash plain.—Along the east side of the valley of the Black river, from a point one mile north of Ironia to a point 100 yards south of the Chester branch of the Central Railroad of New Jersey, west of Chester, there is more or less fine yellowish sand. With one exception it is not found on the west side of the valley. This exception is where Tanners brook joins the Black river. At this point there is a small area of sand on either side of the brook.

The northern limit of the sand is about one mile north of Ironia, at an elevation of 840 feet. Its upper limit declines southward until at Ironia it has a maximum elevation of 960. South of Ironia the sand continues along the river, above the swamp, rising 180 feet above the river east of Horton's station. It is found more or less distinctly, south to Cooper's mines. It is absent in the upper course of the small creek west of Cooper's mines, just north of Chester,

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though it is present in the lower course. South of the Chester depot of the Delaware, Lackawanna and Western railway it again rises to an elevation of 760 feet, and then declines southward. At its southern terminus, the sand is last seen at an elevation of about 680 feet. Tanners brook has a bordering sand plain at an elevation of 700 feet where it joins the Black river. South of Ironia the sand sometimes has an indistinct terrace-like form at an elevation of about 740 feet, that is, about forty feet above the level of the stream.

Exposures.—The sand along the Black river is well exposed to a depth of seven feet in an old mining shaft a few hundred yards north of Horton's station and a few rods above the railroad. The sand is stratified and the upper part contains many gneiss fragments of small size. Between Horton's station and Horton's mine, at an elevation of about 740 feet, sand is exposed in an old shaft. It is also exposed in Horton's mine, where its surface has a rather high oxidation color. It is said to be ten feet deep at this point, but it does not retain its high color to a depth of more than five feet from the surface. A road cut west of Horton's mine shows that the sand is not a residuary product. It is irregular in depth, and overlies a red oxidized clay. The sand contains occasional fragments of rock, both gneiss and quartzite. A piece of quartzite was also seen in the red clay beneath it. At the Cooper mines, northeast of Chester, at an elevation of 880 feet, the sand is also exposed. It is three feet or more in depth, and is composed largely of rounded quartz grains. It here overlies gneiss residuary material. The same sand may be seen at the Squier's mine. Just east of Chester, on the Delaware, Lackawanna and Western railway, a fresh exposure made in digging a cellar (1893) showed three feet of sand with high coloration and containing some pieces of black flint and some fragments of gneiss.

The sand can be distinguished from the sand of the overwash plain below, by its higher position and by its higher coloration. It is possible there may be a distinction made between that on the hills and that in the valleys above the overwash plain, but no certain criteria for such discrimination were found in the field. No satisfactory interpretation of this sand has been reached. Reference will be made to it later.

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POHATCONG VALLEY.

The amount of drift in Pohatcong valley is in marked contrast to that on the mountains adjacent. Only in the vicinity of Oxford Furnace are considerable amounts of drift found on Scott's mountain. In other places it is found only in small patches and isolated erratic bowlders; but in the Pohatcong valley there is an extensive bed of drift. Its upper end is near Karrville. It stretches uninterruptedly down the valley through Washington and New Village to Stewartsville. Beyond this point its continuity is somewhat interrupted, but it is nearly continuous down to Carpentersville and Phillipsburg.

Topographic distribution.—The drift of the Pohatcong valley has an altitude of about 600 feet above Karrville, and an altitude of 300 to 400 feet fifteen miles further down the valley. It occupies the valley nearly down to the level of the stream, and runs up on either side of it to heights of from 60 to 100 feet. Above it on the north rises Scott's mountain, the slopes of which have very little drift, and above it on the south Pohatcong mountain, on which there are no more than traces of drift, chiefly in the form of scattered bowlders. This drift is therefore pre-eminently a valley formation.

Constitution of the drift.—The constitution of the drift is best apprehended by a description of some of its principal sections. Good exposures are found—1°, along the Delaware, Lackawanna and Western railway north of Washington, where it is exposed to the depth of fifteen to thirty feet; 2°, near the Morris canal, northwest of Washington, fifteen feet exposed; 3°, along the Delaware, Lackawanna and Western railway, between Broadway and Stewartsville, twelve to fifteen feet exposed; 4°, along the road east by north of Stewartsville, six feet exposed; 5°, at Thatcher Hematite mines, two miles south of New Village, fifteen feet exposed, partly stratified; 6°, along the Lehigh Valley railway, two and a half miles southeast of Phillipsburg, fourteen feet exposed; 7°, Hamlin Hematite, a half mile southwest of Port Warren, thirty-five feet exposed; 8°, Warren Foundry, in Phillipsburg, eight to ten feet exposed, the lower half stratified.

Exposures in the vicinity of Washington.—Railway cuts north of Washington expose fifteen to forty feet of drift, which has the general appearance of till. Its color is yellow brown with, in places, a reddish tinge. The stony material includes bowlders from the following

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formations: Potsdam (?), Oneida, Medina, crystalline schist (gneiss), shale and slate, presumably Hudson river. Gneiss bowlders range from four to five feet in diameter, while the quartzite and sandstone bowlders do not often exceed one or two feet. Striated stones are rather common. Gneiss and crystalline schist constitute more than one-half the stony material, ranging from forty to seventy per cent. The Potsdam (?) bowlders are twice as abundant as the Oneidas and Medinas.

At the canal.—The exposed drift here varies in thickness from five to fifteen feet, and the bottom of the drift is not exposed in all places. The matrix of the drift at this point is arkose rather than clayey. The variety of the stony material is essentially as in the last. Striated material is present but not abundant. All the stony materials common to the drift are present. The quartzites and hard sandstones show unmistakable signs of age. Some of the gneiss bowlders, the form of which distinctly indicates wear, are much decomposed. The color of the drift is such as to indicate complete oxidation of its constituents.

Along the Delaware, Lackawanna and Western railway, southwest of Broadway.—One mile southwest of Broadway station drift is exposed to the depth of twelve feet, and the bottom of the drift is not seen. The material of the drift is largely of gneissic origin. The bowlders of gneiss are all distinctly weathered, and some of them are so much decayed that they could not have been transported any considerable distance in their present condition. All the sorts of rocks mentioned as occurring near Washington are present here, as are also black flints. Glacially-striated stones are very rare if present. The matrix is rather arkose and the underlying rock is limestone.

One-half mile northeast of Stewartsville, railway cuts expose the drift to depths of about fifteen feet. The material here is mainly of gneissic origin. Its matrix is very arkose, resulting largely from the disintegration of gneiss bowlders since they were left in this position. Almost without exception the gneiss bowlderets, less than one foot in diameter, are deeply weathered, and many of them so completely disintegrated as to crumble at a slight blow. The other sorts of rock common to the drift of this region are present, though in very small quantities. The bits of shale are frequently striated. One large gneiss bowlder, 4 x 3 x 2 feet, was seen, which was comparatively fresh and showed distinctly-striated surfaces.

The second and third cuts northeast of Stewartsville show phe-

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nomena similar to those just described. Striated material was not found in these cuts but there was the usual variety of foreign bowlders. The railway ballast near at hand is made up of cobbles from the moraine near Dover and Port Oram. The contrast in color, freshness and hardness between these and the gneiss fragments of the cut is very marked, the latter being much more distinctly disintegrated, roughened and discolored by oxidation.

Thatcher Hematite.—At the locality marked Thatcher Hematite on the map, one and a half miles south of New Village, a stratified layer of drift, four or five feet thick, is intercalated between compact foliated layers which appear to be till. The color of the drift is brown, its matrix clayey, with a large percentage of gneissic material. The stony material is of considerable variety. Black flints from the local limestone are present but no limestone pieces were found.

Exposures near Phillipsburg.—Although the drift about Phillipsburg and along the lower course of the Lopatcong is not strictly in the Pohatcong valley, it is yet continuous with the drift of this valley and will be considered in connection with it.

At the Lehigh Valley railway cut, two and a half miles southeast of Phillipsburg, a maximum of fourteen feet of drift is exposed, lying above limestone. Its average thickness is six or eight feet. The matrix is compact and clayey, but not bowldery, although a few Potsdam bowlders, one and a half feet in diameter, may be seen, and there is one measuring at least two and a half feet. Shale is also present, probably from the Hudson river formation. No distinctly-striated pebbles were found.

Exposures at the pit of the Warren Foundry and Machine Company.—This pit gives the best exposure in the vicinity of Phillipsburg. A very compact clayey bed of stony drift, averaging three or four feet in thickness, but ranging as high as six feet, grades downward into a clayey gravel, and that into a cleaner gravel, and then into coarse sand. This stratified drift varies from three to six feet in thickness. In one part of the pit, as exposed in 1893, another bed of compact drift underlies the stratified layer. In other places the gravel and sand are underlain by a fine, reddish, clayey loam, without stone. The line of demarkation is sharp and undulatory. The underlying yellow loam is perhaps residuary material.

The upper member of the section has a yellow-brown color tinged with orange in places. All the drift exposed is deeply oxidized and

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nowhere calcareous. The unstratified material is exceedingly compact. The stones are so firmly imbedded that they frequently break in being moved. The stony material is generally of rather small size, rarely reaching a foot in diameter. Gneiss cobbles, generally little worn and much decayed, form a small percentage of the stony material. Cherts and flints of various colors constitute about one-sixth of the whole. Potsdams, Oneidas and Medinas are the most abundant constituents and in the order named. Hudson river greywacke and shale are very common among the smaller stones. The stratified bed contains a much larger percentage of slate and shale than the unstratified. Limestone is not present. Striæ are rather common on the slate fragments and are present on some of the sandstones.

In addition to the descriptions of specific exposures, a few words may be added concerning the general character of the drift in various other parts of the Pohatcong valley.

In the vicinity of Broadway, the line of demarkation between the drift and the gneiss wash from Scott's mountain is very indefinite. Exposures are rare and surface indications are not decisive. Southeast of the creek the drift is more marked. Erratics are numerous, constituting as much as fifty or sixty per cent. of the materials in the fence piles. Striæ are present on the softer rock. The thickness of the drift is probably not great. Occasional cuts, three to five feet deep, show the underlying limestone in some places, while in others the drift is considerably thicker, though its depth is not known. The drift, even a few inches above the limestone, is, in general, not calcareous.

In the vicinity of Still Valley, the drift, though not very stony, has occasional bowlders three feet in diameter. Striæ are not plentiful, but what appear to be planation surfaces are not rare. The percentage of gneiss found in the drift in this vicinity is small, there being no more than occasional bowlders; but to the southeast gneiss bowlders increase in abundance, until near the Pohatcong they constitute a considerable percentage of the stony material of the drift. Northwest of Still Valley, the gneiss bowlders and cobbles form a very small part of the coarse material of the drift and a still less proportion of the fine.

At the cut on the Delaware, Lackawanna and Western railway about a mile northeast of Phillipsburg, scarcely five per cent. of the

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bowlders and cobbles seen on the surface are derived from the crystalline schist areas. Potsdam, Medina and Oneida bowlders and masses of flint predominate. This paucity of gneiss bowlders continues to the north and northwest, becoming greater towards the southwest end of Marble mountain.

The ice movement in this region is known since glacial striæ were found on the lower part of Chestnut hill, at Easton. The striæ were seen on a much-decomposed surface of rock, laid bare by the excavation for the water works at this point. The direction of striæ was south, twenty-nine degrees west. This direction of movement would cause a distribution of gneiss bowlders very similar to that which we find in this vicinity. That part of the ice which moved obliquely across the narrow ridge of Marble mountain incorporated much less gneissic material into the drift than that part which passed over Scott's mountain. The result was that part of the valley lying in the lee of Marble mountain received but little gneiss, whereas that lying south of Scott's mountain received much more. The distribution of the gneiss, so far as observed, would seem to imply a more southerly movement of the ice which deposited the drift above Still Valley than is indicated by the striæ at Easton.

Musconetcong valley.—The drift in the Musconetcong valley is not so extensive nor, on the whole, so well developed as in the Pohatcong. The drift in this valley occurs in patches from Hackettstown to Bloomsbury. Its topographic distribution is, in general, similar to that of the drift in Pohatcong valley, but it does not generally so closely approach the level of the stream. It is, on the whole, less distinctly valley drift, although it lies distinctly below the mountains on either hand.

There is a considerable area of drift at Hackettstown and southwest from there, at a maximum elevation of 657 feet. It is exposed in railway cuts just north of Hackettstown depot and along the canal a half mile or so north of the depot.

There is another considerable area at a maximum elevation of about 700 feet, south of Rockport. The Musconetcong river at this point has an elevation of about 480 feet, so that the drift can hardly be called valley drift in the proper sense of the term. This area is separated from the crystalline schist to the north by a slight valley. Railway cuts expose five to twelve feet of the drift. At the southern end of the principal cut, about seven or eight feet from the surface, is

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a distinct layer of sand and gravel, traceable for as much as fifty yards. Above it is unstratified till-like material. Several striated pebbles were taken from the cut. Few large bowlders occur; bowlderets, ten to twelve inches in diameter, being much more abundant than larger stones. Of the erratics, something like fifty-five per cent. are of gneissic origin. Sandstone and quartzite constitute thirty to forty per cent. more of the material, while flints and quartz make up the remainder. South of the river south of Rockport the drift comes down to within thirty feet or so of the stream.

Still further down the valley, at Port Murray, there is another considerable area of drift ranging from 640 feet down to 440. Towards the stream it reaches the edge of the trench cut by the Musconetcong, apparently in recent times. The composition of the drift is much the same as that at Rockport, but there is less of gneissic material. The railway cut gives a good exposure, where the drift is seen to have a thickness of about ten feet, though it attains a maximum of nearly thirty.

South of Port Colden there is an area of drift lying partly on the gneiss slope and partly in the valley. South of Port Colden the drift extends down to within forty feet or so of the Musconetcong. The drift is here similar in all essential respects to that at Port Murray. At Junction there is another small area, which lies at an altitude varying from 420 to 360 feet, the river flowing at about 340. There is no positive evidence that there is any considerable bed of drift at this point, as decisive exposures are not at hand.

Below Junction, the best-defined areas of drift in the Musconetcong valley are northwest of Asbury and Bloomsbury, respectively. Direct proof of glaciation was not found in the area one and a half miles northwest of Asbury, but foreign bowlders of considerable variety are present, though not in great numbers. Distinctly foreign material is more or less completely buried in a matrix which is largely of gneissic origin. The thickness of drift at the Hematite mine is nearly thirty feet. The foreign bowlders are seen to be imbedded in the matrix considerable distances from the surface. Just west of Valley there are abundant erratics upon the surface, and it is probable there is something of a bed of drift at this point, sixty or eighty feet above the Musconetcong, but exposures are absent. A half mile and more northwest of Bloomsbury there is a considerable area more or less thickly covered with drift. Gneiss forms a large percentage of

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the material. The other materials which characterize the drift of this region are present in varying amounts. Striated stones were found, but they are not abundant. The color of the drift is everywhere such as to indicate a high degree of oxidation, and the physical condition of the material is such as to indicate that it has suffered a considerable degree of disintegration and weathering since its deposition. The best exposures are in the railway cut one and a half to two miles west of Bloomsbury. The gneiss material is by far the most abundant, making 80 or 90 per cent. of the whole, but Potsdam bowlders, Oneida and Medina bowlders, and Hudson river sandstone bowlders, or stones of smaller size, are sparsely imbedded in the drift. Small as their number is, they are quite sufficient to prove that the material is drift. Bowlders, presumably of Potsdam age, are sometimes two and a half feet in diameter, and a Medina bowlder one and a half feet in diameter was found, but the average size of the stony material is less than one foot. The drift in some parts of the cut is at least twenty feet thick. It may be sometimes seen to rest upon gneiss residuary. Below Bloomsbury, the drift does not occur in any quantity in the Musconetcong valley.

In the Delaware valley.—In that part of the Delaware valley north of Marble mountain there is a considerable body of drift, much of which presents the features common to the extra-morainic drift in all this region. The drift is stony, each square mile of the surface being strewn with thousands of Potsdam, Medina and Oneida stones, mainly of cobble size. The first-named predominate, if identification be correct. A distinctive feature of the drift bowlders, noticed at this point especially, but existing in other parts of the extra-morainic drift area as well, is the notable roughening of the surface, due to weathering. On the hard sandstone and quartz surfaces weathering has but little effect, and operates with extreme slowness, yet the surface of most of these stones is pitted and roughened to such an extent as to put them in contrast with the younger glacial gravel of the Delaware, when the two are carefully compared.

The best exposures of the drift in this region are afforded by two gullies about three-quarters of a mile southeast of Harmony station. The upper part of the cuts is rather gravelly. Beneath this gravel layer, in places coming to the surface, is a bed of till, containing many bowlders three to four feet in diameter, some of which are distinctly striated. The greatest known depth of drift in this area is

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twelve feet, but this does not represent the full section, since at this depth the bottom of the drift was not reached. Gneiss bowlders are almost entirely absent from this region. The few which were noted must have been carried for a long distance, since there is no gneiss to the northward for many miles. This area is separated from another small one to the northeast by the Trenton gravels, which were brought down the Buckhorn creek. This second area lies west of the Buckhorn and east of Roxburg station. At the southern end of this Roxburg area, the drift has the general characteristics of the extra-morainic drift, but at its northern end the indications are not so conclusive. Many of the bowlders here appear to correspond with those further south, but there is also a considerable admixture of fresher-looking material. Striæ are more numerous. Limestone bowlders are common. There are here no exposures, but the surface indications seem to suggest that the ice pushed out upon the northern part of this area, northeast of Roxburg station, during the moraine epoch, and incorporated a certain amount of fresh material with that which existed there before. The proportion of fresh material increases toward the moraine, which is less than a mile distant.

Stratified drift.—Allusion has already been made several times to stratified drift in connection with the unstratified along the Pohatcong, Musconetcong and Delaware valleys. At a number of points stratified drift exists, intercalated between layers of till. The best example of this, and one which has been mentioned, is that at the Warren Foundry pit, at Phillipsburg. At this pit the material of the gravel is largely shale and differs in constitution from the till. It has more the appearance of being river gravel, and yet its relations to the overlying and underlying unstratified drift are such as to make it seem certain that the two are connected in origin.

On the brow of the hill, a half mile southeast of Harmony station, there is a very considerable bed of gravel. It is composed largely of shale, but quartzite pebbles are common among the larger pieces. Many of the pebbles are disk-shaped. This gravel is much like that at the Warren Foundry pit. At first sight it appears to be fresher than the till which succeeds it higher up the slope. On closer study this appears to be rather the result of difference in composition. Whether the gravel passes under the till is not evident at this point. Again, east of Martin's Creek station, there is a narrow area above the limit of the last glacial gravel, which is covered by gravel made

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up to a considerable extent of shale. It is clearly older than the Trenton gravel. The same thing is true south of Roxburg station.

Similar gravel is found in the Delaware, Lackawanna and Western railway cuts southeast of Phillipsburg, near the Warren Foundry pit. Here the layer of gravel is several feet thick, but the cut is old and the exact thickness cannot be seen. Another exposure is seen along the road a quarter of a mile southeast of Lopatcong. In this vicinity the gravel was seen to be underlain by till. The gravel here attains a thickness of ten feet. It is made up largely of shale, granite and quartz.

All these localities are within a mile or so of the Delaware river, and this distribution might suggest an origin connected with the drainage of the river. But gravel which is exactly similar has been found at distances of two and three miles from the river. Thus, a half mile southeast of Still Valley it is seen on both roads leading up the side of the hill. In the vicinity of Springtown station, on the Central Railroad of New Jersey, it occupies a considerable area. Toward the higher ground it seems to pass under the till, but there is no section which distinctly shows this relationship.

The various altitudes at which these gravels have been observed are as follows:

Southwest of Roxburg station	280+ 10
Near Martin's Creek station	320+ 5
Harmony station	420 to 440
Warren Foundry pit	300 to 320
Railroad cut near Warren Foundry	280 to 300
Southeast of Lopatcong	240 to 320
Southeast of Still Valley	320 to 340
Springtown station	300 to 320

This gravel seems to be always closely associated with the till, either overlain or underlain, or both, by it. It occurs on side hills and near the brows of hills, places where it may have been readily revealed by erosion of the overlying till. Near Hopatcong it is seen overlying till, and in Still Valley it is seen to pass under stony clay as the top of the hill is reached. At Springtown it probably passes beneath the till, but the relationship is not so clear. The gravel readily washes and creeps down slopes, giving it the appearance of having a wider vertical range than it really has. The greatest known depth is ten feet, near Hopatcong.

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This stratified drift is not easy of interpretation. It seems to be distinctly separated from the gravel train which heads in the moraine, and which, further down the Delaware, is known as the Trenton gravel. On the other hand, it seems to be distinctly unlike the extra-morainic drift of any other series of localities. In spite of its unlikeness it is believed to be connected in time with the great body of extra-morainic drift and to represent merely a local phase of it.

Drift in the Delaware valley below the limit of glaciation.—Besides the late glacial gravel there are three well-defined areas of drift in the Delaware valley south of the limit to which glacier ice is believed to have extended. These areas of drift are at Washington's Crossing, at Titusville and at Raven Rock.

1°. *Raven Rock.*—About six miles above Lambertville is the northernmost well-defined area of drift material in the Delaware valley below the limit of glaciation. Near the mouth of the Lockatong, and west of it, there is a well-marked rock bench, similar to those on which drift occurs at Titusville and Washington's Crossing. It projects from the steep slopes of the highlands to the northwest, which here rise to a height of nearly 500 feet. The bench reaches somewhat above 200 feet, while the Delaware river at its base is about sixty feet above tide, thus making the top of the bench about 140 feet above the river. On the east side of the Lockatong the slope is gentle, but there is no distinct bench. Though by far the largest amount of foreign material is on the bench west of Lockatong, there is some on the east side. On the west side, the foreign material reaches up to an altitude of about 200 feet. Over much of this bench the drift is thin, but at some points it constitutes a bed, the depth of which is considerable. The matrix of the drift is largely of a sandy or loamy nature. The stony material consists of gravel, cobbles, and bowlders, the latter ranging up to five feet in diameter. The Potsdam, Oneida and Medina formations are represented, the first-named most abundantly. By far the larger part of the bowlders are well-rounded. A few have flattened and smoothed faces, suggestive of glacial wear. A single bowlder was found with distinctly-marked glacial striæ. A bowlder similarly marked was found on the slope east of the Lockatong, at a height of about 160 feet. Something of the abundance of the stony material may be inferred from the fact that several small fields are inclosed by fences built of the bowlders.

The topographic situation of this material is such as to protect it

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against erosion. The slope of the bench is gentle, and it is protected by valleys on either side from wash at the hands of the waters descending from the higher lands. These valleys receive and carry away such waters. It seems reasonably certain either that this material was deposited by the Delaware river when it flowed at this level, or that it was deposited when the sea stood at this level, 180 to 200 feet higher than now. The drift reaches down from the top of the bench to the upper line of the Trenton or later glacial gravel in great thickness. It is clear, therefore, that the rock valley of the Delaware at this point was as low as the upper surface of the Trenton or later glacial gravel, when this old drift was deposited.

2°. *Titusville.*—At Titusville there is a body of drift situated similarly to that at Raven Rock. The bench projects from the steep trap ridge known as Moore's hill, and which reaches an altitude of 482 feet. The bench itself has a height of 120 to 130 feet. It is well situated for retaining such drift as may have been deposited upon it at any time. On the top of this bench, and extending somewhat down its slopes, there is considerable stony material of foreign origin. Of fine material of distant origin there is relatively little. Numerous bowlders occur, ranging in size up to five feet. So plentiful are the bowlders that fences have been built of them, in one instance for a distance of sixty rods. The bowlders are of yellowish-brown sandstone, quartzite and conglomerate, probably of Potsdam age, and of Oneida and Medina sandstone. A single piece of much-decomposed gneiss was also found. The bowlders are of various shapes. A few are well-rounded, and some of them have flattened and smoothed faces. The maximum altitude of the drift is scarcely more than 130 feet. The steepness of the slope above this level, however, is not such as to be favorable for the retention of such loose materials as might have existed there. From the bench, the drift is found on the slope down to the level of the Trenton or later glacial gravel below. The amount of drift on the slopes of the bench is locally so great as to indicate that the valley of the Delaware, at the time of the deposition of the drift here described, was at least as low as the upper surface of the glacial gravel.

As in the case of the Raven Rock drift, there are two possible explanations of this drift. Either it was brought to its present position by the Delaware river when its channel was at this level, or it

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was deposited during a period of depression, when the sea stood at or near this level.

The stony material of the drift at this point is in striking contrast with that of the late glacial gravel in the valley below. Indeed, they are so unlike that no one familiar with geology would think of classing them together. The older drift material of the upper bench occurs down the slopes to the Trenton gravel. The amount of it on the slopes is not great. In places all there is might be thought to have descended from the benches above. But this does not seem to be true at other points.

3°. *Washington's Crossing.*—The drift at this point occupies the surface of a bench which extends from a point a short distance below Washington's Crossing to the mouth of Woolseys brook. The bench has an altitude of 130 to 140 feet. The river at the foot of the hill is about twenty-five feet above sea-level, thus making the bench about 110 feet above the river. The slope from the bench towards the river, especially at the northern end, is rather steep. At the southern end the bench is cut by Woolseys brook. Trenton or late glacial gravel exists on the slope to a height of eighty or ninety feet. Above this, and reaching up to an altitude of something more than 140 feet, is the older drift. This consists of sandy material, varying in thickness from zero to four feet or more, and containing but a small amount of stony material. The sand is for the most part fine, and has a dark, yellowish color. In the poor exposures seen, there is no trace of stratification. The thickness of the sand varies with the topographic situation. On the steeper slopes it is thin, while on the flatter top it attains its maximum thickness. On the slopes the sand is often present in traces only. It is quite probable that much of that which lies on the slopes has been derived from the material above, and is now in a secondary position. But this does not seem to be true of all of it. This locality joins with those already mentioned in indicating that the rock valley of the Delaware, at the time of the deposition of the drift here described, was at least as low as the upper surface of the glacial gravel.

Of the stony material, little need be said. There is almost no gravel; there are a few bowlderets of quartzite and sandstone conglomerate. A single bowlder of sandstone, three feet in diameter, was seen. This occurs at an altitude of 130 feet. The upper limit of this bed of drift is not well defined, though there is certainly no

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considerable depth of it above 140 feet. What traces of sand occur above some such level have probably been carried to their position by wind from the lower levels.

While pebbles and larger pieces of rock of foreign origin have been found at a few other points above the Trenton gravel, along the east side of the Delaware valley, these three areas are the only places where it occurs in quantity. It will be observed that the lèvels of these three benches are harmonious. The two lower ones have nearly the same level, while that at Raven Rock, twelve miles further up the river, is somewhat higher, but not so much higher as to be inconsistent with the supposition that the drift of the three localities was deposited by the stream at the same or approximately the same time. Neither are the topographic relations of the drift of the three localities such as to be inharmonious with the alternative hypothesis that the drift of these localities was deposited during a period of land-subsidence, when the sea stood at the levels where the drift occurs. Differential changes of level, either in the sinking or the later rising, might well account for the differences in the elevation of the drift at the three localities. The topographic positions and relations of the drift at the three localities are so similar that it seems probable from this consideration alone that the drift of the three localities was deposited at the same time and in the same way.

The stony material is similar in all three localities. Not only are the same kinds of rock represented at each place, but the proportions are nearly the same. Not only are the kinds and proportions of the bowlders the same, but their physical condition is constant. All lines of evidence would seem to indicate that the drift at the three points was formed at the same time.

From the size of the bowlders and from the fact that distinctly-glaciated ones exist, it is necessary to suppose that floating ice assisted the river in their transportation. The testimony of the drift therefore seems to point clearly to a connection with some stage of the ice period. The drift is clearly separated in origin, and separated by a considerable interval of time, from the late glacial gravels which lie below it, and which are essentially different in kind and condition. The height of the old drift above the Trenton gravel at corresponding points of the valley indicates the maximum amount of erosion which was accomplished after the deposition of this drift and before the deposition of the lower-lying glacial gravels of later age.

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Before the last glacial epoch, the epoch during which the new glacial gravel was deposited in the bottom of the Delaware valley, the stream appears to have cut its channel down essentially to the present level. At Washington's Crossing this level is about twenty-five feet above sea-level; at Titusville its level cannot be more than five feet higher. At the first of these points, therefore, the bench drift is 105 to 115 feet above the river; at Titusville, about 100 feet. Some of this cutting was accomplished in the older drift. Had it been otherwise, the slopes of the benches on which the drift occurs would have been of rock, not of drift. If the drift at Raven Rock, Titusville and Washington's Crossing was deposited by the river when it flowed at the levels of these benches, any earlier valley there may have been must have been filled up to this level at the time of the deposition of the old drift. In this case the river subsequently cut down its valley from the level of the old drift, and the vertical distance between the same and the bottom of the valley before the last ice incursion would accurately represent the amount of interglacial stream erosion in this valley. In this case we would have the following maxima of erosion for this period: at Washington's Crossing, about 110 feet; at Titusville, about 100 feet; at Raven Rock, about 140 feet.

It is to be noted that these figures are maxima. It is to be remembered that this amount of erosion was not all, and probably not principally, in solid rock. How deep the valley was prior to the deposition of the Raven Rock-Titusville drift we have no means of knowing.

On the other hand, if these beds of drift are the result of submersion which allowed the sea to rise to these levels, it is not necessary to suppose that so much erosion took place between the deposition of the old drift and the new. The drift might have been no more than a coating on the slope of the valley, up to the height to which the water rose. The trough of the valley may have remained a trough still, after the deposition was completed.

The relation of this valley drift to drift outside the Delaware valley further south, seems to help us to decide between the two hypotheses already mentioned in connection with the origin of the drift. That at Titusville and Washington's Crossing has about the same height as the Jamesburg formation about Trenton Junction, and from there to New Brunswick. The composition of the two is essentially

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the same. To explain the latter, subsidence is necessary. The former was probably deposited at the same time in the bay which extended up the Delaware. If the subsidence were greater to the north it would account for the drift at the greater elevation at Raven Rock. The drift at Titusville, Washington's Crossing and Raven Rock, therefore, is regarded as of Jamesburg age (see *ante*) and is the time equivalent of the outer border of the glacial drift. After its deposition the river excavated a valley through such deposits as it found in its channel, and through more or less rock beneath the drift, down to its present level. Then came the partial filling of the valley with late glacial gravel.

Since that time the Delaware river has excavated a much narrower channel in the late glacial gravel to a depth of about sixty feet at Washington's Crossing, and to a depth scarcely so great at Raven Rock.

Drift southwest of Summit.—The drift here spoken of has no immediate connection with that heretofore described. Southwest of Summit, in the valley of the Passaic, in the valley between the two crests of Second mountain, and in the valley between Second mountain and First mountain, there is more or less till. In the valley of the Passaic this is confined to low levels. It covers the surface about New Providence and southwest, reaching as far as Union Village. It does not constitute the surface formation at levels below 220 and 230 feet. It does not rise above 260 feet at Union Village, nor does any bed of it exist above 300 feet south of Berkeley Heights. Traces of the drift extend up on the slopes to a somewhat greater height, especially east and northeast of Murray Hill station. In the vicinity of New Providence, the surface of this drift is comparable to that of a poorly-developed terminal moraine—that is, it is marked by hollows and sinks of irregular arrangement. Throughout this area, the till is clayey, very sticky, and possesses the characteristics which have elsewhere been referred to as marking subaqueous till. It is believed that this till stood beneath the waters of Lake Passaic after it was formed. It is possible that some of it may be berg till.

Below a level of 220 to 230 feet the till is commonly covered by lacustrine clay, which is distinctly laminated, and which was deposited in Dead lake * after the ice had left this part of the State.

* See chapter on Lake Passaic.

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Drift between the crests of Second mountain.—Three-fourths of a mile southeast of Murray Hill, and from this point southwestward for two miles along the valley between the two crests of Second mountain, there is a small amount of drift, which is confined strictly to the valley. There are no deep exposures in this drift, and there is opportunity to learn less of its extent and thickness than could be desired. It is best exposed along the road crossing this valley between Feltville and Murray Hill, where its till-like character is shown. A mile further southwest, down the valley, on the east side of the road leading north from Scotch Plains, there are some large granitic bowlders, the largest being about nine feet in diameter. In the valley, a half mile southwest of the road last named, there are a number of huge bowlders, which in this place are most striking. The largest has a diameter of about twelve feet, and all the large ones are of gneiss or Green Pond mountain conglomerate. They do not have the appearance of being exceedingly old. They do not occur so far to the southwest as the till on the north side of Second mountain, though they occur at a much greater elevation.

Drift between First and Second mountains.—Between First and Second mountains, and on their lower slopes, especially on the lower slope of First mountain, there is considerable drift in the vicinity of Feltville. This runs northward until it reaches the moraine, though the morainic drift and that which is outside do not correspond very closely in character. The drift extends in patches to a point a mile southwest of Feltville.

Southwest of the Scotch Plains-Berkeley Heights road no drift is found until the longitude of Somerville is reached. On the north slope of Second mountain, drift bowlders, referred to floating ice in connection with Lake Passaic, are found not rarely, but above the level of the lake drift has not been found. There is no evidence that these parts of the trap ridges were ever covered by the drift.

On Long hill, on the other hand, pieces of Green Pond mountain conglomerate and of gneiss have been found at two or three localities between New Providence and Long Hill village, well above the level of Lake Passaic. In all cases these drift bowlders, which are exceedingly rare, appear to be very much weathered, but since they are conglomerate the weathering shows itself principally in discoloration. It is not safe, therefore, to base important inferences upon it.

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SECTION III.

THE TERMINAL MORAINE.

The course of the terminal moraine across New Jersey is indicated on the State map accompanying this report. It enters the State from the east at Perth Amboy. For the first eight miles it curves gradually to the northwest, to the point where it is crossed by the Lehigh Valley railroad. For the next four or five miles its course is nearly due north to Fanwood. Thence it turns slightly east of north for about six miles, to the latitude of Summit. From this point there is a continuation of the moraine two or three miles further northeast, to a point two miles north of Short Hills.

At the Passaic river northwest of Summit the moraine is interrupted by the valley. While much of the morainic material may remain, the morainic characteristics of the surface are gone. Beyond Chatham, the course of the moraine is northwest by a gentle curve for about five miles, to a point just east of Morristown. Here again the distinctive character of the moraine is interrupted by the valley of the Whippany river. North of this stream the course of the moraine is nearly due north, curving slightly eastward for the space of six or seven miles. Just above Denville, where it is again interrupted by a river valley, this time the valley of the Rockaway, the moraine turns abruptly westward and follows a westerly course to Saxton falls.

Between Denville and Saxton falls the moraine is much interrupted and interfered with by the Rockaway river, so that its continuity is destroyed. It is partly on the north and partly on the south side of the stream, and is not everywhere well developed. Near Saxton falls the moraine bends somewhat to the south, and from this point to the Delaware its course is west by southwest. The Delaware is reached two miles below Belvidere. From Townsbury to the Delaware the course of the moraine is along the Pequest valley, or in its immediate vicinity, and as is usual under such circumstances, the moraine does not preserve all the features which generally characterize it outside of valleys.

The course of the moraine is perhaps most serviceably located by

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means of the cities and villages which lie upon or near it. Starting with the southeast, the position of the following cities and villages gives its approximate course: Perth Amboy, Ford's Corners, Menlo Park (near its inner border), Metuchen (just at its outer border), Fanwood, Locust Grove, Summit, Short Hills, Madison, Convent, Morristown (lying for the most part just west of it), Morris Plains and Denville (both of which lie just west of it), Rockaway, Dover (where the moraine is just north of the river), Mount Arlington (on the outer border), Port Morris (on the inner border), Stanhope (just north of the inner border), Petersburg, Vienna, Danville, Townsbury, Butzville, Bridgeville and Oxford Church.

Attention is here directed to a significant feature in the course of the moraine. Its southward extension is not independent of the sub-drift topography. It extends farthest south on the low area of Triassic rock in the eastern part of the State, and fails to reach so low a latitude in the central and western parts, where the country over which the ice came was high and rough, and opposed greater resistance to ice-flow. The relation between the position of the moraine and the topography to the north is still further illustrated by the fact that the moraine lies further south in the western part of the State than in the central part. In the former region, the capacious northeast and southwest valleys, facilitated the movement of the ice, as compared with the central highlands, so that it extended itself further south before being melted.

The same relationship between the position of the moraine and topography appears in detail as well as in general. Thus, at the crossing of every considerable pre-glacial valley, the moraine bends somewhat to the south, showing that the valleys facilitated ice movement. The larger the valley the more extensive the protrusion of the ice in it, as shown by the position of the moraine. This gives the outer edge of the moraine a slightly lobate course.

On the other hand, local elevations had the opposite effect on the position of the moraine, causing it to recede from its general course. As the Watchung mountains are approached, for example, the moraine retreats so as to make a notable bend in its course. There is a corresponding change in its course where the moraine leaves the Trias and passes to the crystalline schist territory, north of Morris Plains. At several points, also, where single high hills stand much above their surroundings, the moraine's course is locally

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changed, its outer edge bending northward about the hill. In tracing the outer border in detail, many instances of this sort may be noted.

The outer border of the moraine in detail.—The outer border of the moraine is often, though not always, distinct. At many points it is bordered by an overwash plain of sand and gravel, and the line of junction of these two formations is sometimes a rather arbitrary one. In other places this is not true. Where no overwash plain is present the border may or may not be well defined. It frequently happens that the extreme outer border of the drift, made during the same ice epoch as the moraine, lies slightly beyond the border of the drift, which is distinctly morainic. Although the following paragraphs involve some repetition, it seems best to trace the outer and inner borders of the moraine in some detail.

From a point two miles or so west of Perth Amboy, the outer border of the moraine has a northwest course to a point just south and west of Ford's Corners. There it lies just north of the road between Ford's Corners and Metuchen, until the latter village is approached. The outer edge of the moraine then becomes slightly irregular. It crosses the railroad just above Robbindale station, then turns southward, so as to include the hills in the north edge of Metuchen. Thence the outer border is continued northwestward to a point a half mile west of Oak Tree. From Oak Tree to Netherwood the border is again slightly irregular, but, in a general way, it is the line of junction between the high, rough land on the east and the low, level land on the west. The station of Netherwood is approximately on the outer border of the moraine. Thence the outer line runs east of north, passing east of Scotch Plains and just west of the Springfield triangulation station, on First mountain. Thence its course is nearly due north to Summit, and a little beyond. Here it curves southward, crossing the railway track just west of the station, and bends south sufficiently far to include most of the village; thence it turns northwest to a point about three-quarters of a mile south of Stanley. Here the Passaic interrupts the line.

Beyond the Passaic, the outer border of the moraine is about three-quarters of a mile southwest of the Delaware, Lackawanna and Western railroad as far as Madison. Its course is then a little more easterly. It approaches the railway, which it crosses just east of Convent. From this point the border of the drift which is mapped

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as moraine has an irregular course in a northwesterly direction to a point a quarter of a mile from the Whippany river.

Beyond this river, the outer border of the moraine is but a few rods east of the railway to a point a mile or so south of Tabor. Here it swings around the hill on which Tabor is built, the hill determining a slight re-entrant angle at this point. Thence it has an irregular northwest course to Denville. West of Denville its outer edge is irregular for a few miles, and there is room for difference of opinion as to the exact position which should be assigned it. Its irregularities are not easily described, but may be seen on the map. It extends further south in the valleys, and recedes to the north around the elevations. For two miles west of Denville it lies north of the Rockaway. It crosses the Rockaway a mile south of Rockaway, bends a mile north around the high hill west of that village, and south again on the west side of the same hill to the northwestern part of Dover.

At Dover the outer border is interrupted by the Rockaway river. West of the Rockaway river it lies between Sterling mine on the north and Spring mine on the south. The outer border bears west-northwest until it approaches Duck pond, near Rustic, where it swings south, including this pond. At Rustic it bends sharply to the north for nearly a mile. Mount Arlington station, on the Delaware, Lackawanna and Western railway, lies on its outer border. This station is at a re-entrant angle of the moraine nearly a mile in north-south extent. Mountain pond lies on the west side of the re-entrant angle, as Mount Arlington station does on the east. From Mountain pond the line extends three-quarters of a mile further south, from which point the border runs west and then southwest to the point just north of Wolf mine. Further west, the outer border of the moraine borders the marshes between Wolf mine and Budds lake. It lies a half mile or so north of Budds lake, whence it has a westerly course to a point a half mile south of Saxton falls. Here the moraine turns abruptly to the south.

From a point on Musconetcong creek, about a mile north of Hackettstown, the line crosses the valley first in a west then a northwest direction to a point on the Hackettstown-Allamuchy road, just south of the canal. From this point it runs nearly north for half a mile, keeping to the west of the road and following a small stream. The surface on one side of this small valley is till; that on the other,

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gneiss residuary. The line curves west and then southwest, in this way looping around on the north and west sides of the 980-foot hill, but ascending to the 910± col on the west side of the hill, whence it descends to cross the Hackettstown-Petersburg road near the former residence of A. R. Day. Thence for nearly a mile it lies just north of the east-west road which connects the Petersburg road to Hackettstown with the Petersburg road to Townsbury. Further west the line marking the outer limit of the moraine crosses this road, turns south on the west side of the 1,066-foot hill, and descends to the Hackettstown-Vienna road. This it crosses and then turns west, or a little south of west, extending along the north side of a 1,146-foot hill at an elevation of about 920 feet. It crosses the Danville-Beattystown road one and a half miles southeast of Pequest river. From this point the line is deflected a little to the northwest and passes just to the north of the crest of the 936-foot hill. Although the moraine phase of the drift is here limited to the north side of this hill, it is clearly evident by the amount of new till on the south slope that the hill was overridden by the ice, which extended half a mile down its southern side.

For two miles west-southwest from this point the moraine lies in the Pequest valley, its outer margin lying against the steep slope of the gneiss highland to the southeast. The moraine does not rise above the foot of the steep slope, but foreign bowlders of equal age are found on the slope at altitudes above the moraine.

Three-fourths of a mile south of Townsbury the moraine boundary turns west and crosses the valley, reaching the Pequest a mile southwest of Townsbury, where it crosses the valley. The outer margin of the moraine is not distinctly marked, and there is room for considerable difference of opinion as to its exact location. By Professor Cook * it was placed half a mile further north, where the strongly-marked morainic topography begins, but faint indications of morainic topography extend to the line above located. A tongue of ice stretched down the valley certainly as far as Pequest Furnace and possibly as far as Oxford Furnace, but did not develop the moraine at its farthest limit.

From the point on the Pequest where the outer edge of the moraine touches the river, its limit extends northeast along the right bank of the river, a little above the road. Just before Townsbury is reached

*Annual Report for 1880, page 31.

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it turns north, then west for three quarters of a mile, and then south, crossing the Townsbury-Buttzville road about forty rods east of the corner where the road to Hope turns northward.

By these curves the moraine has bent northward over a mile, and looped around the 1,016-foot hill west of Townsbury. On the road leading west from this village, no drift is seen on the steep eastern face of the mountain above a shelf about 140 feet above the Pequest, nor along the road across its top, until the corner of the Hope road is almost reached. The only exceptions to this statement are a few quartzite bowlders which are believed to belong to the old drift. Here, within the space of less than a rod, the transition is complete from the reddish-brown gneiss residuary soil to the lighter color of the till. Driving along the road, the line can be distinctly seen crossing the plowed fields, and entering the woods to the southwest. Nowhere else is a more marked and sudden transition from the residuary soil to the till observable.

For two miles to the southwest of the point last mentioned the boundary line is nearly parallel to the Townsbury-Buttzville road, and no more than an eighth of a mile to the southeast. A quarter of a mile north of the Pequest, and near the southwestern end of Mount Mohepinoki, the boundary turns southeast for half a mile, and passes just east of Pequest Furnace, whence it turns southwest, passing just north of the summit of the 726-foot hill, between Oxford and Buttzville. Thence it continues westward for two miles, nearly parallel to the Lehigh and Hudson River railroad, and half a mile south of it, passing north of two gneiss hills 723 feet and 725 feet in altitude, a mile south by southeast from Bridgeville. It then turns southwest, and then south into the valley of Pophandusing brook, about half a mile east of Oxford Church. The boundary extends along the brook to Oxford Church, whence it runs northward for two miles, reaching the Pequest river near its union with its tributary, Beaver creek.

West from Oxford Church to Belvidere, on the Delaware, there is no trace of the moraine, but two and a half miles southwest of Oxford Church, and two miles south of Belvidere, is an area measuring a little more than a mile from northwest to southeast and half a mile in the other direction, in which the morainic topography is well marked. This area is surrounded by stratified gravels, and cannot be connected by morainic topography with the moraine near Oxford Church.

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The inner margin in detail.—While the outer margin of the moraine is, with few exceptions, clearly marked and readily located, the same cannot be said of the inner margin. Very often the moraine topography passes gradually into the more gently undulatory surface of the ground moraine. Consequently any line which may be drawn to represent the inner margin of the moraine will not everywhere separate phases of drift which are markedly unlike each other.

Starting from the northern part of Perth Amboy, the line which has been drawn to mark the inner border of the moraine is sometimes confessedly arbitrary, so far as its exact position is concerned. It runs approximately parallel with the outer border, a mile to a mile and a half distant from it. The inner border lies just northeast of Menlo Park. A little further northwest there is an eastern spur which has been mapped as a part of the moraine lying northwest of New Dover. From the Lehigh Valley railroad northward to the western border of Westfield, the inner border is a mile to a mile and a quarter east of the outer. Just north of Westfield there is another eastward projecting spur of the moraine running out from Locust Grove a mile and a half, nearly to the Rahway river. Just north of Locust Grove, the inner border of the moraine is from a half to three-quarters of a mile distant from the western. Thence it runs in a northeasterly direction to a point a half mile west of Springfield. Here it turns northwest, following a northwesterly course to a point half a mile south of Short Hills; thence it curves to the east, and a northward projection runs to the north two miles beyond Short Hills. From this point the inner border curves southwest to a point a mile or less east of Stanley.

Crossing the Passaic valley, the inner border of the moraine nearly to Boonton is difficult of exact location. The inner face of the moraine through this stretch was modified by the waters of Lake Passaic, and below the level of the waters of this lake some of the characteristic morainic features were destroyed. Through this stretch, therefore, the location of the inner border is a little arbitrary. The line has been drawn just east of the railway to a point just north of Madison, then near the roadway from Madison to Whippany, until a point due east of Morristown is reached.

Across the Whippany the inner border is on the east face of the 495-foot hill, one and a half miles northeast of the center of Morristown. Thence it passes northward through Littleton and north-

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eastward to the road from Denville to Parsippany, reaching the same midway between these villages. Here a spur of drift, which has been mapped as moraine, runs off towards Boonton for a mile or so.

Beyond this spur the line runs northward to the Rockaway river and then turns westward by a zigzag course to a point a mile north of Rockaway village. From this village a crooked east-west line to Mount Hope marks the inner border. From a point just south of Mount Hope, two and a half miles north of Dover, it crosses the southern point of Green Pond mountain and extends westward in a nearly due westerly course from near Silver Spring mine to Lake Hopatcong. On the west side of the lake, the inner border of the moraine lies just north of Brooklyn. From this point it bends southward to Port Morris. Thence it extends south of west, passing to the south of Stanhope village, but including the Stanhope station on the Delaware, Lackawanna and Western railway. From Stanhope station the line runs south of west for one and a half miles, and then west by a slightly undulatory course to Saxton falls.

Where the moraine crosses the Musconetcong valley its inner margin lies one and a quarter miles north of the outer; thence it turns northwestward, crossing the Hackettstown-Allamuchy road about two miles south of Allamuchy pond. From this point it runs nearly west, passing just north of Petersburg, and following closely the road from this village to Vienna. Between Vienna and Danville, and for one and a half miles northwest of Danville, the inner limit is marked by the Pequest meadows. It then extends southwest past the southern end of Green's pond and around the southern point of Jenny Jump mountain, reaching Beaver brook half a mile below Sarepta. Beaver brook marks the limit from this point southwest to its junction with the Pequest. Between the point on the Pequest where it is joined by Beaver brook, and the Delaware to the northwest, there is a small area of drift possessing the hummocky topography of the moraine. Most of the material is stratified, but some of it seems to be till. Since it is so slightly separated from the moraine area across the Pequest to the southeast, it is included in the same category.

Width.—The width of the moraine varies from half a mile to something more than two miles. Its average width is about a mile. From Perth Amboy to Fanwood its average width is about one and a half miles; from Fanwood to Springfield, about one; from Chat-

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ham to Tabor, less than one; at Dover, nearly two and a half. This is one of its widest points. From Dover west, it narrows until at the re-entrant angle near Mount Arlington it is less than one mile in width. It rapidly widens again further west, and at Lake Hopatcong it has a width of two miles. West of this lake it narrows, having an average width of little more than one mile between the longitude of Port Morris and that of Budds lake. Between Budds lake and Saxton falls it is still narrower, often being less than three-quarters of a mile in width. Where it crosses the Musconetcong valley, it is one and a quarter miles wide; between Vienna and Danville, one and three-quarters; at Townsbury, including the prolongation down the valley, nearly three; between Townsbury and Green's pond it narrows to three-quarters of a mile; south of Green's pond its width is a mile and three-quarters, and at Oxford Church nearly the same.

The topographic position and relations.—The vertical range of the moraine between Perth Amboy and the Delaware is about 1,200 feet. The highest point (1,208 feet) is a little more than a mile east of the south end of Lake Hopatcong. The lowest point is near the sea-level at Perth Amboy. From Perth Amboy to Fanwood the moraine rarely reaches a height of 200 feet. In the next six miles it rises to an altitude of more than 500 feet. From Chatham to Littleton its crest rarely reaches much above 400 feet. East of Tabor it rises to an altitude of nearly 600 feet. North of Dover it reaches an altitude of nearly 1,000 feet.

From Dover to Saxton falls the course of the moraine appears to be measurably independent of the topography. It descends into valleys and rises up to the summits of the gneiss hills with apparent indifference. In this region it has a maximum difference in altitude of about 600 feet. The maximum difference in height of the inner and outer borders on any one meridian is about 400 feet. This occurs at Rustic, where the outer border of the moraine has an elevation of about 790 feet, and its inner border, in the same longitude, is a little more than 1,200 feet above tide. West of Dover the outer border of the moraine is fringed by a gravel plain as far as Port Oram. Here the moraine rises rapidly from an elevation of 700 feet to an elevation of 931 feet. It descends into the valley again at Hopatcong Junction. North of Port Oram the moraine covers hills which have an average elevation ranging from 740 to

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940 feet. A little southwest of the apex of the re-entrant angle of the moraine, just west of the Mount Arlington station and a quarter of a mile north of the Delaware, Lackawanna and Western railway, there is a hill which rises to a height of 1,072 feet. The ice does not appear to have covered this hill, though it deposited gravel and cobbles at its foot, building up a plain which slopes to the southward, and which may be seen west of the Mount Arlington station. The ice wrapped around this 1,072-foot hill and, in accordance with the laws of glacial motion, moved down the valley toward Drakesville some distance further than on the highlands to the northeast. At Shippenport the moraine has an altitude of about 860 feet, and a mile west an altitude of 1,181. At Stanhope its inner border has an altitude of 920 feet, while its outer border is 200 feet higher.

In the Musconetcong valley, the moraine has an altitude of 600 to 681 feet. In crossing the mountain separating the Musconetcong from the Pequest valley, its crest reaches heights of 1,005, 1,178 and 1,008 feet. In the valley of the Pequest, its altitude ranges from 580 to 600 feet. From this comparatively low elevation, it rises rapidly on Mount Mohepinoki to a height of 1,131 feet, from which altitude it descends more slowly into the valley of the Pequest at Buttzville. Here its altitude ranges from 621 feet, half a mile west of Pequest Furnace, to 520 and 530 feet near Buttzville. In the vicinity of Oxford Church, it lies upon a side hill, and its height varies from 660 to 360 feet within less than a mile. At its westward extension, near the Delaware, its crest is 387 feet. Within the stretch from Hackettstown to the Delaware, its summit, therefore, has a range of about 800 feet.

The moraine as a topographic feature.—Throughout parts of its course, the moraine is a conspicuous topographic feature, especially as seen from its outer face. It is much less so where seen from its inner face. Commencing at the southeast, the first place where the moraine, seen from the outside, is a conspicuous topographic feature, is just west of Ford's Corners. Here the highest point of the moraine rises something like 140 feet above the overwash plain, southwest of it, within the space of a quarter of a mile. The road from Ford's Corners to Metuchen runs along the overwash plain near the base of the moraine. The western face of the moraine is again abrupt, and, as seen from the west, is a conspicuous topographic feature east of South Plainfield, Avon Park and Plainfield. In the last-named locality

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the abrupt outer face of the moraine is rendered more conspicuous because of its juxtaposition with the nearly-level overwash plain, on which the city of Plainfield stands. East of New Brooklyn, the moraine rises ninety feet within the space of little more than a quarter of a mile. Due east of Grant avenue station, it rises about 100 feet within a like distance. The same general condition of things holds further north to a point a mile northeast of Scotch Plains.

From this point to the Passaic, the moraine is not conspicuous as seen from the outside. From Stanley to Morristown, the moraine is commonly thought to present an abrupt western face, but according to the present interpretation of the phenomena of this region, the abrupt western face which fronts Great swamp is not the face of the moraine, but the face of a long subaqueous overwash plain* or of a series of delta plains, lying just outside of the moraine, and owing their existence to the extinct Lake Passaic. Beneath the delta plain, which terminates with the abrupt western slope, there may be morainic material. If so, it is completely concealed by the sand and gravel deposits in the marginal part of the lake, after the moraine was formed. The moraine itself, above this delta plain or this subaqueous overwash plain, is not conspicuous at any point between the Passaic river and Convent. For two miles or so north of Convent, the moraine, as seen from the outside, is a more notable topographic feature.

From Madison to Morristown the moraine is quite as conspicuous from the inner side as the outer. The inner face rises up as promptly west of Black meadows as the delta front does above Great swamp, on the outer face.

From Morristown to Dover the moraine is nowhere conspicuous as a topographic feature. Approached from the south, at Dover, it rises up promptly from the gravel plain which borders the Rockaway river and constitutes a prominent landscape feature. One block north of the Central railroad depot at Dover, the ascent from the gravel plain to the top of the moraine is made within a distance of 300 yards, within which space the rise is about sixty feet. Where the moraine crosses the higher land, south and southwest of Port Oram, it does not form so marked a feature. In the valley further west, south of Hopatcong Junction, the moraine rises up abruptly twenty to thirty feet. The moraine also has an abrupt outer face at the fol-

*Annual Report of the State Geologist of New Jersey, 1892, page 99.

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lowing points: 1°, south of Mount Arlington station; 2°, south of Shippenport and east of the canal; 3°, south of Stanhope and west nearly to Budds lake; 4°, north of Budds lake. At this point the moraine rises up promptly forty to sixty feet and constitutes a conspicuous topographic feature. From the last point west to the longitude of Saxton falls the moraine is not a strongly-marked topographic feature, as seen from the south.

Looking north from Hackettstown, the moraine appears as a series of low, irregular swells, the whole presenting an abrupt outer face and constituting a low wall across the valley. When compared with the high hills of gneiss and other crystalline rock which so closely hem in the valley on either side, it is an insignificant topographic feature. When contrasted with the low plain of the Musconetcong gravels to the south, it is conspicuous.

On Pohatcong mountain the moraine, as a topographic feature, is very insignificant, although, throughout this belt, the morainic topography is well developed. Although, in general, the moraine is a ridge, or assemblage of ridges, it sinks into relative insignificance amid the greater hills and hollows. Yet occasionally it stands out very markedly against the sky line.

In the valley of the Pequest the moraine again becomes a more notable topographic feature, crossing the valley as a great irregular wall, cut through only by the narrow gorge occupied by the river. On Mount Mohepinoki and westward through Buttzville and Bridgeville, the moraine is not conspicuous so far as its direct effect upon topography is concerned.

The topography of the moraine.—The distinction between the moraine as a topographic feature and the topography of the moraine has elsewhere been emphasized.* The real conception of the nature of a terminal moraine will never be acquired until this distinction is fully appreciated. Considered as a topographic feature, the moraine should be studied especially with reference to the abruptness of its slopes, it height and its relations, *as a whole,* to its surroundings. If it stands up notably above its surroundings, and with steep slopes, it is a conspicuous topographic feature, without reference to the details of its topography. On the other hand, the details of the topography of the moraine may be rather striking, while the moraine itself, as

*Annual Report for 1892, page 76.

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a whole, does not form much of a ridge, and so is not a striking topographic feature.

The character of morainic topography has been described in earlier reports * and need not be repeated here. Illustrations of morainic topography are presented in Figures 2 and 3.

As may be inferred from what has already been said of the distinctness of the outer and inner margins of the moraine, the characteristic morainic topography made by the close association of hummocks, kettles, ridges, and troughs, is in general better marked in

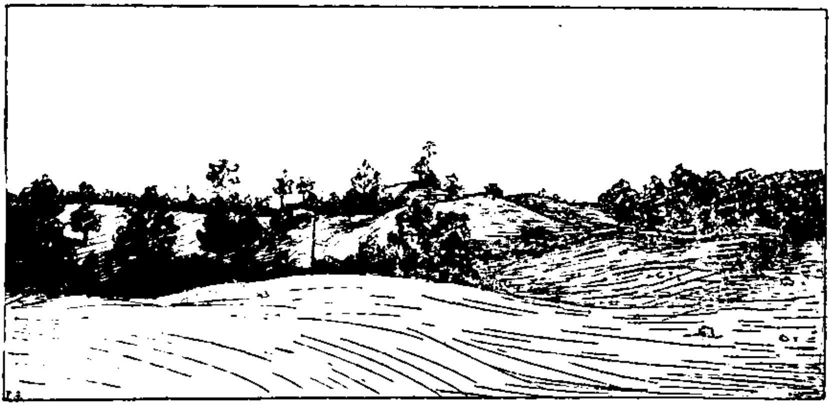

Fig. 2.

Terminal moraine topography as shown a mile north of Hackettstown. (Drawn from photograph.)

the outer half of the moraine belt than in the inner. It is far from being developed with equal strength at all points, either in the outer half or in the inner.

Commencing with the southeast, the morainic topography is not notably rough at Perth Amboy. The undulations of surface which are closely approximated are not more than ten or fifteen feet. Now and then the surface becomes rough enough to attract attention. Thus, northwest of Ford's Corners there are very considerable undulations, giving a strikingly-rough surface, at points so rough that the land has not been cleared. The characteristic morainic topography, though not of an especially-strong type, is shown a half mile north-

*Annual Report of the State Geologist of New Jersey, 1891, page 81; ditto, 1892, page 73.

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northeast of the railway station at Metuchen, and an equal distance northwest of Robinvale station. It is also well marked about Oak Tree. An especially-good development of morainic topography is found north of the Lehigh Valley railroad, between Oak Tree and Netherwood, near the outer face of the moraine. Here the topography is frequently very rough. Striking undulations are of frequent occurrence; hillocks ten, twenty, thirty, and even forty feet high are associated with abrupt depressions of circular or elongated form, some of which are sunk twenty or thirty feet below their surroundings, but more of which are only five to fifteen feet deep. There are numerous little ponds and marshes marking the surface. The type of topography as here illustrated is shown on the map accompanying the annual report for 1891, pages 82 and 84.

North from Netherwood to Locust Grove the roughness of the topography is not striking, though it is commonly of the normal type. From Netherwood to Short Hills and beyond the surface is much forested, so that the topography is less well seen than it might otherwise be. From Passaic river to Convent the topography is nowhere very rough, but north of Convent it is very well displayed at several points. It may be well seen a mile and more east of the Morristown railway station, on the road to Afton, where advantage has been taken of its unique topography for the location of a beautiful summer residence. The rolling topography at this point, while much less emphatic than at some other points, is easily accessible, and illustrates the surface features which characterize the moraine throughout most of its course. From Morristown to Denville the moraine is nowhere very rough, except in the forest region east of Tabor, and here there is little opportunity to see it to good advantage. It has a vertical relief much greater than might be inferred from the topographic map, which at this point has its contour lines at intervals of twenty feet, and so fails to bring out the peculiar knobbiness of the surface.

At a few points in the moraine there are striking depressions. The most notable of these occurs just north of Convent, south of the east-west road which crosses the moraine at this point. According to the topographic map, this depression is something more than sixty feet deep, and it and similar depressions probably represent the position of ice-blocks, about which and over which the drift was deposited. There is another conspicuous sink near Convent, just outside the moraine. This is a few rods southwest of the railway, a half

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mile northwest of the station. According to the topographic map, the depression is about fifty feet deep. It is so situated as to be well seen, and is a striking surface feature.

On the north side of the canal at Dover the moraine has a normal development, with a mildly-accentuated topography, the sinks and hummocks of ten feet relief being more frequent than those of twenty feet. The most strongly-marked topography in this immediate locality is found on the inner border at the Teabo mines, something more than two miles north of Dover in a direct line. At this place the vertical relief between the tops of the hummocks and the bottoms of the sinks is fully thirty-five feet. South of Port Oram the topography of the inner border of the moraine is strong, with a relief of twenty-five feet, but as the moraine rises up from an elevation of 700 feet to the summits of the hills at 931 feet, the topography becomes weak, and the topographic transition from the moraine to the extra-morainic region is gradual. The topography again becomes rough as it descends to the west about Hopatcong Junction. Southwest of the station the vertical relief is about thirty-five feet.

North of the gravel plain of the Rockaway river, which divides the moraine into a north and south division at Port Oram, the moraine has a strongly-accentuated topography, with a relief of fifteen to thirty feet. The inner edge of the moraine here assumes the kame phase. Typical morainic topography is well shown along the Hopatcong branch of the Central railroad, a short distance north of a point where that line of the railroad runs beneath the tracks of the Delaware, Lackawanna and Western railroad. From the railroad, the topography is best seen to the eastward.

The outer portion of the moraine at Mount Arlington station and south of it, has a rough topography, with rapidly rising and falling swells and sinks. Between the tops of the knolls and the bottoms of the adjacent hollows, there is a maximum relief of forty feet. The topography of the inner border of the moraine, which is about 400 feet higher, is much less strongly marked.

There are deep railway cuts through the knolls of the strongly-marked morainic topography a mile east of Mount Arlington station, and again before Shippenport is reached. At Shippenport the relief of the moraine is about thirty-five feet. West of Shippenport, the topography is rough, there being a relief of twenty-five to forty feet. Great kettles are occupied by marshes and some of them by ponds.

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South of Stanhope, the topography of the moraine is more varied, the knolls of which it is made being sometimes broad and gentle, and at other times abrupt and closely set, so as to give the surface a choppy appearance. Between Stanhope and Budds lake the topography of the moraine is characteristic, but not markedly rough. The topography becomes rough again one mile southeast of Saxton falls, where the moraine is narrow. Its surface has here a relief of forty feet.

A mile northeast of Hackettstown the contrast between the flat, level surface of the Musconetcong valley and the hummocky, tumultuous character of the moraine to the north is very striking. The roads

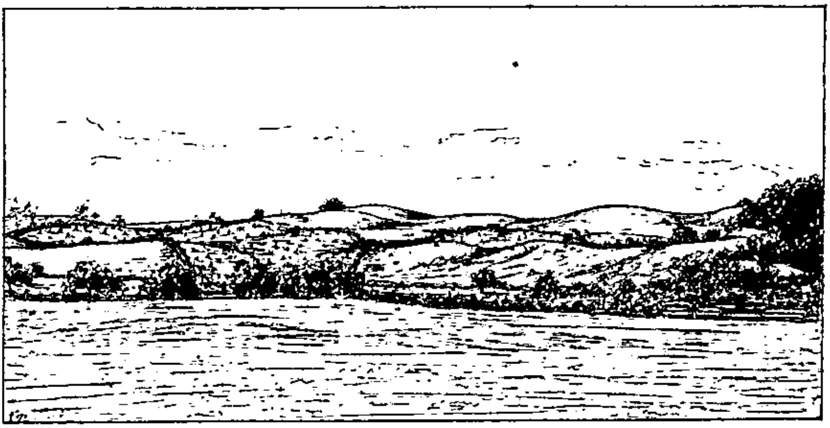

Fig. 3.

Sketch illustrating terminal moraine topography. (Drawn from a photograph of the outer face of the terminal moraine one and one-half miles northwest of Hackettstown. Contrast with Figure 4.)

from Hackettstown to Waterloo, and from Hackettstown to Allamuchy, cross it where characteristic morainic topography is well shown. It is perhaps rather better shown along the Allamuchy road than along the other. Just east of this road there is a large, conspicuous kettle, forty to fifty feet (estimated) deep. Since this is in plain view from the road, it is particularly conspicuous; but other depressions, fully as large, are found in the woods and fields to the northwest. One and one-half miles northwest of Hackettstown the morainic topography is also very strongly developed north of the east-west road which connects the Petersburg road to Hackettstown with the Petersburg road to Townsbury. Looking north from this road across a

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slight depression, the moraine is seen in fine development on the opposite slope (Figure 2). Looking south, the smooth, regular slope of the drift-free gneiss ridge (Figure 4) is in striking contrast with the moraine.

In the vicinity of Townsbury the topography is generally markedly hummocky. Sinks of various shapes are associated with hummocks, giving rise to the characteristic roughness of the surface. On Mount Mohepinoki, west of Danville, the moraine is strongly developed, especially on the undulating top of the mountain. Good views of the characteristic topography can be obtained at a number of places along the road on the mountain west from Danbury. Kettles twenty

Fig. 4.

Slope of a gneiss ridge just outside the terminal moraine. Taken from the same point as Figure 3, but looking in the opposite direction. (Drawn from a photograph.)

to thirty feet in depth are not uncommon. The gently-sloping area about a mile to a mile and a half east of Green's pond is strongly morainic and affords a good illustration of the characteristic topography.

At other points, as on the steep western and northwestern face of the 947-966 hill, southeast of Green's pond, morainic topography is barely discernible, but here, as in almost all similar cases, the very weakly-marked topography is no more than local.

Green's pond is a good example of a lakelet formed in a southward-draining valley, across which a dam of glacial drift was deposited.

Constitution of the moraine.—The constitution of the moraine is very various. In some parts it is mostly of till; in some parts it is

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mainly of sand and gravel; in more places, the two sorts of drift are intimately associated. More commonly than otherwise the gravel lies at the surface of the moraine, even when its deeper parts are chiefly of till, but this is by no means the uniform rule. In many places there are greater or less thicknesses of till over gravel. In general the topography is roughest where there is a good deal of gravel, the individual hillocks having the general character of kames.

From Perth Amboy to Locust Grove the moraine is composed very largely of material of Triassic origin. It is predominately red, and till is more abundant than gravel. This red till of the moraine is well shown in the deep railway cut at Fanwood, and less well along the Pennsylvania railroad between Metuchen and Menlo Park. It is also shown in the cuts along the new line of railway just north of Metuchen, though the till is here associated with stratified sand and gravel. Green Pond mountain bowlders occur at Perth Amboy, and are found more or less abundantly all along the moraine west of this point. All along the moraine there is some granitic or gneissic material, though it is nowhere predominant south of the Passaic river. Where the moraine crosses the Watchung mountains between Locust Grove and Summit, and from Summit northeastward through Short Hills, the trap mountains have furnished much of the material which enters into the composition of the moraine.

From the Passaic to Tabor, gravelly material predominates over till. This is especially true of that part of the moraine between the Passaic and Convent. From Madison to Littleton and beyond, the inner face of the moraine below an altitude of 360 feet has a good deal of gravel, for which the present relations of which Lake Passaic seems to have been responsible. In the vicinity of Morristown, and especially north of this point, gneiss becomes the predominant element of the drift, though material derived from the red shale and sandstone is common, and locally abundant, as far north as Tabor. In the vicinity of Morristown, Green Pond mountain conglomerate bowlders are rather abundant, and have been somewhat extensively collected and used for building purposes. Beyond this point the gneissic material becomes much more abundant. From Denville to Dover, all other constituents are subordinate to the gneiss. From Dover westward, gneiss remains the predominant constituent. At many points all other stony ingredients do not constitute more than five to ten per cent. of the total amount of stony material of the drift. The

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proportion of stony to earthy constituents is variable, the former often constituting fifty per cent. of the whole. The stony material is often in the form of large bowlders, many of which are abundantly striated and conspicuously worn.

Of the minor constituents between Dover and Hackettstown, the Green Pond mountain conglomerate and Hudson river sandstone and slate (or shale) are the most important. The former occurs east of Hopatcong Junction, but no trace of it was seen so far west as Mount Arlington. The Hudson river sandstone and slate occur in smaller pieces than the gneiss and Green Pond mountain conglomerate, and are much more extensively striated. Limestone was found in the moraine a mile east of Mount Arlington, at Stanhope, and north of Budds lake. Where limestone occurs it is usually well worn, and well covered with striæ. The till was observed to be calcareous at a few points only, and that where limestone is mentioned as having been found. Bowlders which appear to be diabase are found sparingly in the moraine at Port Oram. There are a number of good exposures in the moraine between Dover and Saxton falls, chiefly along the railroad. Local descriptions of these exposures serve best to illustrate the constitution of the moraine through this part of the State.

1°. At Dover, about three blocks north and four east of the Central Railroad of New Jersey depot, an exposure about twenty feet in depth shows ten feet of till over stratified sand. The stony material of the till is made up largely of gneiss (eighty-five to ninety per cent.) Other constituents are purple and pink quartzites, Green Pond mountain conglomerate, black flints, grey shale, grey conglomerate and red granite. The gneiss bowlders range up to six feet in diameter, and are generally but little worn. The conglomerates are generally rounded, one to two feet in diameter.

2°. One block north and one west of the same depot, another good exposure, forty feet in depth, shows ten to fifteen feet of till overlying stratified sand. The material of the till is like that already described.

3°. Between Port Oram and Dover there is a railway cut on the Central Railroad of New Jersey, west of the bridge over the Rockaway. The cut is about 1,500 feet long and twenty feet deep. The material exposed is not stratified, but has the character of gravelly till, not very compact. The constituents are similar to those of the other cuts near at hand, with the addition of many angular pieces of

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quartz. The material is coarse, with some striated gneiss bowlders eight feet in diameter.

4°. West of the Delaware, Lackawanna and Western depot at Port Oram there is a railroad cut in the moraine 300 feet long and thirty-five feet deep. A large percentage of the material is stony. The stony material is largely gneissic, but there is some red quartzite, mica schist, Hudson river sandstone and diabase. Many bowlders two to three feet in diameter are present, also larger ones up to eight to ten feet in diameter.

5°. At Hopatcong Junction till is exposed by railroad cuts for several hundred feet. Twenty per cent. of the material is stony. Of the stony constituents, about ninety-eight per cent. are of gneiss, much of which is rounded and striated. Green Pond mountain conglomerate and Hudson river shale are represented.

6°. At Morris County Junction, a railroad cut shows twenty feet of till with a sandy matrix. The stony material makes ten to fifteen per cent. of the whole. Of this, ninety-eight per cent. is gneiss, a few bowlders having a diameter of eight feet. Hudson river sandstone and Green Pond mountain conglomerate are the other formations represented by bowlders or smaller stones.

7°. Near Shippenport, on the Delaware, Lackawanna and Western railway, south of Mountain pond, the railroad cuts give good exposures of till.

8°. At Port Morris, a railroad cut shows that stony material makes more than half the body of the moraine. A large percentage of this consists of bowlders. Of the bowlders about ninety-eight per cent. are gneiss and granite, and the remainder are mainly Hudson river sandstone. Much of the gneiss is not well worn.

9°. At the Lake Hopatcong station of the Delaware, Lackawanna and Western railway, till of the moraine is well exposed. Sixty per cent. of the material is stony, a few gneiss bowlders being seven to eight feet in diameter.

10°. A short distance east of the station at Stanhope, a cut on the Delaware, Lackawanna and Western railway shows fifty feet of till, with a sandy matrix. Twenty per cent. of the material is made up of small stones six inches and less in diameter, though bowlders are not absent. Hudson river sandstone and a small amount of limestone are present.

West of Saxton Falls one of the best-known exposures in the mo-

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raine is found where the Allamuchy road crosses the canal, a mile and a quarter north of Hackettstown. The material is seen to consist of a clay matrix, containing stony materials of all sizes up to bowlders three or four feet in diameter. The whole mass is extremely compact, the stones being so firmly imbedded that they are frequently broken in being extracted. The materials are all glacially worn and fresh in appearance. Sixty to seventy per cent. of the fragments are of fresh bluish limestone, which in nearly every case is most distinctly striated. Hudson river slates and Oneida quartzites are also distinctly striated. The gneiss bowlders have fresh, polished surfaces, and show very little sign of weathering subsequent to the deposition of the till. The color of the till is buff to grey, with a bluish tinge, owing to the great abundance of the blue limestone. When tested with acid the till here is found to be slightly calcareous, even at the very surface, and a brisk effervescence follows when material two feet from the surface is tested.

Going west upon the gneiss highlands, it is not found that the material of the moraine changes greatly. The gneiss and other crystalline bowlders become more abundant, constituting fully fifty per cent. of the whole. Limestone bowlders form about twenty per cent., and various quartzites, sandstones and conglomerates—Potsdam, Medina and Oneida—another twenty per cent. No Green Pond mountain conglomerate or quartzite was found.

Another exposure in the moraine is seen along the road near the first corner, a little more than a mile southwest of Petersburg. Here the material is less coarse than near the canal, and has apparently been oxidized to a greater depth. This is certainly true if its surface was ever equally fresh. Its color is in general reddish brown, streaked with whitish grey. Several small limestone bowlders which were much decayed were noted, while others near them were entirely fresh. Evidently materials in very different stages of decay were originally incorporated into the drift. The material is slightly calcareous four or five feet from the surface. Fine rootlets penetrate the entire depth of the cut (six feet), so that the section does not go below the zone of weathering.

Another good exposure is seen along the Danville-Beattystown road, near the grist-mill, one and a quarter miles southeast of Danville. Here a mass of drift about forty feet deep, mostly of coarse gravel and sand, with bowlders up to three feet in diameter, has been cut

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through by the stream in a gorge thirty yards wide. The drift evidently ponded back the water, forming a small lake, the marshy remains of which are seen a quarter of a mile southward. Much of the material is striated, and but very little water-worn; but it appears to have been slightly modified by water while being deposited. The limestone here constitutes about sixty or seventy per cent. of the stony material. Gneiss, quartzite of various kinds, slate and sandstone form the remainder, in about equal proportions. The matrix is decidedly calcareous, even close to the surface. Save for the first two or three feet it is of a buff to bluish-grey color.

An excellent opportunity for contrasting both the morainic and the extra-morainic topography, and the morainic and extra-morainic material of gneissic origin, is afforded by the area along the road running east and west a mile and a quarter south of Petersburg. (See Figures 3 and 4.) Just at the corner of the late A. R. Day's residence, the road touches the moraine, and then runs to the westward just south of it for two-thirds of a mile, gradually approaching and finally entering it. Along this road, where it runs over residuary soil outside the moraine, the bowlders of local gneiss are angular, showing no sign of wear. They are never smoothed or polished. Some of them are more or less rounded, the result of concentric weathering, but their surfaces are never smoothed in such a manner as to simulate those of glacial bowlders. The gneiss is here coarse grained and quartz-bearing, and the residuary soil contains a large amount of quartz, in particles from the size of a small marble downward. This large amount of quartz gives the soil a loose, coarse, sandy appearance.

Leaving the residuary material to the south, the character of the surface material changes completely so soon as the moraine is reached, a few rods to the north. The change may be most readily seen in the character of the stones along the fences. Potsdam, Oneida, and Medina quartzites, sandstones, limestones, and various gneiss and trap bowlders are found so soon as the moraine is reached. In general, all the bowlders show distinct signs of wear, in that they possess rounded or beveled angles and smoothed sides. The difference in shape of the residuary fragments and the glacial bowlders is very marked.

The contrast in color on the surface is not so marked, but there is yet a difference. A little below the surface, the till is buff to bluish-grey, whereas the gneiss residuary has always the higher color, indicating greater oxidation. In the color of the residuary earths, however,

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much depends on the mineralogical and chemical constitution of the rock from which they are derived.

The material of the moraine is often slighty calcareous just beneath the sod, and becomes more so deeper down. Not infrequently, the stratified drift is highly calcareous, even at the surface. This is somewhat remarkable, as the loose drift is so easily penetrated by water. Observation goes to show that the amount of calcareous matter originally in the moraine varies considerably, but it is everywhere present in the moraine east of Townsbury and west of Hackettstown.

On Pohatcong mountain, the moraine is composed largely of till, but as it descends into the Pequest valley, the amount of stratified material increases very rapidly. In the vicinity of Townsbury, the material is neither typical till nor well-stratified material. Enough fine material was carried away by the water issuing from the ice along the natural drainage line afforded by the low limestone valley, to make the deposit which remains much less compact than typical till. The materials are, however, but little water-worn, and striated stones are not uncommon.

Good exposures are seen in the railroad cuts northward from the Townsbury depot. North of the Pequest, also, there are deep cuts along the railroad, exposing beautifully-stratified sand and gravel. The two high hills (586 and 588 feet) between which the railroad passes, are of stratified sand and coarse gravel, containing huge bowlders, and covered in places by patches of till. The gravel is of a bluish-grey to buff color and is highly calcareous.

In the vicinity of Danville the association of stratified drift and till is well shown in a number of cases. The great mass of the moraine belt is composed of loose, stratified sand and gravel, containing bowlders one to two and three feet in diameter. It is always highly calcareous, the pebbles frequently being coated with lime carbonate and sometimes even cemented together by it. Oxidation has notably affected no more than the uppermost two or three feet. Along the road from the new school-house to the depot, the moraine is largely of till, but the till is only superficial, the stratified drift being found beneath. Southeast of the railroad track, and half a mile east of Danville, there is a broad area but little above the 560-foot contour line. The surface is gently undulatory with shallow kettles. No marked knolls rise above the general level. It partakes slightly of the nature of a pitted plain.

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At the first exposure along the railroad south of the depot, gravelly till is shown overlying and more or less completely surrounding the gravel which thus appears in pockets in the till. On the side of the cut towards the higher part of the hill, a much larger part of the material is stratified, showing that the till is restricted to the lower slopes. This same fact is shown at a gravel pit just south, where till is found on the flank of the hill, at the bottom, whereas the gravel makes up the bulk of the hill. Large bowlders are generally absent from the surface of the higher parts.

Near the bridge over the Pequest, on the road to Beattystown, the moraine is composed almost entirely of very fine sand. There is a good exposure of thirty feet or more along the road as it descends to the bridge. The sand is so fine and so uniform in texture that it is very difficult to say whether it is stratified or not. With the exception of several fresh, striated bowlders of limestone in the bottom of the cut, there are no stones mixed with the sand.

About half a mile southwest of the depot, the railroad runs through a great depression in the moraine, the bottom of which is 529 feet, and the rim of which is more than 560 feet. Evidently a great block of ice was here partially or completely buried by the gravel and sand which the water swept in and piled up around it.

Taking all the facts into consideration, it is clear that the moraine within the Pequest valley, from Danville to the outer margin below Townsbury, was formed by the combined influence of water and ice, whereas in the formation of the moraine lying upon Pohatcong mountain, water had little share.

As soon as the moraine ascends out of the Pequest valley to the west, its material is largely till, sometimes very compact and sometimes loose and gravelly. Its surface is generally strewn with bowlders.

About Buttzville numerous exposures enable one to study the composition, color and amount of post-glacial alteration very completely. The stony material of the drift is made up of gneiss, schist, Potsdam, Oneida and Medina sandstones, quartzites and conglomerates, Hudson river sandstone and shale, limestone, black flint and chert, and a few pieces of igneous rock. The relative abundance is indicated roughly by the above order. The limestones are much less numerous than in the moraine in the vicinity of Townsbury and beyond, but they can generally be found anywhere within the space of a few rods. They

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are more numerous west of Buttzville than near the village and south of it. This variation in the amount of limestone is what should be expected, when it is remembered that the general course of ice movement was southwest by south. The long stretch of gneiss in Jenny Jump mountain lies to the northeast of this locality, and there is no immediate source from which limestone could be derived, save the rock immediately underlying the moraine. The surface and uppermost three to six feet of the till is generally yellow brown, tinged with red, or approaching in places a chocolate color. The stratified deposits in the moraine knolls are usually of a lighter color, buffish to bluish, even very near the surface. One or two cuts show that the till below the oxidized layer is buff. Tests with hydrochloric acid for lime carbonate gave varying results. Generally a slight reaction could be obtained at depths of six or seven feet—the bottom of the cuts in these particular cases. Frequently slight effervescence was observable three, four or five feet from the surface, where the color is yellow brown. The buff and blue-colored drift always gives strong effervescence. The sand and gravels seem slightly more calcareous than the till, but too few observations were made to justify any positive statement.

The moraine in this vicinity contains a large proportion of water-worn materials. These are sometimes abundant under the till, sometimes in knolls and short, irregular ridges, and sometimes they mark the surface of undulatory flats. In this last case, the surface indications of gravel (cobbles and water-worn bowlders) could not be substantiated by evidence from exposures.

North of Oxford Church the material is almost wholly stratified sand and gravel, containing some large bowlders and cobbles. It is arranged in knolls and ridges inclosing kettles, some of which are of considerable size. Three-fourths of a mile north by east of the church one depression is forty or fifty rods (estimated) in diameter, and fifty to fifty-five feet deep. Good exposures are found near the blacksmith shop a little east of Oxford Church, and again along the road from Oxford Church to Bridgeville, about half a mile southwest of Pequest river.

A deep railroad cut half a mile north of the Buttzville depot, and another shallower cut the same distance northwest of the Bridgeville depot, give good exposures, and show the relationship of the till to the gravel and to the underlying rock.

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This part of the moraine shows the tendency already mentioned in connection with the moraine near Townsbury, to change to stratified drift in the valleys, along which there was strong glacial drainage. From Buttzville westward the stratified drift forms the larger proportion of the moraine until the valley of the Delaware river is reached. Here the moraine topography is interrupted by and gives place to the gently-undulating surface of the overwash plain, which is continued south as a valley train to Trenton and beyond. At the last-named city the gravel is widely known as Trenton gravel. The small isolated moraine area two miles south of Belvidere, rising above the general level of the valley train, is the only example of true moraine material in the Delaware valley south of Belvidere.

Surface bowlders.—The surface of the moraine is often thickly strewn with bowlders. This is true where it is composed of gravel as well as where it is of till. The bowlders are sometimes well worn and sometimes angular. They are of all the various types of material that have been mentioned in the description of the exposures, with gneiss greatly predominating. The gneiss bowlders are generally as much as three or four feet in diameter.

The following places have unusual numbers of bowlders scattered over the surface: 1°, north of Dover, east and south of the Baker mine; 2°, west of Port Oram, on the north and east side of the Rockaway river where it cuts across the moraine in coming down from Berkshire valley, where the bowlders are notable for their large size, many being five and six feet in diameter; 3°, at the south margin of the moraine south of Mount Arlington station and west of Duck pond; 4°, south of Stanhope, toward Budds lake. Here a few limestone bowlders were found in addition to the usual gneiss and Hudson river sandstone bowlders. Bowlder-strewn surfaces are the rule rather than the exception throughout the highland region of the State. They are less abundant east of the highlands and in the Pequest valley.

Depth of drift in the moraine.—The greatest known depth of drift in the moraine which has come to knowledge is reported from Mount Arlington station, where a well has been recently driven 260 feet without striking rock. The drift is also very deep along the moraine from Morristown to Madison. Few excavations have reached its base, although depths of about 200 feet have been reported at several points. Such figures are far above the average depth of drift in the State, which probably falls short of seventy-five feet.

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The overwash plain.—The accompanying map shows the position of the overwash plain which borders the moraine. It will be noticed that it skirts the same continuously from Sand hills, west of Perth Amboy, to Scotch Plains; that from Bound Brook there is an extension of the overwash sand southward up the Millstone valley and through some of its tributary valleys to the Delaware;* that there is a small amount of overwash material south of Summit, between First and Second mountains, and that there is still more of it between the crests of Second mountain, for a mile southwest of Summit. At West Summit, and all along the moraine from Long Hill to Morristown, the moraine is skirted by a subaqueous overwash or delta plain. The gravel plain north of the Whippany river, at Morris Plains, is possibly overwash, and possibly subaqueous overwash in origin. There are other small areas of overwash sand and gravel south of Tabor, south of Denville, and southeast of Dover.

South of the moraine, in the longitude of Kenvil, there is a more considerable body of gravel and sand, stretching along the valley of the Black river to the latitude of Chester. The sand of the Black river valley is connected at Kenvil and at Flanders with a similar formation in the valley of Drake's brook. This is the most considerable area of overwash drift in the highland area. The material is gravelly at the north near the moraine, but becomes finer and finer to the south. There can be little doubt that the present course of the Black river is post-glacial. From a point somewhere near Hacklebarney, two miles from Chester, the drainage was northward to the Rockaway until the moraine was deposited as a barrier just north of the latter stream. No longer finding an outlet in this direction, the water is believed to have accumulated south of the moraine, forming a lake along the present marshy valley from Succasunna to Chester. When the water rose high enough, it overflowed the divide to the southward, and escaped via Pottersville to the Raritan.

There is another small area of overwash drift between Budds lake and the moraine. In the Musconetcong valley there is a considerable valley train, continuously developed from the moraine to Beattystown and beyond, and represented by various narrow areas of gravel at several points further down the valley. East of Pequest Furnace

* See Annual Report for 1892, page 115, *et seq.*

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there is an area of stratified drift, deposited by water while the moraine was making.

Down the Delaware there is a long but narrow gravel train, which runs down to a point below Trenton, where it becomes less distinct. The same sort of gravel is well known on the Pennsylvania side of the river to a point below Bristol.*

The gravel in all these places is believed to have been contemporaneous in origin with the moraine.

*Annual Report of the State Geologist of New Jersey, 1892, page 113.

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SECTION IV.

DRIFT DEPOSITS MADE UNDER THE INFLUENCE OF STAGNANT ICE.

In mountainous regions, where the friction of ice-flow was great, it sometimes happened that considerable masses of ice became stagnant during the dissolution of the ice-sheet. After surface-melting had proceeded so far as to bring the upper surface of the ice below the crests of the inter-valley ridges, allowing them to project through the ice, great lobes of ice still occupied the valleys. In some cases, this valley ice doubtless retained movement after the ridges were laid bare. If movement persisted, the ice in the valleys constituted valley glaciers. The length of time during which these valley glaciers retained motion, must have depended on the amount of ice supplied

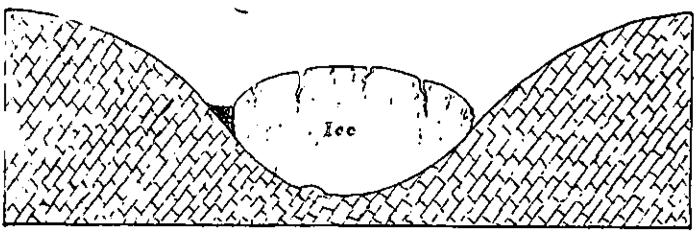

Fig. 5.

Cross-section of a valley with stagnant ice in its bottom, illustrating deposition of gravel as described in text. A stream has flowed down one side of the valley between the ice and the rock face, and has deposited gravel and sand between it and the irregular face of the ice.

them at their upper ends. When this supply was sufficiently diminished, flowage ceased. Where valley ice became stagnant, it exerted an important, though passive influence in determining the position of certain drift deposits and the forms which they assumed.

Let us suppose a mass of stagnant valley ice, lying near the edge of the ice sheet, but beyond its main body. The melting ice further north discharged its waters along the lowest accessible lines. These lines, under the conditions assumed, were the valleys, but not the bottoms of the valleys, as they now exist. The bottoms of the valleys were occupied by the ice, as indicated in Figure 5. Since disso-

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lution of the ice is in progress, by hypothesis, the ice does not rest snugly against the slopes on either hand. Warmed by the sun, the slopes melt back the ice, leaving miniature valleys between the rock slope and the edge of the ice on either side, as represented in the figure. The junction of the ice and the bounding bluff would, therefore, be the position along which such glacial drainage as found its way through the valley, would flow. Streams might flow down one or both sides. Along their courses, the streams would deposit more or less of the gravel and sand they were transporting.

Since the valley bottom was occupied by the ice, it would be protected from deposition at the stage represented in the figure. If the stagnant ice endured longer than glacial drainage through the valley, the deposits made by the drainage would be confined to the sides of the valley, at a greater or less height above the bottom, after the ice was gone. The exact position would be dependent upon the volume of the ice. The thicker the ice the higher would be the line of junction between it and the bluff. If glacial drainage through the valley continued after the disappearance of the ice, the bottom of the valley would be likely to be aggraded, so that deposits would not be confined to the sides of the valley above the bottom.

The edges of these valley ice masses against which the deposits were made were irregular. The sand and gravel deposits made by the streams were limited on one side by the irregular ice face. This ice face was the mould in which the deposits of sand and gravel were cast. After the ice had melted, the sand and gravel deposited against it would constitute a sort of constructive terrace against the valley slope.

Terraces formed in this way would have one unique feature, distinguishing them sharply from terraces formed in the usual way. Since the terrace material was deposited against the irregular face of the ice, the valley-ward face of the terrace cast in the irregular ice-mould would be correspondingly irregular, and its roughnesses would be the exact counterparts of those of the ice. The gaping crevasses leading from the edge of the ice toward its center would be likely to be filled with sand and gravel. After the ice had melted, the filling of such crevasses would stand out as ridges, wide toward the valley bluff and narrower toward the center of the valley, just as the crevasse was. The present slopes of such a crevasse ridge would be assumed after the ice melted, and would be essentially the angle at

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which loose material would lie. Crevasse-filling might be somewhat rare, but the other sorts of irregularities would be abundant, and, by them, terraces formed after the fashion here described could be recognized.

The filling might go so far as to bury considerable parts of the sides of the ice as it rested in the valley. When the underlying ice melted there would be unequal settling of the gravel which overlay it. This would give rise to hollows and hummocks, vertical irregularities, along the valleyward face of the terrace. The irregularities of the ice might be such as to interfere with the regularity of drainage and cause the terraces to be somewhet unequal in height at different points. Unusually rapid alternations of coarse and fine material might result.

As the stagnant ice disappeared it might be separated into more or less distinct masses, the line of separation being determined by preexistent transverse crevasses. If this happened while glacial drainage was still coursing through the valley, deposits might completely cross the valley between the separated ice masses. If glacial drainage ceased to deposit before the separate blocks of ice melted, the position occupied by each would constitute a hollow, and the fillings between the ice blocks where they extended across the valley would constitute dams or partition ridges, separating the hollows more or less completely from one another. These might severally become the sites of lakes.

At many points in Sussex county there are phenomena which correspond with those just sketched. They are prominent in many parts of the county. They have thus far been observed especially in the Walkill valley, from Ogdensburg to Hamburg; in the Black creek valley, northeast of Hamburg; in the upper reaches of the Pequest valley, from Sparta Junction to Huntsville and beyond. The remarkable chain of valley lakes southeast of Newton and northeast of Sparta Junction are believed to owe their origin to stagnant ice-blocks, as sketched above. It is probable that many chains of lakes in considerable valleys in regions of glacier drift find their explanation in stagnant ice-blocks.

Stagnant ice phenomena have also been noticed at points further west across the Kittatiny mountains, in the vicinity of Peters valley. Indeed, they seem to be of common occurrence in the valleys of the northwestern part of the State. Though they have not been studied

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in detail, the chains of valley lakes between Monroe Corners, three miles west of Franklin Furnace, and Andover, are probably due to deposits made under the influence of stagnant ice. They are believed to represent the sites of the valley ice masses, into which the valley ice was differentiated after motion ceased.

Gravel deposits of the class here referred to are not generally conspicuously developed on both sides of the valley. Their restriction to one side indicates that the glacial drainage was chiefly down one side of the valley only.

Where the ice occupied the trough of the valley until after glacial drainage had ceased to flow through it, or until after the glacial drainage had ceased to bring large quantities of sediment into it, the bottom of the valley might be relatively free from drift, after the ice was gone, while stratified drift existed on one or both sides of the valley above its bottom. Such is frequently the condition of things in the valleys of Sussex county. One of the most striking features of the valleys of the region about Newton is the fact that many of their bottoms are marked by numerous outcrops of bare rock, often in the form of knobs or narrow ledges, the direction of which corresponds with the strike of the strata. The explanation of these phenomena is believed to be found along the lines indicated. Ice continued to occupy the troughs of the valleys without having made considerable deposits there, while glacial waters flowed down between the stagnant ice tongues and the valley slopes, making heavy deposits of gravel and sand on the sides of the valleys.

The irregularities of the valley-ward faces of these terraces are often striking. Standing on one side of a valley, and looking across to the opposite terrace face, the latter is seen to be marked by few or many depressions, hummocks, ridges, &c., a part or all of which may be gentle or abrupt. That is, the face of the terrace, in its general topography, closely resembles the topography of a terminal moraine. This, as explained, probably represents in reverse the irregularities of the ice mould.

These terraces constitute a type and deserve a special name. The several hummocks and ridges, with their associated depressions, are generally identical with the roughnesses of the topography of kames. The source of the material and the method by which it is deposited are in all essential respects the same as that of kames. In both cases the active agent is the water which comes from melting ice, and in

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both cases the sand and gravel are glacial. The manner in which the roughnesses of topography were brought about is also similar to the manner in which the roughnesses of kame topography are often produced. In both cases it was deposited about ice, or against rough faces of ice, or in hollows or re-entrants in the edge of the ice. Since these rude terraces have much in common with kames, both in the matter of topography, constitution and genesis, they might appropriately be designated *kame terraces.* A kame terrace, therefore, is a terrace of glacial sand and gravel, deposited between a valley ice lobe (generally stagnant) and the bounding rock slope of the valley. More or less isolated kames are sometimes associated with kame terraces.

This is essentially the sense in which the term *moraine terrace* has been used,* although the term as heretofore used does not imply the absence or essential absence of motion on the part of the ice. The term was sometimes used by Hitchcock to designate terraces which are probably similar in origin to those here described, though at that time their origin was otherwise explained.† But the differentiation of drift deposits, and knowledge concerning their origin have progressed so far since the term was first used, that the designation *kame terrace* seems more appropriate at the present time.

Kame terraces are often far from continuous. They often occur in patches only, the separated parts having elevations which correspond in a general way with each other. A short kame terrace is well shown at McAfee, and may be best seen by looking eastward from the road west of the railway, where the road below the village crosses the track.

The great spur of gravel which runs out from the east side nearly across the valley at Ogdensburg represents one of the spurs which is believed to be the filling of an ice crevasse.

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*Chamberlin, Third Annual Report, U. S. G. S, page 304.

†Geology of Vermont, Vol. 1, 1861, pages 150 and 190.

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SECTION V.

DRIFT PHENOMENA OF THE PALISADE RIDGE.

BY ROLLIN D. SALISBURY AND CHARLES E. PEET.

Topographic relations of the ridge.—The Palisade ridge of New Jersey, occupying the northeastern border of the State for about twenty-seven miles, is a conspicuous topographic feature. It is separated from the highlands to the west by a very considerable trough occupied in part by the Hackensack drainage system. It is separated from the land area to the east by the Hudson river valley. The ridge has a maximum height of about 550 feet near its northern end, but declines somewhat gradually to the south, reaching sea-level at its southern terminus. It has a maximum width of about two miles, though its average width is not more than one and a half.

In cross-section the ridge is asymmetrical. (See Figure 6.) On the east it has a precipitous or nearly vertical face, varying in height from something more than 500 feet at its northern end to about 300 feet at Fort Lee and 200 feet at West Hoboken. South of Jersey City the ridge becomes low, and the eastern face is much less steep. At the northern end of the ridge, or at the northern end of the New Jersey portion of the ridge, a decline of 500 feet is accomplished in less than one-eighth of a mile on the eastern face. At Fort Lee, a fall of 300 feet takes place in a similar distance.

As is well known, the crest and east face of the ridge are composed of trap. At the very base of the eastern slope Triassic (Newark) rock outcrops at many points, and Stevens Point, Hoboken, is an isolated hill, apparently belonging with the crystalline schist serpentine series which occurs on the opposite side of the Hudson, and on Staten Island. The course of the Hudson follows the eastern base of the trap ridge, departing from it only at Stevens Point.

The western face of the trap ridge is much less precipitous than the eastern. On the west side, at the northern end, a decline of about 500 feet is accomplished in the space of one and one-half to two miles. Along the middle part of the ridge a decline of 300 feet is accomplished in the space of about one mile. From Englewood to

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Jersey City the western face is much steeper than further north. Indeed, in the latitude of Ridgefield, Granton and West Hoboken, the western face is rather abrupt. West of Guttenberg a decline of 200 feet is accomplished in the space of one-quarter of a mile, while at West Hoboken a descent of 200 feet is made in little more than half that distance. The asymmetry of the ridge in cross-section is shown by the upper lines of the diagrams on the following page, drawn to scale at the points indicated.

The lowest line of the trough-like depression occupied by the Hackensack drainage system is nowhere high. The Hackensack river at the northern boundary of the State is only about forty-five feet above sea-level. The valleys of the creeks east of the Hackensack, at the base of the ridge, are even lower than the Hackensack itself at the north line of the State. The creek east of Neuvy and Norwood is only thirty feet above sea-level. From the marsh at this point drainage goes northward into the Hudson and southward into the Hackensack. The northern part of the Palisade ridge, therefore, is nearly 500 feet above the depression to the west. The eastern base of the Palisade ridge, washed by the tide-swept Hudson, is at the level of the sea. On this side, therefore, the ridge rises abruptly up to its full height from the level of the sea. With these relations and dimensions the ridge is conspicuous.

West from the northern end of the Palisade ridge it is eight or ten miles before elevations are reached comparable in height to the Palisade ridge. The width of the trough between the Palisade ridge on the east and lands of corresponding elevation on the west, is therefore eight to ten miles, and remains nearly constant until the latitude of Hoboken is reached. Here the Palisade ridge becomes so much lower that lands having a corresponding elevation are found at a less distance to the west, though it is eight or ten miles west of the southern end of the Palisade ridge before elevations are reached comparable to those of the northern end of the Palisade ridge.

From Paterson south, the eastern ridge of the Watchung mountains constitutes the western limit of the trough lying west of the Palisade ridge. Like the Palisade ridge, the Watchung mountains are composed of trap, and each ridge is comparable in many ways to the Palisade ridge itself. Like the latter, they have their gentler slopes to the west and their steeper slopes to the east. Like the latter, they are underlaid at their eastern bases by Triassic shale or

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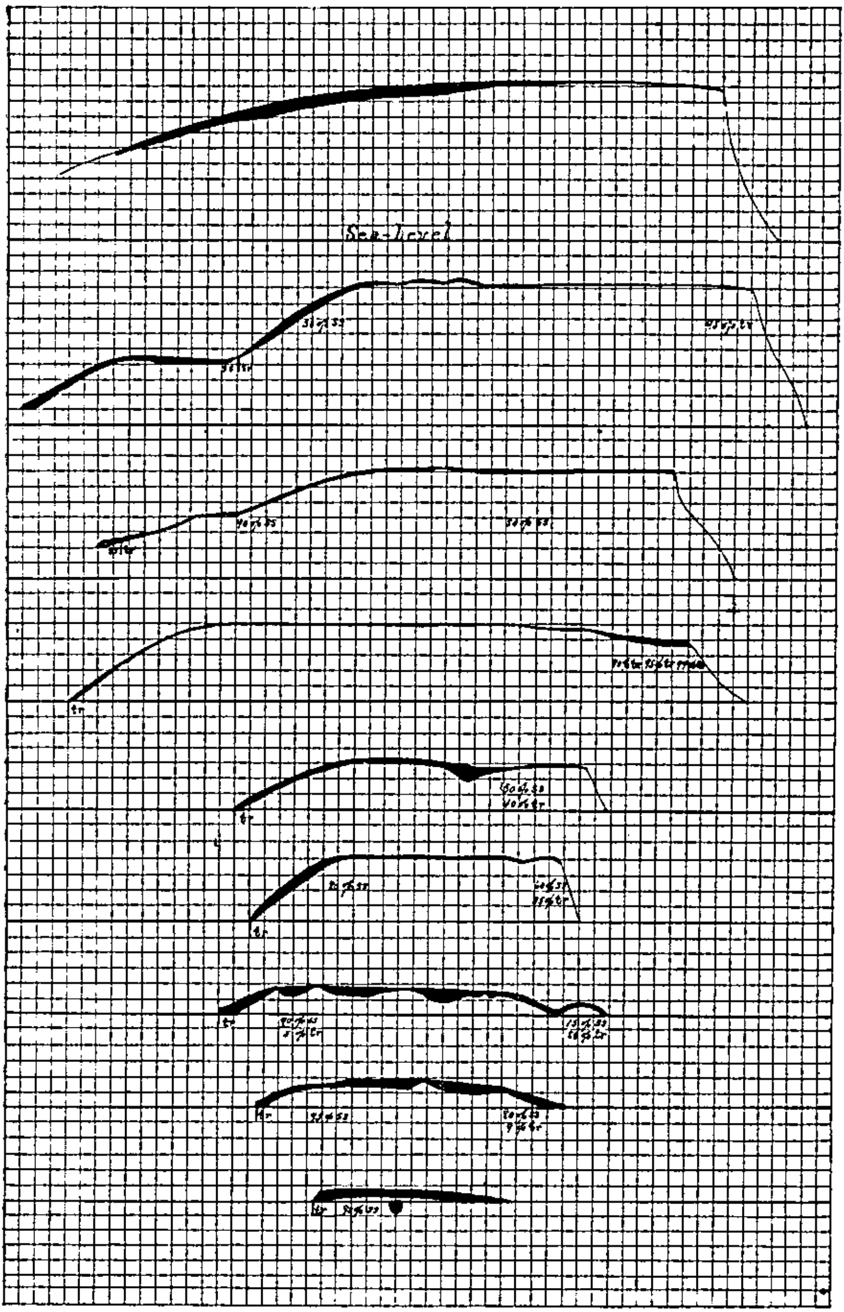

Fig. 6.

Series of cross-sections of the Palisade ridge from north to south—1, at Alpine; 2, at Tenafly; 3, at Englewood; 4, at Granton; 5, at New Durham; 6, at Tyler Park; 7, at Marion; 8, at West Bergen; 9, at Bergen Point. Horizontal scale, twenty-four squares to the mile; vertical scale, one square for fifty feet. The sections show the relative thickness of drift, represented by the thickness of the heavy black lines, the vertical scale being exaggerated about four and one-half times. The percentages represent the proportions of sandstone and trap in the drift, and the junction of the trap and sandstone on the west face of the ridge is shown at some points.

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sandstone. Here, also, the Triassic shale or sandstone laps up on the gentler western slope. In both cases the dip of the sedimentary rocks accompanying the trap is to the north of west, and the sedimentary rock rises much higher on the western than on the eastern slopes of the ridges. This relationship is indicated on the Palisade ridge, in the figure.

Relation of the Palisade ridge to the general direction of ice movement.—The Palisade ridge lies within the area which was covered by the ice of that glacial epoch which made the terminal moraine which is well known in New Jersey. The southern end of the ridge lies but a few miles north of the terminal moraine on Staten Island, and is about twelve miles northeast of Perth Amboy, which marks the position of the moraine in the eastern part of New Jersey. The Palisade ridge was therefore complely covered by the ice. It is a matter of some interest to determine the relationship which this ridge sustained to the ice movement and to determine the effect which it had on such movement.

It is well known that the line marking the limit of the advance of the ice in the last glacial epoch is not straight, but lobate, indicating that, near its margin, the ice was differentiated more or less into lobes. One of these ice lobes had its axis in the Hudson river valley. Thence the moving ice diverged to the southeast, into New England, and to the southwest, into New York.* In the latitude of New Jersey, as will be seen presently, the axis of the lobe did not correspond with the Hudson river valley, but with the great valley west of the Palisade ridge.

The eastern part of New Jersey marks the southernmost point of the moraine east of western Pennsylvania. From Perth Amboy the moraine curves to the northwest through Metuchen, east of Plainfield to Summit, and then northwestward, by a more or less direct course, to Belvidere, and beyond to Allegany county, New York. East of Perth Amboy, the moraine curves promptly northward, across Staten Island and Long Island, to Cape Cod. It will be seen, therefore, that the Palisade ridge lies in the central part of the great lobe whose axis was for a considerable distance the Hudson river valley. Its situation is therefore favorable for determining something concerning the effect which might be exerted by a ridge of rock, several hundred

* For map showing lobation of the ice front, see Chamberlain, Third, Sixth and Seventh Annual Reports, United States Geological Survey.

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feet above its surroundings, upon the axial movement of a great ice lobe near its marginal part. Since the rock is hard and not easily weathered, it is well adapted to receiving and retaining such striæ as the ice might give it. From them the direction of ice movement over and about the ridge may be accurately known.

STRIÆ.

Direction of striæ.—On the Palisade ridge glacial striæ and glacial grooves are abundant. They are found in all latitudes, from the northern boundary of the State to Bergen Point. The general course of the striæ is east of south. (See map accompanying, also table of striæ, page 166.) The only exceptions occur at the western base of the ridge, toward the south end. The amount of divergence from a southerly direction is inconstant, but almost always considerable. The Palisade ridge, therefore, lay within the left half of the lobe of ice which occupied the Hudson river valley; that is, it was east of the axis of this lobe. On the Watchung mountains, across the depression to the west, the direction of striæ is uniformly west of south, indicating with equal conclusiveness that the direction of ice movement was here in this direction, and therefore that the Watchung mountains were in the right half of the Hudson river lobe; that is, west of its axial portion. It is therefore apparent that in the latitude of northern New Jersey, the present Hudson river valley was not the axis of the ice lobe which made the moraine of Long Island, Staten Island and eastern New Jersey. The axis of this lobe lay to the west of the Palisade ridge, and between it and the eastern Watchung mountains. From the direction of striæ on Snake Hill, and from a comparison of their direction with that of the striæ on the Palisade ridge to the east, it appears that in the latitude of Snake Hill the axis of the lobe lay between that hill and the Palisade ridge, but nearer the former than the later. This would locate the axis of the lobe in this latitude near the western base of the Palisade ridge, rather than in the center of the depression between the Palisade ridge and First mountain. This suggests that the center of the lobe would have been further east than it was, had it not been for the influence of the ridge.

The distribution of drift materials, when studied in relation to their sources, can likewise be made to throw light on the question of the

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position of the axis of the ice lobe. This point will be referred to more fully farther on, but it may be here stated that the result of this line of investigation is harmonious with that derived from the study of the striæ.

From north to south the direction of striæ on the Palisade ridge changes, the easterly divergence being greater at the northern end than at the southern. On First mountain the westerly divergence of the striæ is greater to the north than farther south, so far as observation has gone. On both sides of the axis, therefore, the divergence of movement at the time the existing striæ were made, seems to have been more pronounced to the north than to the south. It should be said that the number of striæ observed on First mountain, on the west side of the axis of the lobe, is small compared with the number recorded on the Palisade ridge on the east side, so that less reliance can be placed upon the apparent increasing westerly divergence from south to north, on the west side of the axis of the ice lobe.

The decrease in the easting of the striæ from north to south is illustrated by the following facts concerning the direction of striæ: In the latitude of Closter and Alpine, the maximum easting is 74°; in the latitude of Englewood, 63°; in the latitude of Fort Lee, 52°; at Edgewater, 59°; at Guttenberg, 49°; at Weehawken, 59°; at Hoboken, 43°; at Communipaw, 43°; at Pamrapo, 54°. These figures show that, while there is not a uniform decrease in easting, there is on the whole a decrease. The average difference in direction between striæ at the north end and the south is between 20° and 30°.

Several suggestions arise when the explanation of this general fact is sought. If the trough in which the axis of the lobe lay were wider to the north and narrower to the south, the ridges on either hand would be nearer the axis at the south. Since ice motion in the axis of an ice lobe is not divergent, and but slightly so at slight distances from it, it follows that the motion of the ice over ridges close to its axis would be less divergent than motion over ridges which were farther removed from it. But this suggestion does not seem to meet the case. The trough in which the axis of the lobe lay appears to have a nearly constant width along the whole western face of the ridge. This, then, is not the true explanation of the greater divergence of striæ from the axis of the lobe in the latitude of the north end of the ridge.

If the confining ridges on either hand were higher at one end than

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at the other, it might be that the higher parts would be more effective than the lower in confining the ice. Under these circumstances the spreading of the ice, and so the divergence of the striæ, would be less where the confining ridges were higher. We should then expect to find the divergences less where the ridges were higher. Like the preceding, this suggestion does not seem to meet the case, for the Palisade ridge, at least, is much higher at the north, where the divergence is greater, than to the south, where the divergence is less.

If the change in direction of the striæ from north to south were confined to the east side of the axis of the lobe, the change of direction might be supposed to be due to the varying distance of the axis of the lobe from the ridge. If this were the explanation of the varying divergence of striæ on the Palisade ridge, the striæ should turn more to the west on the west side of the ice-lobe axis in the latitude where they turn less to the east on the east side. But since the striæ on both sides of the axis appear to diverge most in the same latitude, while the width of the trough in which the axis lies remains tolerably constant, this cannot be the explanation of the observed divergence.

On general principles it would seem to be true that the divergence of the ice movement should have been greatest nearest its margin. This alone would tend to make the easting and the westing of the striæ, on the east and west sides of the ridge respectively, greater to the south than further north, so far as they were contemporaneous. This is contrary to the fact. No one of these suggestions to account for the existing divergence of striæ seems to stand the necessary tests.

If the striæ now in existence were not strictly contemporaneous in origin, but made at successive intervals, some of the difficulties in the case would seem to be removed. While the margin of the ice lay in the latitude of Elizabeth or further south, it might be supposed that the easterly and westerly divergence of motion from the axis of the lobe was such as to give rise to the striæ now seen in this latitude, or slightly above it. As the ice receded still further north, say to the latitude of Passaic, the striæ made by the margin of the ice in that latitude would have had a degree of divergence corresponding to the ice movement in that latitude at that time, and this might not correspond with the direction of movement at the same point when the margin of the ice was further south at Elizabeth. As the ice edge receded still further north, say to the latitude of Englewood and Closter, its divergence of movement would have been determined by

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the marginal conditions in that latitude. It is probable that the existing striæ were made by the successive receding marginal parts of the ice. In this event, it is clear that the striæ which now exist are the legacy of the last stages of the glacial epoch.

It is conceivable that similar results might be brought about in reverse order. The striæ made by successive advancing margins of the ice would, if preserved through the subsequent vicissitudes of the glacial epoch, possess corresponding differences in direction. In view of the fact that the Palisade ridge is very meagerly covered with drift, the trap being exposed at very many points, it would seem much more probable that the striæ belong to the closing stages of the glacial epoch than to the beginning. While this does not seem to be an altogether satisfactory explanation of the varying directions of the striæ, it is the best which has suggested itself.

Since the Palisade ridge stood in the way of the ice movement it must have opposed it. It might seem unnecessary, therefore, to inquire whether the easterly movement of the ice was because of the ridge, or in spite of it. But it seems to have been true at many points during the closing stages of the ice epoch that the ridges were laid bare while the intervening valleys still contained moving glaciers. Not only this, but the amount of ice in the valleys seems sometimes to have been such that its upper surface was even higher than the crests of the ridges which were free from ice. Under such circumstances, there was a tendency to divergent ice movement from the valley *towards the ridges* on either hand.* The ice movement followed the general law of movement of viscous fluids; that is, it flowed from higher to lower levels.

If the Palisade ridge caused movement toward it from the west, it should have likewise caused movement toward it from the east. Of such movement there is no indication either in the direction of the striæ or in the character of the drift. The striæ on the east side of the ridge, as well as the trap bowlders carried across the river, from New Jersey, clearly show that the movement of the ice was to the eastward, completely over the Palisade ridge and the Hudson river valley, into New York. This last fact is in itself fatal to the suggestion that the easterly movement over the west side of the ridge was due to the ridge itself. We conclude, therefore, that the ice movement was in spite of the ridge, and not because of it.

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*Chamberlin, Seventh Annual Report, U. S. G. S., page 184.

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Conspicuous a topographic feature as it is, the Palisade ridge seems not to have been a sufficient obstacle to the ice to seriously interfere with the normal divergent course of its movement on opposite sides of the axial trough of the glacial lobe. Nevertheless it is not probable that the Palisade ridge was without effect upon the ice.

It will be noticed that the ice of the last epoch reached its extreme southerly limit in the eastern part of the United States in the southerly continuation of the axis of the trough west of the Palisade ridge. Further west the ice which was compelled to cross the highlands of New Jersey did not reach so low a latitude. The highland area, with an altitude of from 800 to 1,300 feet, and a relief of 500 feet, more or less, offered such resistance to its advance as to greatly interfere with and restrain its movement. Where the moraine crosses the Watchung mountains it is bent sharply to the north, because the ice movement was opposed and therefore retarded by those mountains. Beyond them the moraine ceases to curve to the northward. East from Perth Amboy, the southernmost point of the moraine, the latter turns somewhat promptly to the northeast and its general northeasterly course is held across Staten and Long Islands.

The moraine on the western part of Long Island must have been made by ice which crossed the Palisade ridge, and the ridge perhaps offered enough resistance to the ice to limit, in some measure, its southward advance. Had the Palisade ridge not been in existence, it is probable the ice would have moved sufficiently far south in the longitude of the western part of Long Island to have formed the terminal moraine somewhat further south. Further east, where the moraine was made by ice which did not cross the Palisade ridge, its course is more easterly. It is not meant to imply that the Palisade ridge is alone responsible for the northward bend of the moraine on Staten and Long Islands. The great valley to the west of the ridge had probably even a greater measure of responsibility in causing the ice to extend farther south in its axis, than had the ridge in restricting its advance outside the axis, but the ridge is in some sense a part of the trough, so that its effect was felt both in deflecting the ice movement down the valley to the west of it, and in diminishing the amount of ice which passes over it to the southeast. The trough and the ridge together were probably but partial factors in determining the course of the ice movement, and factors of still less consequence in determining the extent of its advance.

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Besides the change in direction of striæ from north to south, two other peculiarities of the striæ are to be noted: 1°, proceeding from the west side of the ridge to the east, the easterly divergence increases; 2°, in some places striæ cross each other, or discordant striæ are present on the same surface.

Changes in direction of striæ, with relation to altitude.—1°. In the latitude of Alpine, the change in the direction of striæ, passing from the west to the east side of the ridge, is from S., 32° E., at an elevation of 400 feet, to S., 58° E., at an elevation of 480 feet, a difference of 25° for a rise of 80 feet, or 1° for a fraction more than three feet. A little farther south, striæ at an elevation of 260 feet have a direction S., 46° E.; 100 feet higher, striæ run S., 67° E., a difference of 21° with a rise of 100 feet, or an average change of 1° with a rise of little more than five feet. Rising from 360 feet to an elevation of 420 feet in the same latitude, there is no apparent change in the direction of striæ, but in rising from 420 to 440 feet, the striæ change 3°. South of Englewood, the direction of striæ is S., 9° E., at an elevation of 140 feet, while at an elevation of 220 feet their course is S., 19° E., a change of 10° with 80 feet rise, or 1° in eight feet. From the elevation of 220 feet to 300, in the same latitude, the striæ change from S., 19° E., to S., 38° E., 19° in 80 feet, or 1° in a little more than four feet. In the latitude of Bulls Ferry, the course of the striæ on the west side, at an elevation of 110 feet, is S., 2° E.; at an elevation of 150 feet, their course is S., 5° E., or 3° change with a rise of 40 feet. From 150 to 190 feet, the striæ change from S., 5° E., to S., 12° E., a change of 7° in a rise of 40 feet. From an elevation of 190 to 240 feet, the course of the striæ changes from S., 12° E, to S., 29° E., or 17° change with a rise of 50 feet. Twenty feet higher the direction of striæ is S., 37° E., a change of 8° for 20 feet. South of Guttenberg the striæ, at an elevation of 40 feet, are S., 1° W.; at 120 feet, their course is S., 6° E., a difference of 7° for 80 feet of rise. Sixty feet higher, at an elevation of 180 feet, the direction is S., 42° E., 36° change in a rise of 60 feet. Just north of Tyler Park, at an elevation of 30 feet, the striæ have a direction of S., 2° W.; at an elevation of 80 feet, S., 1° W.; at an elevation of 160 feet, S., 24° E, a change of 25° for 80 feet.

In general, it may be said that the greatest deflection of the ice to the westward by the Palisade ridge, or perhaps better, the greatest

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influence of the ridge in keeping the ice from greater movement to the east, was where the western face was steepest. In general, the easting not only increased toward the top, but toward the top it increased much more rapidly for a given amount of rise than near the base.

On approaching the east edge of the crest of the ridge, the striæ, in a few places, show a slight tendency to southward deflection. Thus, at Weehawken the striæ on the edge of the bluff have a direction varying from S., 27° E., to S., 30° E., while at the east foot of the bluff their course is S., 25° E. This difference in direction may be due only to the deflecting effect of the tributary valley at this point. At Hoboken the striæ, at an elevation of 200 feet, have a direction S., 53° E., and S., 47° E., while 20 feet lower down, on the east side, their direction is S., 41° E., and S., 34° E. These facts suggest a tendency to independent movement down the Hudson valley, but the data are too meager to make this at all certain.

Crossing of striæ.—In a number of places on the Palisade ridge, glacial striæ, which are discordant in direction on a common surface, have been observed. In general, the discordant striæ do not represent two distinct series, crossing each other at a definite angle. Their directions are various up to a certain maximum of divergence. Many of these discordant striæ actually cross others, so that crossing striæ are by no means rare.

Crossing or discordant striæ may be seen at the points mentioned below, although this enumeration does not include all localities where this phenomenon may be seen. The figures given represent the extremes of direction at the several localities: (1) Bulls Ferry, on the north side of the road leading down to the river; directions, S., 54° E., to S., 60° E. (2) Guttenberg, crest of the ridge; directions, S., 41° E., to S., 35° E. (3) West Hoboken, brow of the east bluff of the ridge; directions, S., 34° E., to S., 41° E. (4) One block south of West Hoboken and a little west; directions, S., 42° E., to S., 53° E. (5) Brow of east bluff, due west of Stevens Point; directions, S., 27° E., to S., 34° E. (6) Five blocks north of the Delaware, Lackawanna and Western railway tunnel, on the east edge of the ridge; directions, S., 31° E., to S., 39° E. (7) The west slope of the ridge, at an elevation of 60 feet, four blocks north of the Jersey City reservoir; directions, due south, to S., 16° E. (8) Near the east end of the Pennsylvania railway cut at Jersey

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City; directions, S., 31° E., to S., 51° E. (9) Three blocks west of the last, along the Pennsylvania railway; directions, S., 28° E., to S. 32° E. (10) Three blocks north of the Pennsylvania railway cut, on the edge of the east bluff; directions, S., 39° E., to S., 46° E. (11) Bergen Point, on Newark bay, north side of the Central Railroad of New Jersey; three sets; directions, S., 13° W; S., 10° E., and S., 1° E.

It will be noticed that the observed difference in direction between divergent or crossing striæ is rather less, on the average, to the north than to the south. The discordance of striæ is not confined to any part of the ridge. Observed discordances are more abundant south of the latitude of Englewood than further north. They are rather more abundant on the brow of the east slope than elsewhere, but are by no means rare in other topographic situations.

The crossing of striæ may be brought about in various ways. While the ice was advancing over the ridge from the northwest, the direction of movement at its margin at any particular stage of advance may have been somewhat different from the direction of movement at the same point when the margin had advanced further south. Let this be supposed to be the fact. In case the striæ made by the margin of the ice during an early stage of advance were not obliterated while the ice made a certain further advance, and if, at this second stage of advance, the ice, with a different direction of movement, made a second set of striæ without destroying the first, two sets of striæ would co-exist. If these two sets of striæ were preserved through all the later vicissitudes of glaciation, as might be, discordant striæ might still be seen on a common surface. Discordance of striæ would be likely to be especially marked where the surface was marked by valleys. Locally, valleys would largely control the direction of movement while the ice was thin, both in its advancing and declining stages. But meantime, while the ice was thick at the same place, its movement was more independent of local topographic features.

Or again, if while the ice was at its position of extreme advance, it made striations upon the bed rock at a given distance back from the margin, such striæ would have a direction corresponding to the direction of ice movement at this point at the time they were made. Later, when the ice had receded so that its edge stood at the point where the earlier striæ had been made, the direction of movement at this point might depart from the earlier direction. If at this later

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stage striæ were made on the surface already affected by the earlier set, the two sets might be discordant in direction. It is within the range of possibility that these two sets of striæ should be developed on a surface affected by a still older set made by the margin of the ice during its earliest advance. In this way three sets might co-exist—the first made by the margin of the ice during its first advance, the second made well back from the margin during a period of greater advance, the third made by the edge of the ice during its recession. The first and last of these three sets might correspond with each other or might not. Such complexity of striæ on a common surface would be rare, since striæ made at any one stage were liable to be destroyed by any movement of the ice which was capable of developing a second set on the same surface. The foregoing case is mentioned only to bring out the fact that discordant striæ may readily be developed by the ice of a single epoch. The numerous oscillations to which the edge of the ice is believed to have been subject within a single epoch, afforded conditions favorable for the development of discordant striæ at many points.

It follows that two or more sets of striæ affecting the same rock surface do not constitute proof of separate ice invasions. In regions affected by two glacial epochs, it is conceivable that striæ developed during the first might be preserved, here and there, both through the interglacial interval, and through the second glacial epoch. In such case, the striæ of the second epoch might co-exist with those of the first on a common surface. This would be an exceptional condition of things, and would be likely to be found only near the limit of advance of the ice in the second of the two epochs concerned.

Time relations of discordant striæ.—Where crossing striæ affect a common surface, it is sometimes impossible to tell which set was made first. Where relations can be made out, it seems to be often, but not always, true that the striæ of the Palisade ridge having the greater easting were made before those which cross them with a less easting.

Significance of the variations in the glacial marks.—The ice markings on the Palisade ridge present nearly every phase which has ever been described as characterizing ice scorings.* The great variety in the ice markings is of interest and significance, in that it gives evidence of the methods by which the ice worked, and of the conditions under

*For an exhaustive discussion of the whole subject of ice scorings, see Chamberlin, Seventh Annual Report, U. S. Geological Survey, 1885-1886.

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which it operated. In themselves or in their relations, many of the striæ demonstrate that, hard and brittle as the ice seems, it is still capable, under proper conditions, of adapting itself even to trivial irregularities of surface. The degree of pliancy of ice, whatever its real nature, appears to be dependent upon—1°, the amount of water which it contains; 2°, its temperature; and 3°, the pressure under which it moves. Under sufficient pressure, ice probably fits the irregularities of surface over which it flows very snugly, without reference to the other conditions which favor pliancy; but wherever the ice was thick enough to be under great pressure, its lower portions were probably of such a temperature, and so charged with water, as also to favor a high degree of mobility.

Striæ on plane surfaces.—Considerable areas of plane surface do not exist on the ridge. But limited areas which are nearly flat are found at various points along the crest of the ridge. In such situations striæ are often found without possessing features unlike those which characterize glacial striæ in general.

Striæ on ascending plane surfaces.—Ascending plane surfaces, considered with reference to the direction of ice movement, are more favorably situated for receiving striæ at the hands of glacier ice than plane surfaces, or than surfaces in any other attitude whatsoever. The western side of the Palisade ridge, as a whole, was an ascending plane surface, considered with reference to the direction from which the ice came. If ice were pushed up an ascending slope parallel with the direction of greatest inclination, the striæ would run up and down the slope. If the ice were to move at right angles to the direction of greatest slope, the striæ would be parallel to the base of the slope. Where the movement of the ice was oblique to the maximum slope, the striæ would be neither parallel with the direction of maximum slope nor at right angles to it. Their position would be oblique. The striæ of the western face of the Palisade ridge belong to this category. From them, as already pointed out, we know that ice ascended the west face of the ridge by an oblique course.

Striæ on vertical surfaces.—While the stoss side of the Palisade ridge is to the westward, it has many irregularities of surface, and vertical surfaces of small extent exist at many points. These vertical surfaces are frequently striated. A good example of striation on such a surface is found in the cemetery at New Durham. The striæ here are both horizontal and inclined. The inclination from the horizon-

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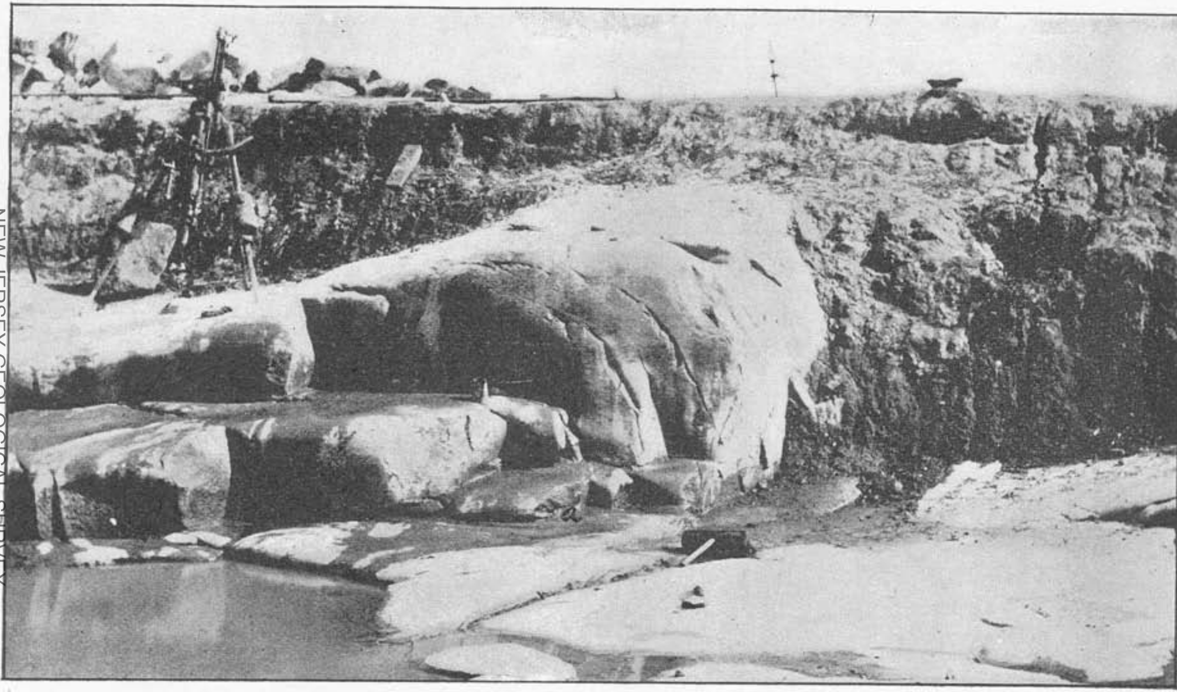

Plate I.

Showing glaciated vertical and horizontal surfaces of trap rock. Surface exposed by excavations for the water-works reservoir at Weehawken. The horizontal groove on vertical face is not well shown in the figure. It is in the foreground, just left of the center of the figure. The figure also shows the phenomenon of "plucking."

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tal is sometimes upward and sometimes downward. The maximum upward inclination is 18°, and the maximum downward inclination is, at another point, 74°. Striæ which are horizontal occur within six feet of striæ which decline 54° to 74° from the horizontal. This great angle of descent occurs on the lee side of a projection on the face of the cliff. Twenty-four feet south of the point where the striæ have the position last noted, the striæ are inclined upward 1°, while nine feet farther south their course is 14° above the horizontal.

Other localities where striæ were observed on vertical surfaces are the following: 1, at Marion, a few hundred yards east of the Pennsylvania railway station; 2, along the Pennsylvania railway near the east face of the ridge, and 3, at Weehawken, in an excavation for the water-works reservoir. The following figure, from a photograph of the striæ at the latter place, shows the striæ on the vertical surface, and also illustrates the pliancy of the ice in fitting itself to irregularities of the surface so closely as to polish and striate them. It is frequently to be noticed that, while horizontal rock surfaces in a given locality are deeply grooved, vertical faces of the same rock in the same locality are polished and striated only, the grooves being absent. (Plate I.)

Striæ in grooves.—Locally, striæ may be seen in horizontal grooves on vertical faces. The locality at Weehawken, just cited, furnishes an example. The groove is about six inches in vertical extent, and recedes into the vertical face four inches. The surface of the groove is polished and striated on its innermost side, as well as above and below. A still more remarkable example is found at Jersey City, near the eastern end of the Pennsylvania railroad. Here there is a groove with a maximum depth of nine inches in a vertical face of trap. It terminates at its south end in a blind pocket, three inches deep, into which and out of which the ice passed, so as to polish its entire surface. Outside the pocket, the groove is polished on its inner face and on its upper and lower surfaces. This condition of things gives striking testimony concerning the pliancy of the ice.

Striæ on rounded angles.—In adapting itself to contiguous horizontal and vertical faces, the ice abraded the angle between them, rounding and smoothing it. Sometimes the striæ on the rounded angles are parallel to the striæ of the horizontal and vertical faces, when the striæ of these faces correspond, and sometimes the striæ on the angles diverge from those on the horizontal or on the vertical

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surfaces, or from both. Striæ on rounded angles, in the relations here referred to, are shown at all points mentioned as showing striæ on vertical rock faces, but nowhere better than at the Weehawken reservoir. (See Plates I. and II.) Now and then the angle between contiguous horizontal and vertical faces remained sharp, instead of being rounded, and the striæ on the contiguous horizontal and vertical surfaces diverge from each other. Several instances of this sort have been noted on the ridge, one occurring at the locality last named. Striæ in such situations are a further illustration of the ability of glacier ice to adapt itself to the irregularities of its bed.

Striæ on vertical surfaces which are horizontally curved.—Vertical surfaces of trap are sometimes curved in a horizontal sense. The striæ and other ice markings frequently show that the ice was able to adapt itself to these horizontally-curved vertical surfaces. Striæ in such situations are found in more than one place on the Palisade ridge. They are perhaps best illustrated on the exposed trap surfaces (1893) at the Weehawken reservoir (see Plates I. and II.), at the New Durham cemetery, and by the exposed rock surfaces east of the Marion station of the Pennsylvania railroad.

Striæ on roches moutonnées.—Numerous examples of miniature *roches moutonnées* are found on the ridge. They are often two, three, five and eight feet in height, but they are not commonly of greater vertical extent. Low as these domes are, rather remarkable divergences of striæ are sometimes seen upon their surfaces. Examples of small *roches moutonnées* with divergent striæ, may be seen one mile east of Englewood, on Palisade avenue, also at Linwood, Edgewater, Marion and in the northwestern part of Guttenberg. East of Englewood the striæ on a *roche moutonnée* only five feet high, thirty-three feet long and seventeen feet wide diverge 32°. It is incredible that such divergence is due to so small a prominence, and it would seem to be necessary to suppose that much of this divergence would have existed without the rock knob. Similar divergences of striæ are to be seen at some points on nearly-flat surfaces. The striæ on another *roche moutonnée* near the last, no more than three feet high and with a horizontal surface equal to that of the one just mentioned, diverge 14°.

Polishing.—By the help of the fine earthy material at its base, the ice sometimes produced extremely-smooth surfaces, often giving them a high degree of polish. The trap of the Palisade ridge is of such a

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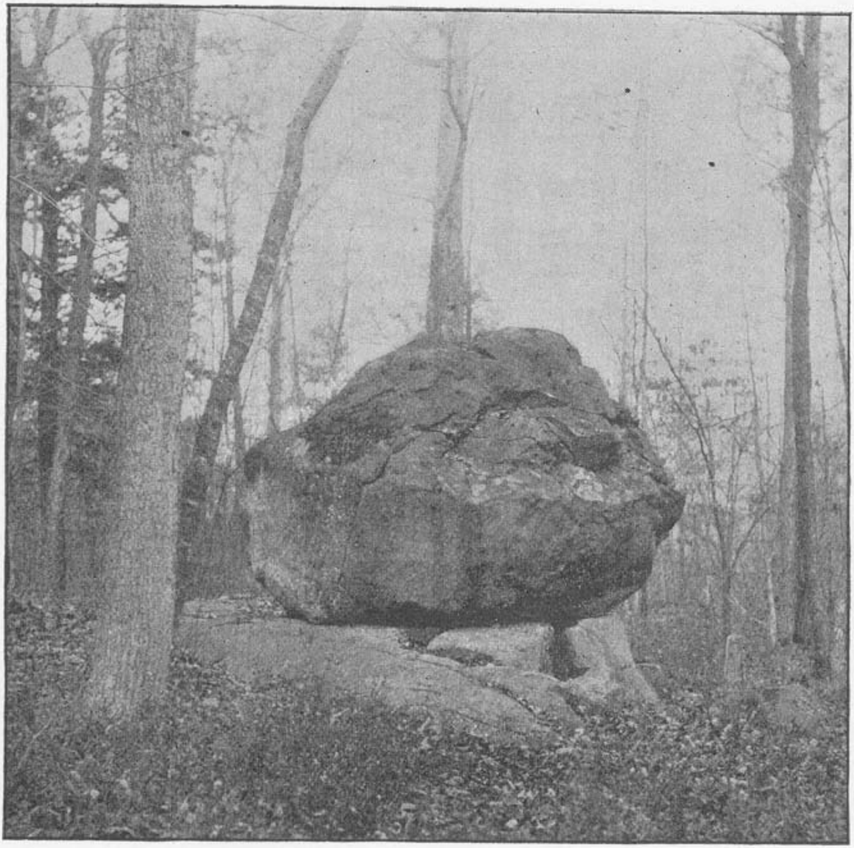

Plate IV.

Perched block of Triassic sandstone near the summit of Palisade ridge, east of Englewood, N. J. Bowlder 12 x 8 x 8 feet.

Beneath the bowlder the trap surface shows polishing and grooving, but where the surface has not been protected, the polishing and grooves have disappeared by weathering. The bowlder was lifted at least 160 feet by the ice.

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character that it is capable of taking a fine polish. (See Plates I., II. and III.) Fine, hair-like lines frequently accompany the polishing. Examples of polishing, along with delicate lining, may be seen at various points, but especially well—1°, at Bergen Point, on Newark bay, just north of the Central Railroad of New Jersey; 2°, along the Pennsylvania railroad from Marion to Jersey City, and 3°, along the east bluff at Guttenberg, where ideal illustrations of glacial polishing, together with delicate striation, are to be seen. Near the school-house at Alpine also, good illustrations of glacial polishing may be seen. Polishing is often seen to good advantage in connection with deep grooving.

In many situations where the rock has not been protected, post-glacial weathering has destroyed the polish of the surface without obliterating grooves and deep striæ. On the north end of the ridge the bare or nearly-bare rock surface has lost its polish. In the north-western part of Guttenberg, on the other hand, surfaces which appear to have been exposed since the glacial time still retain the smooth surfaces which the ice developed, though apparently not with all their original freshness. This difference is probably due to some difference in the texture or composition of the rock in the two localities, a difference which constitutes the rock of the one locality more resistant to weathering than that of the other.

Grooving.—Glacial grooves, with or without the retention of polishing, are best seen at the following places: One mile east of Englewood, on Palisade avenue (see Plate III.); 2°, at Linwood, and between that place and Fort Lee; 3°, at Alpine, near the school-house; 4°, in the eastern part of Edgewater; 5°, at Shadyside; 6°, at Bulls Ferry; 7°, in the western part of Guttenberg; 8°, along the east bluff in West Hoboken; 9°, at Marion, east of the station; and 10°, along the east bluff, a short distance south of the Pennsylvania railroad.

In size the gouges or grooves vary greatly. They are sometimes several feet in width, and several inches to a foot in depth. Thus at Englewood some of them are five feet wide and fully a foot in depth. At Marion there are grooves two feet in width and six inches deep. The accompanying figure shows wide, shallow grooves near Englewood.

Chatter marks.—Chatter marks are well shown at a number of places on the Palisade ridge. They have been seen—1°, north of Marion station, west of the Delaware, Lackawanna and Western rail-

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road tunnel; 2°, on the east bluff of the ridge just north of the Delaware, Lackawanna and Western railroad tunnel; 3°, seven blocks north of 2°, near the bluff; 4°, on Newark bay, south of the Lehigh Valley railroad. Their origin has been described as follows: "It is well known to machinists that a vibratory motion is very common whenever a gouging tool is forced over a resistant surface if there is any want of firmness in the fixing of the tool, or any unsteadiness of motion, or any persistent unevenness of the surface or of the texture of the material acted upon. Under any one of several conditions chatter marks are the result."* Their convex sides are opposed to the direction of ice movement. If a bowlder or pebble be conceived as the tool in the grasp of the ice, and if the motion of the ice furnishes the movement to carry the tool over the surface of the trap, the machinery necessary for the formation of the chatter marks is at hand, and where the above conditions were present, chatter marks were sometimes formed. In size the chatter marks vary. The arms of the curve are sometimes six inches apart at the extremities, though commonly less. They are sometimes no more than one inch across.

Distribution of striæ.—On the map showing striæ, it will be noted that there is great irregularity in their distribution so far as they are open to observation. The table showing the direction of striæ illustrates the same point. (See page 166.) They are much more numerous on the trap than on the sandstone, and on the trap they are abundant in patches. The principal causes of these irregularities are—1°, the variability in the frequency of exposures, because of variability in the thickness of the drift, or because of more frequent artificial excavations at some points than at others; 2°, the unequal weathering which the exposed rock has suffered since the striæ were made. There are other minor causes for the apparent differences, such as differences in rock texture.

In general, the trap is much less deeply covered by drift than the sandstone, and there is, therefore, much greater opportunity for the observation of such striæ as exist upon it. But this does not altogether explain the apparent differences in the distribution of the striæ on trap and sandstone. The difference in the character of the two formations concerned is partly responsible for the apparent and probably real difference in abundance of striæ. While the sandstone must have

*Chamberlin, Seventh Annual Report, U. S. G. S., page 218.

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Plate II.

Glaciated surface of trap at Weehawken. Showing striæ and polishing on rounded surfaces. The figure also illustrates the phenomenon of "plucking."

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taken markings more easily than the trap, it is not calculated to retain them so well. Where trap has been exposed since the glacial time, it frequently, though not always, retains the striæ to the present time. Where the softer sandstone or shale has been exposed for an equal length of time, it is almost sure to have lost such striæ as it once possessed.

The trap itself seems to differ somewhat in its ability to retain striæ, as has been already noted, the rock at the north end of the ridge appearing to retain them less uniformly than that to the south. To the south, it is true, there are many more artificial exposures showing surfaces of trap which have been buried, and so protected against weathering, until very recent times. But the natural exposures toward the south end of the ridge, many of which appear to have been in existence since the days of the glacial period, show striæ much more frequently than corresponding exposures at the north end. There seems to be no uniformity in the amount of protection necessary to preserve striæ on the trap. At some points the striæ have disappeared beneath a covering of two or three feet of drift, while they have remained without any protection at others.

Where protected surfaces of trap have been recently exposed, striæ are well nigh universal. There are but few places where excavations have exposed a surface of trap which had been protected by so much as four or five feet of drift, where striæ are not shown. From this we conclude that the surface of the trap was striated almost everywhere. But one well-marked exception to the foregoing rule was observed. At the quarry northwest of Linwood the exposed surface of the trap (1893) below three to fifteen feet of drift showed no striæ. At a few other points, where exposures were trivial in extent, striæ were not seen.

No striæ were found on the vertical face of the east side of the ridge. If striæ were ever present on this face, they have been very generally destroyed by post-glacial weathering; but it is hardly probable that striæ were ever developed to any extent on this face. The abrupt lee slope is as favorably situated as a rock surface could well be, for escaping polishing and striation.

Post-glacial weathering of glaciated surfaces of trap.—In this connection, an interesting case of preservation of striæ through post-glacial time may be mentioned. On the crest of the ridge near Englewood just west of the boulevard and north of Palisade Avenue, there is a

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remarkable perched block of Triassic sandstone, a representation of which appears on Plate IV. The bowlder has horizontal diameters of eight and twelve feet, and is about eight feet high. The trap is exposed at numerous points about the bowlder, and the bowlder itself rests on a clean surface of trap. Nowhere about the bowlder does the trap surface show polishing or striæ. As may be seen in the figure, the lower surface of the bowlder is irregular, and the surface of the trap on which it rests is not flat, so that the two surfaces touch each other at a few points only. Because of these irregularities of the two surfaces, one may look beneath the bowlder, where the surface of the trap is seen to be beautifully striated and polished. The trap surface has been protected by the bowlder, which has kept the rain-fall from the surface of the underlying rock, and what is equally important, has protected it against the direct rays of the sun, and so against the contraction and expansion to which sudden changes of temperature would have given rise.

At many other points on the ridge, deep striæ and small grooves are still distinct, although their surfaces have lost their smoothness. The result of observation on this point seems to indicate that the amount of weathering which the trap surface has suffered since the disappearance of the ice is very slight. Where smooth surfaces of trap were left exposed, a small fraction of an inch (a fourth would probably be excessive) would represent the average amount of dis-integration which has been effected in post-glacial time. The fresh-ness of the surface outcrops on the Palisade ridge are in marked con-trast to the weathered character of the outcrops of trap on the un-glaciated Watchung mountains, north of Bound Brook and Somer-ville.

GLACIAL EROSION ON THE PALISADE RIDGE.

While the ice, with its armature of rocky material was gouging and striating and polishing the surface of the rock of the Palisade ridge, it was at the same time doing another sort of work. Where circum-stances favored, the ice tore large blocks of rock from its bed, and by urging them along beneath itself, wore them into less angular forms. Where the ice passed over a prominence with an abrupt face to the leeward, the rending power of the ice was probably greatest. In such situations, masses of rock were broken off from the lee side of the ledges, leaving the lee faces rough and angular, while the opposite face of the same prominence was smoothed. This phenomenon has been

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Plate III.

Showing moutonnéed surface of trap. One mile east of Englewood. Broad, shallow grooves are also seen, the surfaces of which are marked by striæ.

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termed "plucking." The rock surface at the reservoir at Weehawken shows the results of plucking. (See Plates I. and II., pages 171 and 172.)

Much of the eastern face of the Palisade ridge was so situated as to have suffered this phase of ice wear. As already noted, this face has an abrupt descent, sometimes amounting to serveral hundred feet. All along the bluff face, the tendency of the ice must have been to break off the upper edge of this face. While the eastern face possesses the roughness and ruggedness which would characterize a ledge face operated upon in this fashion, there is no evidence that the plucking proceeded to such extent as to shift the eastern brow of the ridge any considerable distance to the westward. If the brow of the bluff was moved westward, as a result of plucking, the base of the ridge must have been transferred in the same direction at nearly equal pace, since the east face is often nearly vertical. The base of the ridge could hardly have been shifted westward by this process, and apparently not to any noticeable extent by any other. We must conclude, therefore, that plucking was not very effective on the east face of the ridge.

There seems to be no way of estimating, even with approximate accuracy, the amount of erosion which the ridge suffered at the hands of the ice. It is certain that such decomposed or half-decomposed materials as lay upon its surface were removed, and that the surface of the rock, down to the limit to which any observable amount of oxidation had reached, was removed. Little more than this can be said. There are abundant bowlders of trap east of the Hudson which seem to have come from below the zone of weathering. They are, on the whole, of fresh-looking rock. But there is no warrant for believing that the ridge lost any considerable part of its height, or that its surface configuration was greatly changed. Many small ravines were doubtless obliterated, and minor rugosities of various sorts effaced. The great features of the ridge, however, are believed to have been much the same before the last ice period as now.

THE TILL OF THE PALISADE RIDGE.

The aggregate of material which the ice gathered together and ground up, or partially ground up, in the progress of its motion, constitutes the drift. The drift of the Palisade ridge includes both the

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stratified and the unstratified varieties. The stratified drift is confined to the lower part of the west side of the ridge and to a few points near the base of the eastern slope. The unstratified drift, or the till, covers the larger part of the ridge above the western basal slope.

The till of the ridge may be classified in several ways for the sake of bringing out its various characteristics. It may be classified on the basis of its origin into superglacial and subglacial. It is mainly of the latter class. It may be classified upon the basis of its physical character into—1°, bowldery till, in which the stony constituents are large and abundant, and set in a matrix of earthy or sandy material; 2°, gravelly till, in which the stony constituents are abundant, but small and well rounded, the matrix being usually sandy; 3°, sandy till, in which there is very little stony material, the sand being the major constituent, and 4°, clayey till, which, as the name implies, contains little stony material, while the matrix is predominantly of fine earth or rock flour. The till may be otherwise classified on the basis of its lithological constitution. On this basis the till of the Palisade ridge represents two well-defined types—that composed mainly of Triassic sandstone, and that composed mainly of trap. Between these two types there are all degrees of gradation.

Till classified on the basis of its lithological constitution.—The red sandstone type of till, composed mainly of Triassic (Newark) sandstone and shale, is characterized by its redness. Its matrix is sandy where it is derived from sandstone and clayey where it is derived from shale. The stony material as well as the matrix of this type of drift is predominantly Triassic. This type of till is characteristic of the lower part of the western slope of the ridge up to and somewhat above the junction of the trap and sandstone. Where the ridge is low, as toward the south end, red till occupies its crest at many points.

Below the level of the trap rock on the west face of the ridge gneiss is the second most important constituent of the till. Where the red till lies on the surface of the trap well above the sandstone, the trap is often the second constituent in importance. In addition to the gneiss and trap, quartzite, limestone and quartz pebbles occur in the red sandstone type of till.

The trap type of till is in sharp contrast to the till derived from the Triassic sandstone in the matter of color. It is yellowish brown instead of red. The trap till occupies the crest of the ridge at most points where the ridge is high, and reaches down a variable distance

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below the crest on the west slope. The minor constituents of the trap till in the order of their importance are Triassic sandstone, gneiss, quartzite, limestone and quartz pebbles.

Between these two types of till there is every degree and phase of gradation. The zone of gradation occupies the western slope above the line of junction of the two formations. The diagrams (see page 159) representing the positions of the accumulation of drift show also the percentages of trap and sandstone in the stony material of the till at different heights. It will be seen that so far as the stony material is concerned the sandstone predominates far above the junction of the sandstone and trap and that the red material predominates at some points on the crest of the ridge and even beyond it on the east brow. In the course of the Palisade ridge the stony constituents of the drift often change from eighty per cent. of sandstone on the western face to eighty per cent. of trap on the brow of the east slope.

From the detailed descriptions of till given below it is to be observed that, besides the change in the constituents in passing from west to east, there is also a change in the proportions of stony constituents in passing from north to south, in the direction of the decline of height of the ridge. The till at the south end shows, on the whole, a much higher percentage of sandstone than that at the north, though there is as large a percentage of sandstone on the west slope at the north as at the south. This difference is very likely due in part to the greater height of the ridge at the north, and in part to the fact that the ice which deposited the drift on the southern end of the ridge had passed over a greater stretch of country where the Triassic formation had constituted its bed.

Bowlders foreign to the ridge—Limestone bowlders are more frequently seen at Union than further south. South of Union the matrix of the till often contains so much calcium carbonate that it is easily detected by acid, though its percentage is never high. Gneiss is present with approximate uniformity from the north end of the ridge to the south. Quartzites are more abundant at the north end, while white quartz is more abundant south of Jersey City. Pebbles, which, judging from their appearance, may have come from former remnants of the yellow gravel formation, are found at a maximum elevation of 360 feet as far north as the latitude of Highwood. They are more abundant at lower altitudes toward the south end of the ridge, but beds of yellow gravel are nowhere exposed on the

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ridge. Serpentine is found in the drift only at Stevens Point, Hoboken, where there is an outcrop of this rock. Nowhere was it seen in the drift west of the outcrop.

No single Green Pond mountain conglomerate bowlder has been found on the ridge. West of the Hackensack, such bowlders are found in abundance, and this in spite of the fact that in New Jersey the movement of the ice along the Green Pond mountain range was to the southwest, approximately parallel to the range itself. Glacial movement in this direction could not have carried bowlders from the New Jersey part of the Green Pond mountain formation to the Hackensack valley. It would seem that the conglomerate ledges which furnished the Hackensack valley bowlders must have lain somewhere north of New Jersey, in the axis of the ice lobe, or perhaps a little to the west of it, and that the bowlders derived from this ledge were carried southward in the direction of ice movement, and finally out of the valley onto the highlands to the west by the westerly-diverging currents, but that they were not brought within the influence of the easterly-diverging currents, and therefore were not carried eastward upon the Palisade ridge. Another hypothesis which would equally well explain the distribution of the Green Pond mountain conglomerate bowlders, but for which there is no demonstrative evidence at hand, is that these bowlders were carried southeastward from their parent ledges by an earlier ice movement, the movement in the last epoch being to the southwest over or along the Green Pond mountain formation. A good deal may be said for this suggestion. The distribution of these bowlders has not been studied beyond the State of New Jersey.

Types of till based on physical constitution.—Between bowldery till, gravelly till, sandy till and clayey till there are all possible gradations. There seems to be no general law governing the distribution of these several types, further than that they were severally made where the proper rock constituents were at hand. The sandy till is found on or near sandstone, which is readily reduced to sand. The bowldery till is likely to be found where the underlying rock was of such a nature, or in such a condition, as to yield abundant material in the form of bowlders. Clayey and gravelly till are likewise determined in part by the nature of underlying or adjacent formations, and in part by the vigor and effectiveness of the water which accompanied the ice.

There is a belt on the ridge extending from Union to Marion,

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where the till, as seen in section, has more bowlders than is its wont. This does not refer so much to the abundance of bowlders at the surface as beneath it. At Stevens Point, again, the till contains many bowlders, and is well exposed along the north and northeast sides of the hill. Between Centerville and Constable's Point also the till is very bowldery. This may be due to its close proximity to the terminal moraine, for terminal moraines are generally composed of a larger proportion of bowlders than any other phase of the drift, and this feature is rather likely to characterize the till adjacent to terminal moraines along their inner borders.

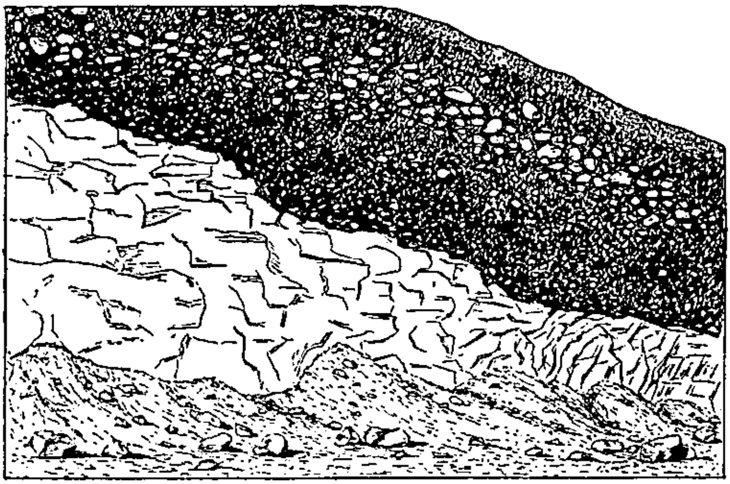

Fig. 7.

Stony type of till. Section at Stevens Point. (Drawn from a photograph.)

The largest bowlders found on the ridge are as follows: A perched block of Triassic sandstone, 8 x 12 x 12 feet, east of Englewood (see Plate IV., page 176), near the east side of the ridge, at an altitude of 360 feet; 2°, a block of the same sandstone, 15 x 10 x 6 feet, one-third of a mile northwest of Linwood, at an altitude of 230 feet; 3°, a gneiss bowlder, a few hundred yards east of Tyler Park station, 12 x 20 x 6 feet; and 4°, a trap bowlder at Stevens Point, 8 x 8 x 3 feet.

The perched block near Englewood has already been referred to, in connection with the striæ preserved beneath it. The position and relations of this perched bowlder, together with its splendid size, are

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such as to attract much attention. Since it is in immediate proximity to a considerable center of population, in a region which is sure to be closely built up in time, and since it is within easy reach of several large cities, it is very desirable that an appropriate tract of ground about this perched block be set aside as a public park. It is one of the best examples of a perched block the writers have ever seen. It is one of the most curious and striking surface features on the whole Palisade ridge. It is not simply curious, but it is exceedingly instructive as well. It is capable of teaching most important lessons concerning several questions connected with glacial geology and rock decomposition. One of them has already been pointed out (page 176). The bowlder was carried up the west face of the ridge from the sandstone below. Its distance from its parent ledge is not known, but the amount of vertical lifting which it has undergone is not less than 160 feet, and may be twice that amount.

The gravelly type of till is represented at the north end of the ridge on the west slope from the State line to Tenafly. It is not often found at an elevation of more than 360 feet, and is rather common below some such altitude. The same type of till occurs south of Tenafly in a small area on the east side of the railroad, and may be seen on the road from Englewood to Tenafly. It may be seen east of Nordhoff, on the steep slope; southeast of Leonia and toward Taylorville; and one-half mile northeast of Marion station, on the east side of the water-works reservoir.

Sandy till has little development on the ridge. The till in the eastern part of Ridgefield, derived mainly from the sandstone, has something of this character.

The clayey type of till has its best development at the southern end of the ridge along Newark bay, where it occurs under stratified sand. It may also be seen at Greenville, west of the depot. Even at this place the till contains not a few stones, though the matrix is of a clayey nature.

Chemical changes in the till in post-glacial time.—The constitution of the till is not such as to favor an easy determination of the amount of change it has suffered by weathering since its deposition, but such change appears to be very inconsiderable. Much of the till is not calcareous, so that there is no simple way of testing the amount of leaching by surface-water in post-glacial time, and there is no other soluble ingredient readily available for the determination. Where

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the till is calcareous, it is but slightly so, and the calcareous matter is absent to a depth of five to eight feet on the southern portion of the ridge; the same material has not been leached out of the till to nearly so great a depth in some other parts of the State. In the western part of the State, for instance, where the limestone content of the till is locally of quantitative importance, the till is often calcareous up to within one or two feet of the surface. Most of the other constituents of the till of the Palisade ridge, the trap, the gneiss, the conglomerate, &c., do not give certain evidence of any considerable amount of weathering since the till was formed. Sandstone bowlders and fragments have suffered more change, but since these fragments change rapidly, the change they have undergone does not indicate a great length of time.

In some regions, change of color is as significant of post-glacial weathering as is loss of soluble matter. But much of the till of the Palisade ridge is of such constitution that weathering alters its color but little. Where the till is red, it does not show the effects of oxidation, if oxidation takes place. The typical trap till changes on weathering to a somewhat greater extent, changing from a greyish cast to a buff or buff-brown. On this basis, the trap till has not suffered a great amount of change, though the uppermost two or three feet of it frequently shows the effects of oxidation which has taken place, presumably in post-glacial time.

LOCAL DESCRIPTIONS OF THE DRIFT.

1°. Two-thirds of a mile north of the railway station at Closter, a railway cut six feet in depth shows till covered by a layer of yellowish loam two feet in thickness. The stony material is made up of quartzite pebbles of various colors, white, grey, purple, &c., of small angular bits of gneiss, of Triassic sandstone, of coarsely-crystalline diabase, some of which is distinctly worn and striated. The matrix is variable, being sometimes of a clayey and sometimes of a gravelly nature.

2°. A few hundred yards further north, there is an exposure of till to a depth of eight or ten feet. The general nature of the material is the same as that in the locality described above. The stony material is coarser, and in addition to the materials named above, there is limestone containing galena.

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3°. On the crest of the ridge in the latitude of Closter the till is very thin. Rock often comes to the surface, and where it is covered it is frequently buried no more than two or three feet. The till is of the trap type, the matrix having the yellowish-brown color which is characteristic of earths derived from trap. Its stony material, likewise, is mainly trap. Sandstone bowlders which must have been transported from the valley to the west, and bowlders of gneiss, which must have come from the highlands beyond the valley, and been carried up on the ridge, are also present, though not in abundance. The drift on the summit of the ridge further south has the same general character. Outcrops of rock are very frequent as far south as the latitude of Tenafly.

On the west slope of the ridge in the same latitude the till is more gravelly than on the crest, and the matrix is much more sandy. There is less trappean material in the drift, which the sandstone formation below the trap has contributed much more generously. The line of junction of the trap till and the Triassic sandstone till is never sharp, though the transition is sometimes rather prompt.

4°. In the latitude of Tenafly, the till on the west slope of the ridge is less gravelly than in corresponding positions further north. It is largely made up of Triassic material, with the usual admixture of gneiss, trap, limestone and quartzite. The depth of the till on the west slope of the ridge in this latitude is from ten to forty feet, while on the crest the drift has a thickness of only two to six feet. On the crest the drift is made up, for the most part, of trap fragments, and of earths which have come from the comminution or disintegration of this rock. In this latitude, there are white quartz pebbles in the till which have such an appearance as to suggest that they came from a former northern extension of the yellow gravel. These were observed at an elevation of 360 feet, a height which corresponds very well with the top of the hills on which the yellow gravel is well developed further south. (See page 39.)

5°. Between Tenafly and Highwood, on the Northern Railroad of New Jersey, an exposure of drift shows an intermixing of till and stratified drift. There is a coating or structureless yellow loam to a depth of something like five feet. Except near its base, the loam is stoneless. At its base it is more or less mingled with stony material, several sandstone bowlders occurring at its junction with the under-

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lying drift. Striated bowlders are abundant below, many of them being of large size.

6°. In the latitude of Englewood loam frequently covers the till on the west slope of the ridge to the extent of five feet or more. The till beneath is often gravelly, but in a few exposures the matrix is clayey enough to show distinct foliation.* This is especially well shown in the 164-foot hill east of the Englewood depot. In this vicinity the average depth of drift is about ten feet. It has the red color which betrays the large contribution of the Triassic formation. Seventy to ninety per cent. of the material of the till in this locality came from this formation. On the summit of the ridge the trap is frequently exposed. A mile or more east of the depot, on Palisade avenue, several *roches moutonnées* are to be seen.

7°. On the west slope of the ridge, between Englewood and Nordhoff, the yellow loam, which has been referred to as occurring at various points, is well developed. Its greatest elevation is about 240 feet. Rarely bowlders occur on its surface. The underlying till is usually red, with a clayey matrix, containing a goodly proportion of stony material. Of the latter, forty-five to seventy-five per cent. is of Triassic origin, while the gneiss constitutes from fifteen to forty-five per cent. Gneiss and quartzite are the next most abundant constituents.

8°. At a trap quarry one-third of a mile northwest of Linwood, at an elevation of 220 feet, there is a large perched block of sandstone 15 x 10 x 6 feet. The greatest ascertained depth of drift on the summit at Linwood is eleven and a half feet. The drift is generally very thin on the summit, outcrops of trap being very common. Some of them show polishing and grooving.

9°. West of Taylorville, in the latitude of Leonia, depths of thirty feet of till are said to exist. This would seem to indicate that the till is much thicker on the slope than on the summit of the ridge in this vicinity. At some points the Triassic sandstone has contributed as much as ninety-nine per cent. of the stony material of the till.

10°. From Fort Lee to Edgewater, the summit of the ridge is marked by numerous outcrops of trap. The drift is very meager, and contains very little material foreign to the ridge. Further west, on the west slope, a road cut at Palisade park shows twenty feet of

* See Annual Report, 1892, page 52.

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till, fully ninety-nine per cent. of the material of which appears to have come from the sandstone.

11°. Two-thirds of a mile south of Fairview exposures of till occur to a depth of ten to fifteen feet. Below an altitude of twenty or thirty feet the uppermost portion of the drift appears to have been deposited or worked over by the water. It is covered by yellow sand, beneath which is gravel. Beneath the gravel there is till containing characteristically-striated bowlders of sandstone, most of which are small.

12°. Shallow exposures of till occur in the northwestern part of Edgewater. The till here has the general appearance of till, but a good deal of metamorphosed Triassic shale was carried over from the west side of the ridge by the ice. This shale gives rise to till which is not markedly different from trap till in general appearance.

13°. In the northern part of Shadyside, on the east road running between Edgewater and Shadyside, there is an exposure of trap till ten feet in depth. Many bowlders of trap and gneiss occur on the surface, and continue as far south as Guttenberg.

14°. An exposure of trap till, seven feet in depth, occurs near Bulls Ferry. It contains, beside trap, sandstone, quartzite and gneiss bowlders and fragments. A very large striated trap bowlder, ten feet in its greatest diameter, may be seen here.

15°. The depth of the drift from Granton to Guttenberg is an exception to the general rule that the drift is banked up against the west side of the ridge, while it is thin on the summit and east side of it. The hill projecting to the northwest at Granton has little drift upon it and many outcrops of rock. The west slope of the ridge at Granton is covered by only about three feet of drift on the average. The summit of the ridge at Guttenberg has very numerous outcrops of trap, while near the eastern bluff ten to fifteen feet of till exist. Numerous exposures of till on the crest in this latitude show it to be made up almost wholly of trap in many instances, and predominantly of trap in all cases.

16°. In the cemetery at New Durham red till is exposed. The material which is derived from sources other than the Triassic sandstone does not constitute more than from one to five per cent. of the whole. The till at this point is foliated.

17°. One-half mile east of the depot at Schuetzen Park, at an elevation of 100 feet, the trap is covered by fifteen feet of till, mainly of the sandstone type. It has the characteristic red color of such

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till, and its stony material is made up of fully eighty per cent. of sandstone. The sandstone and the trap fragments are largely angular, while the gneisses and the quartzites are well worn. The till is foliated.

18°. In the northern part of Union, near the point where the elevated railroad makes a sharp turn, a ten-foot exposure of till exists. Its stony material is fully one-half of Triassic sandstone. Here again the till is foliated.

19°. At Weehawken, in the excavation for the reservoir, till was exposed to a depth of six feet. The till here is very red and non-calcareous. The stony materials are small in size and not abundant. No more than 100 yards to the west the till is very largely of bowlders, nearly forty per cent. of the stony material being two feet in diameter. Sandstone is the most abundant constituent, with trap a close second.

20°. At Stevens Point the depth of the till overlying the serpentine is about twenty feet. It has a reddish tinge, due to the presence of material derived from the red Triassic sandstone and to material derived from the red jasper, which, according to Prof. Cook,* lies just west of the serpentine. The stony material here is more largely of trap than of any other material, but sandstone from the west side of the ridge is present, as are also quartz, gneiss and serpentine. Something like fifty per cent. of the whole body of the till is made up of stony material, the larger part of which is only one to six inches in diameter. Four to six feet of stoneless loam covers the surface.

21°. On the north side of Stevens Point, close to the reservoir, there is a still deeper exposure of trap till which stands (1893) with vertical face, thirty to forty feet high. This is an excellent example of bowldery till. Figure 7 is reproduced from a photograph taken at this point. The lower part has a much higher percentage of local rock than the upper. The stones of the lowermost ten feet of till are largely (eighty to ninety per cent.) of serpentine, predominantly angular. The upper part of the till is redder than the lower, partly due to the jasper associated with the serpentine. Bowlders of finely-crystalline diabase are found, as are also shale, red jasper, white and grey quartz and gneiss. The stony materials are for the most part well worn and striated. Rounded pieces of trap occur in the yellow

*Geology of New Jersey, 1868, page 325.

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loam on the surface, but such stony material as the loam carries is mostly angular.

22°. A short distance north of Tyler Park station, till is exposed to a depth of thirty feet in a gully. It is very stony, and red in color. The sandstone bowlders and bowlderets are well worn, and predominate greatly over other varieties of stony material. They are commonly small. Large bowlders of gneiss and trap also occur.

23°. Just north of the railway station at Tyler Park there is an exposure of eight feet of till. The uppermost three or four feet are clayey. This graduates into redder and more sandy till below. Sandstone is much more abundant than all other rock constituents, though others are present.

24°. Two-thirds of a mile east of the last-named locality, temporary exposures (1893) of red, clayey till were seen, calcareous at depths of five feet and more from the surface. To the eye, the upper, non-calcareous part of the till was not manifestly different from the part below. Other temporary exposures in the vicinity established the fact that any calcareous material which may have originally existed in the uppermost five feet of the till has been leached out.

25°. West of Stevens Point, three blocks west of the steep east bluff of the Palisade ridge, exposures of red till may be seen on the trap. The sandstone material is at least two or three times as abundant as the trap. The till is not calcareous. The ridge is here well covered by the drift, outcrops of rock occurring only along the east bluff.

26°. One-half mile south of Tyler Park, and a few hundred feet east of the Northern Railroad of New Jersey, there is an exposure of till forty feet in depth. The till is of the bowldery type, ninety per cent. of it being of sandstone. Many bowlders two and one-half feet in diameter are present. Some of them are worn and striated, and some of them are angular. The trap fragments are less worn than the gneiss.

27°. One-third of a mile south of the place last named, just at the 140-foot contour, a vertical exposure of bowldery till twenty feet in depth is to be seen. It has a clayey matrix with abundant sandstone bowlders two or three feet in diameter.

28°. Gravelly till, covered by yellow loam, is exposed east of the reservoir at Jersey City, to the depth of six feet. The proportions of stony constituents are as follows: Sandstone, ninety per cent.; trap,

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fifteen per cent.; gneiss, four per cent. Quartzite is the principal remaining constituent.

29°. West of the Jersey City reservoir, near the west end of the Erie railway tunnel, at an altitude of thirty feet, good exposures of mingled till and stratified drift occur. Yellow loam, containing pieces of sandstone, trap and gneiss, covers the surface. Below this, the stony material is very largely of sandstone. Large bowlders are present, along with a much larger number of small stones.

30°. Along the Pennsylvania railroad from Marion to Jersey City the till is well exposed to various depths, ranging up to forty feet. Good exposures occur just east of the Marion station. The till is here covered by two or three feet of yellow loam. Sandstone greatly predominates over other materials. Most of the stony material is small, less than four inches in diameter.

31°. One block northwest of Communipaw station, ten to fifteen feet of till is exposed, covered with two or three feet of yellow loam. A great many bowlders, two to five feet in diameter, lie about the exposure. Many of them show striæ. Trap greatly predominates over other material, but sandstone, shale and gneiss are present. The till is clayey.

32°. Near the Pacific Avenue station of the Central Railroad of New Jersey there is an exposure of six to eight feet of drift. The uppermost four feet is loam, becoming grey near its base. It has a structure resembling foliation. The till has a clay matrix, is red and non-calcareous. The stony material is about the same as in the following.

33°. One block north and one block west of the above there is an exposure of ten feet of till, with a covering of stiff loam containing some gneiss, trap and sandstone. Twenty per cent. of the till is of stony material. Much of it is angular, about four inches in diameter. Larger pieces of sandstone, black metamorphosed shale, finely-crystalline trap, black and grey, and quartzite, make up the stony material. The till is not calcareous. Many of the trap and sandstone bowlders are striated.

34°. On the west side of the oil works at Claremont an excavation twenty to twenty-five feet deep and 200 to 300 yards long shows till with a coating of yellow loam two to three feet thick. The till has a clayey matrix, and is sometimes calcareous eight feet from the surface. A great many trap and sandstone bowlders four to five feet in diameter, and some seven or eight feet, are present.

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35°. About one-half mile south of Greenville, or about a quarter of a mile north of the crossing of the Lehigh Valley and Central railroads, six feet and less of fine, yellow, stratified sand, or sandy loam, covers two to fourteen feet of till. The sandy loam has a few stones in it, among which are sandstone slabs lying on their flat sides. These are found near the base of the sand. Red sandstone is the major constituent of the till, metamorphosed shale and trap being next in abundance. Brown and white quartzites, six inches and less in diameter, yellow quartz pebbles, well rounded and less than five inches in diameter, make about two per cent. of the stony material. Black limestone cobbles also are present.

36°. Near Newark bay, and a short distance south of the canal, a road cut (altitude twenty to thirty feet) shows three to eight feet of sand, the lower part of which is stratified and contains an occasional pebble. The till beneath the sand is red, with a clayey matrix cutting like wax and cracking readily in the sun. Stony material makes up ten per cent. of the till. Of this, ninety-five per cent. is sandstone, the remainder being trap, gneiss, and grey, brown and white quartzites.

37°. At Pamrapo, one block south of the Morris canal and one block west of the Central railroad, there is a six-foot exposure of till, covered by three feet of yellow loam. The stony material is of sandstone. Eight blocks south of this, a temporary exposure (1893) showed red till which was calcareous five feet below the surface.

38°. About a half mile south of the Pamrapo depot a railroad cut more than 1,290 feet long and eight to twenty feet deep, and thirty feet above sea-level, shows yellow loam over till, the latter having some of the characteristics of subaqueous till.

39°. At Twenty Second street, Centerville, near Newark bay, a temporary exposure of eight feet of non-calcareous material existed in 1893, red in color, and its stony material small in size. Another exposure at Bergen Point shows similar characteristics. The stony materials are mainly of Triassic sandstone. The till in this vicinity is frequently calcareous at and below a depth of about five feet, but the calcareous character does not always exist at this depth.

40°. Along Newark bay, at West Eighth street, Bayonne city, eight to ten feet of till is exposed along the shore, under ten feet of stratified sand. The top of the section is about twenty-five feet above tide. The till is red, and contains ninety-five per cent. sandstone in a waxy, clay matrix. The sandstone pieces run up to twelve inches

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in diameter, and some of them are striated. Other stony constituents are limestone, grey, compact and well striated; some quartzite, dark-colored gneiss, and a small percentage of trap. The till is not calcareous six to eight feet from its upper limit, that is, sixteen to eighteen feet below the surface of the section.

41°. From Centerville to Constables Point the surface is covered by sand which has been transported by the wind. Beneath this sand at various points along the shore till is exposed and the beach is covered by bowlders washed out of the till below the sand. These bowlders are two to three feet in diameter, and occasionally run up to 4 x 8 feet. There are many pieces of diabase, sandstone, black metamorphosed shale, and gneiss. No limestone was seen.

42°. An excavation for a railroad switch near the oil works east of Centerville shows bowldery till to a depth of fifteen feet. Fifty per cent. of it is of stony material. Bowlders range up to 6 x 5 x 4 feet. The formations represented are sandstone, quartzite, gneiss and one purple conglomerate. The coarseness of the stony material is in striking contrast with the fine material commonly found south of Jersey City.

LIFTING POWER OF THE ICE.

From the foregoing facts it is evident that the ice carried the red sandstone up from the lower west slope of the ridge to the summit, and sometimes in such quantity as to give the till a decidedly red color, even to the east brow of the bluff. This is particularly well seen at some points east of Englewood, at Weehawken, near the new water-works reservoir, and near the east end of the Pennsylvania railroad cut at Jersey City. The till is not predominantly of Triassic material at every point in the localities named, but there are exposures in each of these localities where the till is distinctly red.

The greatest amount of vertical lifting of sandstone cannot be proved to be more than 300 feet, and it may be restricted to somewhat narrower limits. It is not to be understood, however, that this measures the lifting capacity of the ice, or that, indeed, the lifting was not often more than this on the ridge. Triassic material is carried to the top of the ridge at all latitudes. The top of the ridge is not anywhere more than 300 feet above the upper edge of the sandstone on its west slope, and the maximum may be a little less. It is altogether probable that some of the Triassic material on the top

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of the ridge came from ledges of sandstone considerably below the highest level of its occurrence. Some of it, indeed, may have come from the bottom of the valley to the west. In this case, its elevation must have been equal to the total altitude of the ridge, less the altitude of the valley to the west. In some places this would amount to nearly 500 feet.

If the gneiss on the ridge was carried to its present position subglacially, as most of it is believed to have been, it must have reached the crest of the ridge after being carried through the valley which separates the gneissic areas from the ridge, so that where the ridge is highest it must have been lifted fully 500 feet.

A few specific facts concerning the lifting of drift material may be mentioned. East of Closter the highest sandstone outcrop known is at an altitude of 280 feet, and drift derived from sandstone is found on the summit of the ridge at an elevation of 540 feet, within a mile of the sandstone outcrop. It is possible that the sandstone occurs somewhat higher than its highest outcrop. If it does not, the minimum amount of lifting of Triassic material here is 280 feet.

East of Tenafly, red drift occurs at the east bluff about one mile east of the junction of the sandstone and trap. In order to reach this point, which is east of the crest, the sandstone must have been carried up 200 feet within two-thirds of a mile. The line of junction of sandstone and trap is here about 220 feet above tide, and the height of the ridge is 420 feet. The altitude of the red drift east of the crest is 320 feet. The perched block of sandstone east of Englewood occurs 320 feet above the highest outcrop of sandstone in this latitude. But the sandstone probably reaches up considerably higher on the slope than the highest outcrop, being now concealed by the drift. The lowest outcrop of trap known on the west side of the ridge in this latitude is 160 feet above the highest outcrop of sandstone. The block must have been carried up at least 160 feet, and may have been elevated much more.

East of Leonia, one-third of a mile east of the junction of the sandstone and trap, red till occurs 170 feet above the upper edge of the sandstone. Southeast of Schuetzen Park, red till occurs 190 feet above the junction of the sandstone and trap, at a distance of something more than a mile from it. East of Tyler Park, red till occurs at least 160 feet above the junction of the trap and sandstone at a distance of five-sixths of a mile from it.

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POSITIONS OF LODGMENT OF DRIFT.

From the cross-sections of the ridge represented in Figure 6, page 159, it may be seen that in passing up over the ridge from the west, the ice deposited a larger amount of drift on the western face of the ridge than on the crest. From the section in the latitude of Alpine, the drift is seen to be thirty feet deep on the west slope, and about three feet on the summit. At Tenafly, the greatest ascertained depth on the west slope is forty feet, while that on the summit to the east is three to five feet. At Englewood the known depth on the west slope is ten feet, while on the east part of the summit it is three to eight feet. At Granton, the depth of the drift on the west slope is not more than one-third to one-fifth as great as on the summit. At New Durham, the depth on the west slope is thirty-five feet, while on the summit it varies from nearly zero to sixteen feet.

At one point near the east part of the ridge the drift is known to be fifty feet thick. This locality is in line with a deep ravine at Weehawken, and the great depth of drift would seem to indicate a preglacial extension of this ravine northward, the ravine now being filled with drift. At Tyler Park the drift on the west slope is twelve to thirty feet in depth, while on the summit to the east it is from two to nine feet. At Marion there is not much difference between the west side and the summit. The diagram showing depths of drift in the latitude of Marion indicates a much more irregular rock surface than in the other sections. This difference is probably more apparent than real, since much fuller data were available for the construction of the section at this point. The other sections doubtless represent the rock surface more regular than it is, since irregularities are introduced into the diagram only where the less complete data showed them to exist. In spite of these defects the sections are instructive in showing the relative depths of drift on the west side and summit.

From these diagrams it is seen that the thickness of the drift varies in two ways—1°, that from the State line southward to Jersey City the east face of the Palisade ridge is essentially free from drift; 2°, that the drift is thin on the summit, and that north of Marion it increases in depth on descending the west slope. South of Marion the ridge is low, and there is little difference in the depths of the drift on the west and east sides. The thickness of drift on the summit in-

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creases on passing from the north to the south, in the direction of the declining height of the ridge.

The abundance of rock outcrops follows the same law. The east face of the ridge is precipitous, with nearly continuous exposure from the State line to Jersey City. The comparatively flat summit furnishes very frequent outcrops from Guttenberg north to the State line. From Guttenberg to Jersey City the outcrops are numerous on the east and west sides, but rare on the summit. South of Jersey City a few outcrops occur on the east and west sides, and still fewer on the summit. At Guttenberg there are something like seventy-five outcrops to the square mile, while south of this point there are many square miles without an outcrop, and twenty-five is the maximum for any square mile.

Till on the east slope of Palisade ridge.—North of Jersey City there is, in general, little till on the east slope of the ridge. Much of the east face consists of a vertical trap face above, with trap talus at the base, sloping down to the river.

At a few points where the face of the ridge departs notably from the vertical there is a little till. At a few others there is drift which may be till, but which, in the absence of exposures, cannot be satisfactorily classified. Till, or drift which cannot be separated from it, has been noted at the following points:

1. At Alpine landing, and for one and one-half miles north, gravelly drift is present up to a height of about eighty feet above tide in considerable quantity. Exposures are too meager to allow it to be certainly identified as till. Above this there is a little drift to the bluff face but it is largely covered by trap talus. The stony constituents of the till are sandstone, gneiss and trap. Yellow loam covers the surface to a depth of several feet.

2. Between the latitudes of Englewood and Nordhoff, gravelly till (?) covered by yellow loam is found on the east side of the ridge from an elevation of about fifty to sixty feet to the river's edge.

3. At Fort Lee, and for a mile south of that place, there is a considerable body of till reaching a maximum altitude of nearly 100 feet. A little further south, on the gentle slope a mile north of Edgewater, there is also a small area where till occurs. The till is largely of trappean origin, though pieces both of sandstone and gneiss are present. In both these places the till is more or less covered with yellow loam, and sometimes with trap talus.

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4. Some till is found at the foot of the bluff at Weehawken, at the south end of the narrow ridge which is separated from the main ridge by a small stream. The till is largely composed of trap (seventy per cent.), with some gneiss and sandstone. The till extends up the ravine on either side of the brook a quarter to a half mile, and covers all the surface below the trap talus slope that is not "made."

5. Till at Stevens Point and south has been described in another connection. While it is on the east side of the ridge it is not against the steep east face.

There are many other places on the east face of the ridge where trifling amounts of till occur. Their areas are in general much too small to be represented on the map.

PERCHED BLOCKS.

Good examples of perched blocks exist at the following points: 1°, east of Englewood, on the summit, a block of Triassic sandstone, 8 x 8 x 12 feet, resting on trap (see Plate IV., page 176); 2°, a block of similar sandstone, 15 x 10 x 6 feet, resting on till, one-third of a mile northwest of Linwood; 3°, a gneiss block east of Tyler Park, bearing evidence of some wear, 20 x 12 x 6 feet.

PONDS.

There are numerous small ponds on the ridge at various points. None of them rise to the dignity of lakes. In many cases the situation of these ponds would seem to be favorable for determining whether or not they occupy rock basins, hollowed out by the ice. The testimony on this point, so far as it is not conclusive against rock basins, is negative. That is, not a single one of the ponds is known to occupy a rock basin. It should be said in this connection that many of the ponds afford only negative evidence. It may be that some of them have continuous rock basins, the fact being concealed by the drift.

STRATIFED DRIFT. SAND AND GRAVEL.

Distribution.—The stratified drift of the Palisade ridge is confined mainly to the base of the western slope, though it also occurs at a number of points at or near the base of the east face between Con-

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stables Point on the south, and a point opposite Englewood on the north. Constables Point, and all of the land immediately about it separated from the main ridge by the salt marsh, is of stratified drift, more or less modified by the wind. Its maximum elevation is about forty feet. East of Pamrapo and south of Greenville, there is also a little stratified drift, up to an elevation of thirty feet or so. The isolated area south of Claremont, and much of the low land about Communipaw, up to an elevation of twenty feet, or a little more, is of stratified drift. All the low land from Communipaw to Stevens Point which is not "made" is also of stratified drift, mainly sand. It runs up to an altitude of about twenty feet. Above this stratified drift, Stevens Point rises with its covering of till.

Further north, there are limited deposits of stratified drift about Guttenberg, up to a height of about thirty feet. At Edgewater, stratified sand, sometimes with gravel, occurs up to a height of about thirty feet at least, and is nearly continuous to the northward for a distance of about a mile. It locally assumes the form of a terrace. There is a good exposure of the sand near the road leading up the hill at Edgewater. There is some trace of stratified sand and loam on the east side of the ridge east of Englewood, at an elevation of forty or fifty feet. North of Alpine, there is a little of the same sort of material at an elevation of eighty feet.

Stratified drift occurs at low levels along the south end of the ridge, running up to a height of thirty or forty feet on the west side of the south end, and even to somewhat greater heights locally, as west and northwest of Greenville. North of Marion there is stratified drift near the entrance to the railroad tunnel, at a height of forty feet or more. From Marion to Schuetzen Park there is little stratified drift. From the latter place to Granton, stratified sand and gravel occur at the base of the ridge up to an elevation of something like thirty feet. There is more or less stratified drift also from Granton to Fairview, which rises to about the same altitude. Between Fairview and Nordhoff there is but little stratified drift, and that at very low levels. From Nordhoff to Englewood, on both sides of the valley, stratified drift runs up to elevations of thirty feet or more. From Englewood north the stratified drift reaches greater altitudes. At Englewood it runs up to sixty or seventy feet, and further north it sometimes occurs up to heights of more than 100 feet, but where it rises to so great height it is in the form of kames.

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It will be seen that the height of the stratified material at various points is not constant, and that on both sides of the ridge it is greater at the north than at the south.

Topography of the stratified drift. Terraces.—At some points the stratified drift is disposed in the form of distinct terraces. Thus, at Edgewater, on the east side of the ridge, there is a distinct terrace of sand at an elevation of thirty to thirty-five feet. Traced northward, this terrace resolves itself into three terraces, the lowest of which is only ten feet above the river, the next ten feet or so above the first, and the uppermost about an equal height above the second. Below Edgewater there is at least fifteen feet of stratified sand. Where its upper limit is well defined it is about twenty-five feet above the Hudson. The upper limit is not always well marked, and the sand appears to run up to an elevation of forty feet in places. The sand has something of a terrace form at some points, although it does not constitute a distinct terrace along this line. At one point, there is a low ridge-like swell of sandy loam, spur-like in form, separated at its north end from the base of the bluff by a depression at least ten feet deep. It is just south of this that the sandy loam develops into a terrace, at an elevation of twenty-five feet. This sand spur shows cross-stratification, though not of the ebb-and-flow type, where exposures were seen. No pebble was seen in section. The material closely resembles the sandy phases of the loess, both in the soil to which it has given rise, and in section. Above Edgewater, sandy loam runs up above the terrace to a height of sixty feet, but it was not seen to be stratified at these levels.

East of Englewood, at the point where traces of stratified drift were referred to in a preceding paragraph, there is a narrow bench at an elevation of forty to fifty feet, the surface of which is covered with yellow, sandy loam. The lower part may be stratified, though this cannot be asserted to be the fact. Just above Alpine there is some till (?), covered with more or less sand, though the latter is never developed in the form of a distinct terrace. Sandy loam runs up to heights of 100 feet or so, but stratified sand is nowhere exposed above forty feet. Exposures sufficient for the satisfactory determination of the upper limit of the sand were not found.

Between Bergen Point and Marion, the stratified drift at the west base of the ridge does not always assume a distinctly terrace-like form. While its surface is frequently flat or nearly so, and while its

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western edge is abrupt at many points after the fashion of a terrace, its eastern limit is not generally sharply defined. Where it is most clearly marked, it is at an elevation of forty feet or a little less. This may be seen south of the West Bergen depot, for a distance of half a mile. Southwest of West Bergen, the wind has modified the original topography, but the terrace-like form of the stratified drift comes out at several points. Between West Bergen and Marion, a hill composed of till but covered by sand projects through the main body of stratified drift. The sand on its surface may have been deposited by the wind.

Just north of Marion, the western border of the sand is not characterized by an abrupt face as further south. The sand here has a rather flat or gently-sloping surface up to an elevation of thirty to forty feet, but the upper edge of the terrace is ill-defined. Between Schuetzen Park and Granton the stratified drift runs up to a level of thirty or forty feet. It has not a distinct terrace form, though its surface is suggestive of a terrace. At New Durham the stratified drift has the form of a rather broad, gently-sloping plain, above which there is, at some points, a rather distinct bench, though not of stratified drift, at an altitude of fifty feet. This terrace, though distinct at some points, is not continuous, and is distinct at a few points only.

At New Durham there is a sand pit, seventeen feet deep, which shows the structure of the stratified drift at this point. The pit is a short distance southwest of the depot. The section is represented in Figure 8, which is reproduced from a photograph. Commencing with the top, the section may be described as follows:

4. Three feet of unstratified yellow loam.

3. Two feet of fine sand, horizontally stratified, rarely containing a pebble.

2. A layer of cross-stratified gravel and sand, having a thickness varying from a few inches to three or four feet. The crossing of the laminæ is striking and the alternations abrupt. It is of the character designated by Dana "flow-and-plunge" structure, indicating wave action. The parts having the same direction of dip are sometimes as much as nine feet in length, but usually less than three feet. This layer of stratified gravel and sand rests upon the nearly horizontally-stratified sand below in such wise as to indicate erosion of the latter before the deposition of the former.

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1. The lower part of the section is made up of fine sand, with stratification nearly horizontal.

North from New Durham the stratified drift fails to maintain a constant level, and declines and narrows at the same time. This disposition of the stratified drift makes it rather difficult to characterize it as a terrace.

Between Granton and Fairview there is a possible suggestion of a wave-cut terrace at an elevation of thirty feet or a little more, on the tongue of land lying to the west of the Northern Railway of New Jersey. From a point a little north of Palisade Park to Leonia

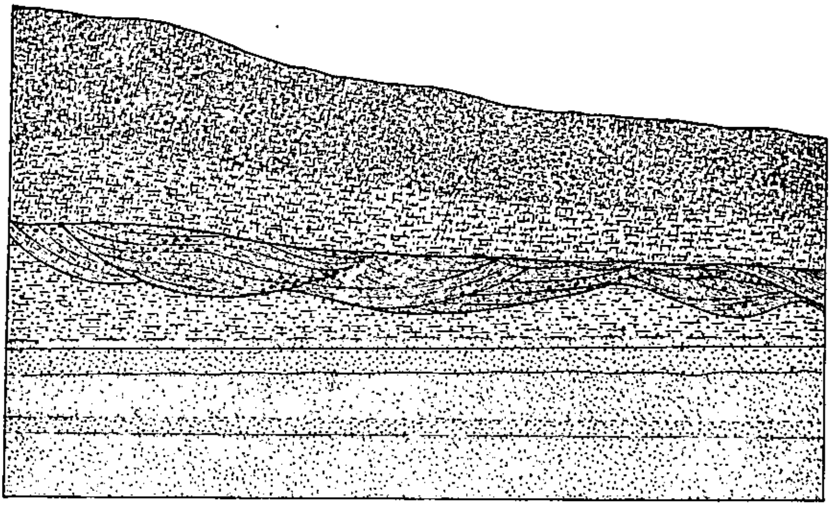

Fig. 8.

Section in the sand plain at the sand pit in New Durham, showing structure. Section faces north. (Modified slightly from photograph.)

there is also some indication of terracing at an elevation of about thirty-five feet, though the material appears to be till. This terrace seems to belong in the same category as the one last mentioned. North of Leonia there is an ill-defined terrace at a similar elevation composed of stratified drift, mainly sand. The stratified drift north of Nordhoff and extending to Englewood has no distinct topographic form, though distinct suggestions of terracing appear at an elevation of thirty feet, and less distinctly at somewhat higher levels. Bowlders are present, occasionally, in the stratified drift at an elevation of forty feet and above.

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From Highwood to Englewood and beyond there is an area of gravel and sand in the valley west of the ridge which, from one side, has somewhat the appearance of a delta. To the north it commences in the vicinity of the two Highwood kames, which rise up from the plain at seventy feet, to an elevation of 90 and 105 feet respectively. Thence the flat, gravelly plain extends south by southwest for about one and and one-third miles to the western part of Englewood. The surface of the plain is generally flat, though minor irregularities are not wanting. These take the form of sinks and, less commonly, of low knolls or gentle swells. The surface descends with little interruption to an altitude of twenty to twenty-five feet. At two points there are step-like descents of trivial extent. The east face of the plain is in sharp contrast to the southerly slope. From Highwood to Engle-

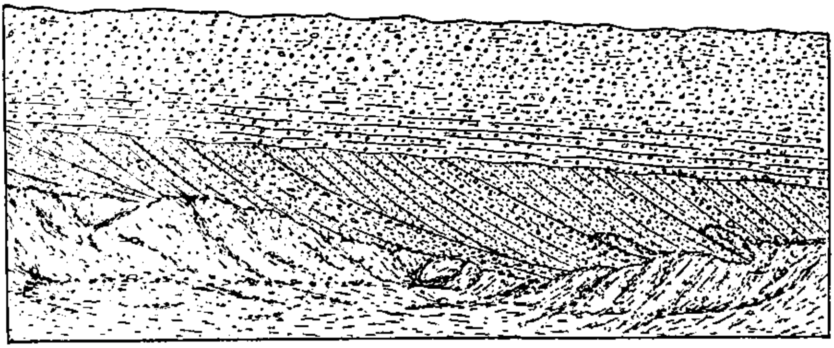

Fig. 9.

Delta-like structure of sand plain as shown in section at a pit at Englewood, near the depot. Section faces west. (Drawn from a photograph.)

wood this face is abrupt, with a descent of twenty feet or more. The western face of the plain is also steep—so steep in some places as to suggest the possibility of its having been deposited against standing ice. The character of some of the slopes of the plain is such as to suggest that they are depositional, not degradational; that is, that the material of the plain was deposited as it now is, and not carved into its present form by surface erosion and subsequent time.

That the slopes are due to deposition, and not to erosion, is suggested by the abruptness of the descent, by the profiles of the slopes and by the peculiar lobate character of the margin of the plain. That they are not degradational is indicated by the small amount of erosion

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which has taken place in other parts of the valley since the deposition of the sand and gravel. If the faces be depositional, the plain might be conceived to be either—1°, a delta, or 2°, a plain, built against or between stagnant masses of ice, while the glacial ice was in process of dissolution. Between these two hypotheses it should be possible to decide. The character of the material of the plain, its structure and topography, should afford the necessary data.

To the north, the material of the plain is gravelly, the pebbles frequently having a diameter of three inches. To the south the material becomes finer, the pebbles disappearing altogether. This would be inconsistent with neither of the foregoing hypotheses. At one of the gravel pits south of the station at Highwood, what appears to be normal delta structure is shown. The gravel is here overlain by fine yellow loam to the depth of three or four feet. Similar structure is also well shown in a gravel pit one block north and west of the new railway station at Englewood, where the lower beds of sand and gravel are seen to slope southward at a high angle. These lower beds are covered by a layer of sand and gravel, stratified horizontally. The structure is shown in the accompanying figure, reproduced from a photograph taken at this point.

The structure at these points would indicate that the plain is a delta, if exposures at other points were consistent with them. But such is not the case. Other pits close at hand show that the sand and gravel has a structure which is fatal to the delta hypothesis. As indicated above, one pit, near Highwood, shows what might be delta structure, but another less than five rods away shows a structure altogether inconsistent with the first. In the first, the dipping beds are toward the edge of the plain, as must needs be in a delta. In the second, the dipping beds beneath the horizontal beds at the top, dip in toward the center of the plain, a condition of things which could not exist in a normal delta. On the west side of the plain, at a single point, the structure of the plain was seen. Here, too, the inclined beds below the horizontal dip in toward the center of the plain, not out, as they should in a delta. The gravel and sand at these two points, one on the west side and one on the east, were deposited from the west and from the east respectively. But to the east and to the west are non-erosion depressions, which the sand and gravel could never have crossed. It seems probable, therefore, that the depressions were occupied by stagnant ice, and that the gravel was deposited against it.

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When the ice melted, the faces of the sand and gravel plains were steep. Such ice faces must have been more or less irregular, and locally the structure of the sand and gravel deposited under such conditions, might be the same as that proper to a delta.

Beyond the little brook west of the plain, opposite the point where the plain in the western part of Englewood has an elevation of forty feet, there is a terrace-like flat against the highland at a corresponding level. This terrace has a sandy coating, though it is not known to be composed of sand. It continues southward to Tea Neck. Across the little valley east of the plain, as it occurs at Highwood, a terrace continues southward along the ridge for a short distance, at an elevation of about sixty feet. At Englewood, no distinct terrace exists on the face of the ridge, but stratified drift occurs above an elevation of fifty feet.

North of the north end of the plain, commencing at the Highwood kames, the surface declines promptly, and the stratified drift is continued northward at a lower level. The Englewood plain and its surroundings would seem to indicate that the ice must have lain at Highwood when it was formed.

North of the Englewood plain, there is a suggestion of a terrace west of the railway, at an elevation of about sixty feet, running northward nearly to Tenafly. The width of this bench-like topographic form is something like 200 feet. Though often ill-defined, this bench is composed of stratified material, mainly sand. From Tenafly to Cresskill, a distance of something more than a mile, an uncertain terrace can be traced, at an elevation of seventy feet, rising to the north. The stratified drift does not occur at so great an elevation as the upper edge of this bench-like form. On the other hand, at Tenafly, stratified gravel and sand rise to an elevation of ninety feet, that is, thirty feet above the point where the terrace seems to be suggested. It is clear, therefore, that the suggested terrace at this point is not proof of submergence.

From Cresskill to Closter there is no trace of a terrace on the west side of the valley which runs from Closter to Englewood and beyond. A mile west of Closter an indistinct terrace occurs at an elevation of seventy feet, though stratified drift runs up somewhat higher. The entire valley in the vicinity of Closter is occupied by gravel and sand, with occasional hills of till projecting up through the stratified drift, or having no more than a shallow coating of sand or gravel

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over them. Still further north, at Neuvy, there is a sort of bench against the highland to the west, at an elevation of about seventy feet. This is traceable as far north as the State line, sometimes having a width of about 200 feet. On the east side of the Closter valley there are no well-defined terraces. North of Highwood, at various points, there are deposits of stratified drift which assume something of a bench-like form, but they are nowhere so well developed that they can be confidently referred to as terraces.

It will be seen from the foregoing that such terraces as exist are rather higher to the north than to the south, just as the stratified drift, on the whole, rises to the north. It will be seen also that the terraces are rather vague.

Beach ridges.—If during the closing stages of the glacial period the sea stood at an altitude higher than the present it might be expected that beach ridges, or other shore marks, would remain. The conditions seem favorable both for their development and retention. These features are not generally present, and nowhere with unequivocal distinctness. From the latitude of Pamrapo to near Bergen Point there is much dune sand, which is suggestive, but not demonstrative, of an earlier beach somewhat above the present. It occurs at an elevation of thirty feet or possibly a little higher. It may be mentioned that a similar condition of things is found east of Hackensack, at an elevation of about twenty feet. The dunes at this point, it will be noticed, are in about the latitude of Englewood, and are much lower than the plain of that region.

Kames.—There are no kames at any point on the Palisade ridge, but at the western base they are well developed at several points. The kames at Highwood at the head of the plain which reaches south to Englewood have already been mentioned. There are here two distinct kames, one of which is about 590 x 145 yards and 20 feet high, and the other 290 x 145 yards and 35 feet high. They are situated a little north of west of the railway station and are striking topographic features. About half way between Highwood and Tenafly there are two kames standing up above the till surface. The southernmost, with a height of thirty to forty feet, is well exposed in a deep railroad excavation. The surface is composed of yellow loam to a maximum depth of five feet. The loam appears to be devoid of stratification, and it is apparently free from stone except in its lower part, where it begins to grade into sand. At the junction of the

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loam and the sand there are several sandstone blocks, partly buried in the stratified gravel, but projecting up into the loam. Below the loam, the material is not always well stratified, and in places it is altogether without structure. The pebbles range up to three and four inches in diameter. Bowlders of Triassic sandstone, gneiss, granite, limestone, trap and quartzite occur, being frequently striated. A few hundred feet to the north there is another kame, 20 to 30 feet high and 500 feet in diameter.

In the vicinity of Demarest there are a number of kames. Something less than a mile east of the station there is a very remarkable group of them, described in the annual report for 1892.* These kames lie above the seventy-foot contour line and show no evidence whatsoever of terracing. Between this group of kames and the railroad there are two small isolated kames. West of the station there are four isolated kames having the usual form of single kames. These isolated hills are rather prominent, rising from twenty to fifty feet above their surroundings. The bases of some of them lie below an elevation of fifty feet, but nowhere do they show any evidence of terracing. The absence of terracing about these kames indicates (though it does not necessarily prove) that after these kames were formed, the sea at no time beat against them. No other kames are associated with the west face of the trap ridge. It will be observed that all of those mentioned are near its base.

Dunes.—Well-developed dunes occur in but one region in connection with the ridge. This is the west base of the ridge near its south end. The dunes are best developed south of the railway at West Bergen, but dune sand covers much of the surface of the west side of the ridge from Marion to the Morris canal. It is less common further south. Between Centerville and Constable's Point, also, the wind has modified the surface without fashioning it distinctly into dunes. At various other points it would appear that the wind has shifted the sand more or less, but not in such quantity as to greatly change the form of the surface, or to make considerable deposits.

Clay.—At various points in the valley west of the Palisade ridge, there are deposits of clay beneath the sand and gravel. For knowledge concerning this clay, recourse must be had to data derived from wells and such other deep excavations as have been made from time to time. Just west of the station of Englewood (about twenty feet above

*Annual Report for 1892, page 93.

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tide), it is stated that beneath fifteen feet of sand there is a depth of something like seventy feet of clay, below which lies the rock. On the low land north of Neuvy (about thirty feet above tide), there are some abandoned clay pits. The pits are so far filled that the clay is not open to inspection. The greatest depth reported is twenty-eight feet. The clay is said to be stoneless, and to be underlaid by material which, from the description, is judged to be till. With reference to its stratification, no data are at hand, but the clays are said to be similar to those at Hackensack and Haverstraw, New York; at both of these points the clay is well stratified. It should be noticed, in this connection, that there is a valley connection between the Hudson river and Neuvy, via Sparkill and Piermont. A depression of less than thirty feet would cover these Neuvy clay pits with the waters of the Hudson, and would allow the Hudson waters to pass down the Hackensack to Newark bay. A depression of sixty feet would connect the Hudson river with Newark bay, via Demarest and Englewood, and a depth of drift greater than this is known to exist at Englewood, where the surface is only about twenty feet above tide. It is thought to be altogether probable that the Hudson once flowed down the west side of the Palisade ridge instead of the east.

BURIED SOILS.

At two or three points in connection with the study of the Palisade ridge, buried soils were found at low levels. These are as follows:

1. On Newark bay, about a quarter of a mile south of the Lehigh Valley railroad, a bed of peat, or peaty soil, two or three feet in thickness, is exposed at intervals for 200 yards along the shore, about four feet above tide, within reach of the storm waves which are now destroying it. It overlies till in some places and stratified sand at others. It is overlain by from ten to thirty feet of sand, much and perhaps all of which has been deposited by the wind. The peat apparently fits the slightly-irregular surface of the drift beneath. A small exposure of peat was found near the Lehigh Valley railroad, not now connected with the larger bed, though it may have been so connected at a former time. Where the till is not protected by the peat its upper part sometimes has the appearance of having been re-worked by water to a depth of three or four feet. If the sand over the old soil be-

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entirely of wind origin, as much of it certainly is, the presence of the soil has no significance in the matter of former relative levels of sea and land.

2. At Cavans Point, Communipaw, the following section may be seen. Its top is about fifteen feet above tide:

(4) Three to six feet of coarse gravel, from four to six inches in diameter, with a few bowlders a foot in diameter. Not stratified.

(3) About one foot of black soil, containing broken clam and oyster shells. This layer is irregular and highly inclined. The oxidation of the sand and loam under this soil is much more considerable than the oxidation of the present surface.

(2) Stratified sand and fine gravel of variable thickness (zero to six feet), containing fragmentary shells, often somewhat water-worn.

(1) Till, exposed at a few points at low tide.

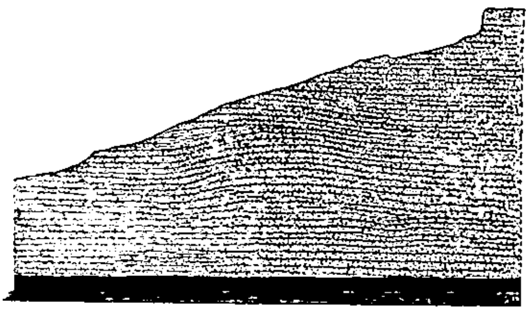

Fig. 10.

Soil buried by sand. Newark Bay.

At first sight this seems to be an instance of a soil buried by natural agencies; but close inspection shows that the soil layer is soil developed *on a dry surface.* The presence of oyster and clam shells in a dry-land soil at once throws suspicion on the whole section. Further study leaves little doubt that the gravel covering the soil has been put where it now is by human agency.

3. An occurrence of a buried soil more remote from the ridge may be mentioned in this connection. At one of the clay pits at Hackensack, the top of which is about ten feet above tide, the following sec-

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tion was seen when it was fresh and clean. As seen at a later time, after exposure and wash, the line of old soil, which was at first very distinct, was not obtrusive and might easily be overlooked:

(5) Eight feet of fine, stratified sand, containing a few gneiss bowlders.
(4) Stratified sand, two feet in depth, overlain by a few inches of blue clay containing fragments of leaves and woody stems.
(3) One foot of black soil.
(2) Six feet of laminated clay, containing a few bowlders, calcareous up to within a foot of its upper limit.
(1) Till, seen in the bottom of the pit on its west side.

The following sequence of events would seem to be suggested by the phenomena at Hackensack:

1. When the ice advanced to the position it had when forming the moraine, either it (*a*) advanced into the ocean, or (*b*) on retiring, submergence took place, so that some of the surface which the ice had occupied was covered by the sea.

2. The clays at Hackensack were then deposited, the ice not having retired so far that bowlders could not be floated down and dropped into the clay then depositing. Well data at Hackensack indicate that the laminated clay has a depth of ninety feet in one place.

3. The land then rose high enough for the soil referred to above to be formed. The time that it remained above water was sufficient to leach the tough brick clay to a depth of something more than a foot at Hackensack.

4. Submergence then took place again to a depth sufficient to allow the deposition of eight or ten feet of sand above the soil at Hackensack.

5. The ice retired for the last time, and the land rose to its present elevation.

6. According to determinations made by Professor Cook, depression has been slowly taking place in recent time.*

It should be stated, however, that we have at present no proof of the marine origin of either the clay (4), or the sand (5).

*Geology of New Jersey, 1868, page 343.

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Evidences of submergence.—There are two facts, or sets of facts, connected with the stratified drift of the Palisade ridge, which suggest that it was lower than now, at about the time the ice left it, or since. These are—1°, the terraces, and 2°, the buried soils.

The terraces already described are found, though not continuously, from Bergen Point to Englewood. Less distinct and more doubtful terraces exist further north along the west side of the valley which lies west of the Palisade ridge. On the east side of the ridge a terrace is found at Edgewater (see page 197), and less distinct ones at other points. Although not connected directly with the Palisade ridge, it may be here stated that terraces are also found in the Hackensack valley. In addition to the terraces, there is a possible delta plain at Hackensack. There is also a spit south of Ridgefield Park. While this is not at the immediate base of the ridge, it is so close to the ridge that it comes to be of significance in this connection.

Concerning the terraces two hypotheses may be considered—either 1°, they were made during submergence, and are therefore shore terraces, or 2°, the valley west of the ridge was filled with sand and gravel in glacial times to the height of the terraces, and erosion has since carried out the main part of this filling, leaving only the terrace remnants. In this case the terraces fall in the category of river terraces. The latter hypothesis involves the cutting out of a valley four miles wide to a depth of thirty to forty feet in post-glacial time. To this hypothesis there is strong objection. In the first place the testimony of the valley streams is that there has been little post-glacial erosion. The streams are often bordered by undrained swamps which do not appear to be the result of stream work. What appear to be depositional plains are found with the lower edge of their outer faces near the level of the streams, and with their outer faces still preserving their depositional forms.

There is, in the second place, a negative consideration which has great weight in this connection. Had the Palisade ridge and its surroundings been lower than now when the ice retreated and later, it would seem that shore terraces or shore marks of some sort should have been nearly continuous along the margins of the area affected by the possible subsidence under consideration. The west face of the Palisade ridge would be admirably situated for the development of terraces were the sea much above its present level. This face is composed largely of loose materials upon which the waves and shore

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currents would act with rapidity. The absence of distinct terraces at most points, and the absence of distinctive shore features of other sorts at nearly all points, make it difficult to believe that the ridge has stood lower than now, relative to the sea, since the ice retired. On the other hand, the sand plain at New Durham, at an elevation of about thirty feet, and the terraces at about the same level at several points south of Englewood would seem to find their best explanation in submergence to the extent of thirty feet, more or less.

Again, if the ridge was lower than now after the departure of the ice, the same was probably true of Snake Hill, Secaucus and the elevation just north of Secaucus. If the land was lower than now after the disappearance of the ice, these elevations must have been islands in the bay which occupied the present marsh west of the Palisade ridge. These islands would have afforded ideal conditions for the development of terraces and other shore features. When they are sought for, they are found to be for the most part absent.

A fairly well-defined terrace does occur at Secaucus, at one point, but it still remains true that shore features are for the most part wanting about these areas. From Harrison to Hackensack the same condition of things obtains. There is here and there a distinct terrace, always at low levels—twenty to thirty feet. But the absence of terraces, or at any rate of distinct terraces, is more general than their presence, even where conditions seem favorable for their development.

On the whole, while the lack of continuity of terraces along the base of the west face of the Palisade ridge, about the elevations in the marsh west of the ridge, and along the east face of the highlands west of the ridge, seems to indicate that the region was not submerged after the withdrawal of the ice, yet the terraces, and in a few places other shore features, occur in such relationship as to be difficult of explanation unless the sea stood at higher levels than it now stands during or since the ice period. The most probable explanation of the presence of the terraces and other shore features at a few points, and of their absence at most points, seems to be that the land stood somewhat lower than now—about thirty feet—during the closing stages of the ice epoch, and that a shallow bay occupied the south end of the broad marsh between Jersey City and Newark; that the waters of this bay, instead of beating against the highlands on either hand, beat against the ice in part, and against the land in part. Where they beat against the land, terraces were developed; where they beat

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against the ice, the ice protected the land from the development of terraces and other shore features. If this hypothesis be correct it must be supposed that as the ice melted the surface on which it rested rose, so that after the ice was gone the waves did not beat against the base of the Palisade ridge, and the corresponding highlands to the west, above the present sea-level, for a sufficient length of time to develop well-defined shore features.

Phenomena which would seem to be explained by the same general hypothesis exist in the southern part of Staten Island. In the vicinity of New Dorp there is a plain which looks very much as if it might have been constructed beneath the surface of the sea; but inland it does not terminate as a shore terrace should. If it be conceived that the waves of the sea beneath which it was deposited, beat against ice instead of land, the relationship would seem to be explained.

It may be said in this connection that while in general it is true that the ice extended farther to the south in valleys than on adjacent highlands, that this is true only where the valley concerned was above sea-level. Where it was below sea-level, the ice, instead of extending further forward in the depression, probably receded, forming a re-entrant angle in the margin of the ice. This would quite certainly be true in the later stages of the history of the ice sheet. Thus it might be that the south end of the marsh area between Jersey City and Newark was a shallow bay, constituting a re-entrant angle in the ice, at the same time that the ice occupied the valley further north in the vicinity of Englewood. It is possible that in the closing stages of the ice epoch, the ice at this latter point might have become stagnant, giving rise to the phenomena that have been referred to in that area.

The buried soils which occur about Palisade ridge have little significance in this connection, as may be inferred from statements already made. That at Cavan's Point is believed to have been buried by human agency. That at Newark bay, chiefly or wholly by the wind. That at Hackensack is so low as to show that the land was higher once than now, or at any rate more elevated than at a subsequent time, and that this elevated condition was succeeded by a period when the land stood at least ten feet lower than at present. This inference is necessary only in case the sand covering the buried soil at Hackensack be marine. If the region is now sinking, the buried soil here indicates several oscillations of surface of very slight extent.

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YELLOW LOAM.

At many points on the Palisade ridge, as well as at various other points in the State, the uppermost part of the drift is so unlike that beneath, as to suggest a difference in origin. The most conspicuous phase of drift on the Palisade ridge which seems to be separated from the main body of the drift, consists of irregularly-distributed loam. In many places, but not everywhere, this loam is sharply separated from the underlying drift. In color, it is generally yellowish, or yellowish brown, closely resembling, in this respect, the lighter-colored soils derived from trap rock. In texture, it varies from sandy to clayey. It sometimes contains pebbles, and even bowlders, though neither are common. They are generally of material foreign to the Palisade ridge. Where the loam contains rock fragments which may have been derived from the local formations, as is sometimes the case, they are generally angular. Frequently there are bowlders at its

Fig. 11.
Yellow loam in a depression in the surface of till.

very base, partially in it, and partially in the subglacial till which lies beneath. Bowlders in such positions are often glaciated. In its typical development, the loam is never distinctly stratified, nor does it ever show foliation such as frequently characterizes the subglacial till.

Distribution.—The loam is found at various points throughout nearly the entire length of the ridge. It nowhere has its typical development at an elevation of more than 240 feet, and, north of Bulls Ferry, it nowhere occurs on the crest of the ridge in such development as to be certainly identified. South of this point, where the ridge is lower, it is found both on the slopes and on the crest. Within the general area of its distribution, its development is irregular and discontinuous. Within the limits of the area where it exists, it covers less than half the surface, though it does not always possess very sharply-defined characteristics. It is absent from steep slopes,

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but is present on gentle ones, and on flat surfaces, and is particularly prone to occupy depressions in the surface of the underlying drift.

From the State line southward to Tenafly, the loam occurs in only a few places. From Tenafly to Highwood, it is frequently present on the lower slope of the ridge above seventy feet, but it nowhere runs above the upper limit specified above. At many points between Tenafly and Highwood, where its presence is suggested, its identification is rather uncertain, or perhaps better, its correlation with the more typical loam from the south is uncertain. Between Highwood and Englewood, the loam affects much of the lower west slope of the ridge, becoming more and more distinct to the southward. It here overlies till, and contains very little stony material.

Along the more eastern of the two north and south roads between Englewood and Nordhoff, the loam is well developed. It here contains occasional Triassic sandstone fragments, which are unworn, and some trap and gneiss bits, but none of the stony material is striated. In this latitude it does not rise above 140 feet, nor does it exist below a level of forty feet. South of Nordhoff, to Leonia, the loam is less continuous than further north. Its limits in altitude are the same as those just noted. From Ridgefield to New Durham, the yellow loam has little development. South of New Durham, and from there to Bergen Point, it has a discontinuous development from the base to the top of the ridge, frequently containing stony material, but in no case stones which are striated. South of Pamrapo, on the third avenue west of the Central railroad, the loam is well exposed in road cuts, showing its relations to the till below, and illustrating the fact that it fits into and fills depressions in the surface of the till. This relationship is indicated in Figure 11. The loam is also present at a few points on the east side of the ridge. This is true only where the lower slope of the ridge is gentle, and on this face of the ridge it has nowhere been distinctly identified above an elevation of eighty feet.

Relations to underlying formations.—The loam overlies both till and stratified drift. In a single case it was seen to rest directly upon the surface of rock. Where it overlies till, there is usually a sharp line of demarkation between the two. Where it overlies stratified drift there is sometimes a distinct line of separation, but there is frequently a thin transition zone, rather than a sharp line, between the two. It is found on till of both the red sandstone and trap types,

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and it is found both where the underlying rock is sandstone and where it is trap.

In a few places the loam sustains a less simple relation to the underlying till than that of mere superposition. In one place a tongue of the loam one foot and less in thickness and nearly ten feet in length was seen to project laterally from the surface layer of loam into the till. This is illustrated in Figure 12.

At another point the loam appears to be mingled with the till in such wise as to indicate the presence and operation of powerful mechanical force after the loam was deposited. Masses of loam of irregular shape are included in the till. One instance of this was observed near Englewood.

The loam overlies till much more commonly than stratified drift. Its identification in the former position is much easier than in the

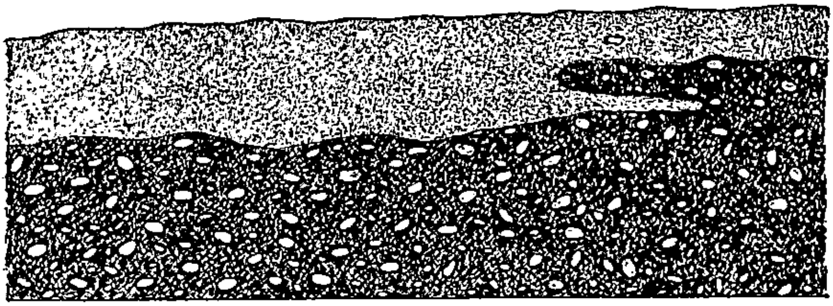

Fig. 12.

Loam infolded with till, three blocks south of the station at Leonia, at an elevation of 100 feet.

latter, because of the greater sharpness of its definition, because of its greater unlikeness to the till, and because loam somewhat comparable in character, but perhaps different in origin, is frequently found on the surface of flat-lying deposits of stratified drift. The thickness of the loam is slight. It nowhere exceeds eight feet, and its average is perhaps not more than three feet.

Chemical condition.—The chemical condition of the loam is comparable to that of the uppermost three feet or more of the drift where the loam is absent. It is thoroughly oxidized, as its color indicates. It is nowhere calcareous.

Characteristic sections and local details.—1°. One mile southeast of Closter, on the road leading southeast from the depot, yellow loam is well exposed in a ravine at an elevation of 150 feet.

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2°. Two-thirds of a mile southeast of Cresskill, at an elevation of seventy feet, on the road leading up the ridge, temporary exposures (1893) showed three feet of yellow loam over stratified sand. Where exposed, there was no stony material present. The sand and the loam were separated by a distinct line.

3°. On the first road leading to the crest of the ridge south of the above, an exposure of five feet of loam occurs at an elevation of 200 feet. A few stones are present in the loam, but there are no stones which show evidence of ever having suffered glaciation. The line of separation of the loam from the material below is not distinct at this point.

4°. The kames east of the Northern Railway of New Jersey, one-third of a mile north of the Highwood station, have a coating of yellow loam which perhaps (?) is to be correlated with that on the ridge. It is quite free from stone, except at its very base, where it becomes slightly mingled with gravel. The loam shows no structure.

5°. A few yards east of the Highwood station, at an elevation of about eighty feet, the loam is exposed to a depth of three feet. It fits into the irregular surface of the till, with a reasonably distinct line of separation. It is stoneless and structureless.

6°. At Englewood, six blocks east of the old railway station on Palisade avenue, the loam has a depth of five feet, and is more clayey than is its habit. The line of separation from the till is not sharp. It contains some stony material, mostly foreign to the ridge. None of it is striated so far as seen.

7°. On the road from Englewood to Nordhoff, one block south of Palisade avenue, a six-foot exposure shows loam which is more sandy than is its wont. It is here that the loam seems to be mingled with the till in such wise as to indicate the presence of a mixing and moulding agent after the deposition of the loam. Masses of loam a foot or so in diameter, and of irregular shape, are involved in the till, which distinctly shows foliation. It is in this latitude that the loam reaches its greatest height, 240 feet.

8°. Five blocks south of Palisade avenue and one block east of the Englewood-Nordhoff road, four feet of yellow loam is exposed, containing sandstone slabs. The slabs are generally at the lower limit of the loam, which is here somewhat loose in texture.

9°. East of the Nordhoff station, at an elevation of forty or fifty feet, temporary exposures (1893) showed three and a half feet of

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stoneless yellow loam over till. A sharp line of separation marked the junction of the two, the loam being noticeably less compact than the till.

10°. Three blocks south of the station at Leonia, at an elevation of about 100 feet, the yellow loam is found to a depth of five to eight feet. A fresh exposure (1893), 110 feet long, with clean, vertical face, showed that the loam rarely contains a pebble. In the whole of this distance, one rounded quartzite pebble, and one angular piece of sandstone were shown in the exposed face of the loam. The till beneath is distinctly red. It was at this place that a tongue of loam was seen to be involved in the drift, as illustrated by Figure 12.

11°. One-half mile east of the depot at Ridgefield the yellow loam is seen to lie directly on the rock in the road cut on the west side of the brook. The elevation is seventy to eighty feet.

12°. The northernmost exposure of the typical yellow loam near the summit of the ridge was observed at Bulls Ferry, where it occurs at an elevation of 170 feet above tide, without stony material. It has a loose texture. Its relations to the till below could not be seen. The exposure is on the south side of the road leading to the foot of the palisade.

13°. At Stevens Point, the yellow loam has a thickness of four to six feet. It is exposed on the east and northeast sides of the hill, at an elevation of nearly 100 feet. It contains occasional rounded pebbles of gneiss and trap, but, so far as could be found, no striated material. The exposure seen was not sufficiently fresh to determine whether or not there was a sharp line of separation between it and the till.

14°. At the gravel pit near the west entrance of the Erie railroad tunnel, at an elevation of forty feet above tide, yellow loam is found of greater compactness than is its wont. It contains some angular trap and Triassic sandstone pieces, and rounded gneiss. The line of separation of the loam from the till below is not sharp, but the zone of transition is narrow.

15°. East of Marion station, along the Pennsylvania railway, at an elevation of about 100 feet, deep cuts show till covered with about three feet of the yellow loam in typical development. Its texture is loose, and stony material is rare, none being stratified. The relation of the loam to the underlying till is not well shown.

16°. South of Pamrapo to Centreville (Twentieth street), the yel-

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low loam is generally present. South of the latter point it is less frequently present. The loam at these low levels presents some features which do not seem to correspond altogether with those of the typical yellow loam.

17°. Three-quarters of a mile south of the Greenville depot of the Central Railroad of New Jersey, at an elevation of twenty to thirty feet, a cut five to eighteen feet in depth shows yellow loam with a tendency to sandiness, overlying till. The loam has a maximum depth of eight feet, but its average thickness is not more than half this amount. Where deepest, it sometimes shows stratification in the lower part. It here contains "buckshot," or small iron concretions. At no other point on the Palisade ridge was the loam observed to have these iron concretions. East of Cedar Grove, on the Caldwell branch railroad, at an altitude of 300 feet, the yellow loam carried similar concretions. The relation of the loam to the underlying till in the cut at this point (Greenville) cannot be definitely stated, as the line of contact is not well exposed. Some flat-lying sandstone slabs are present in its lower portion.

18°. South of the Saltersville depot, in a railway cut which is fully 1,200 feet long and eight to twenty feet deep, at an elevation of twenty to thirty feet, yellow loam is exposed, over till. The loam is three to four feet in depth. The loam is also frequently exposed west of the Central Railroad of New Jersey, in road cuts. It is often sharply separated from the underlying till. The road cuts often show the manner in which it fits into the irregular surface of the till. The loam is found at the southern end of the ridge, at Bergen Point, in irregular patches, being often altogether absent. It was not observed to be stratified in this locality, though it was found below an altitude of thirty feet.

19°. On the east side of the ridge, yellow loam is seen at a few points. The till (?) on the lower east slope of the ridge, near Alpine, is covered with loam to a maximum depth of six feet. This is at an altitude of about eighty feet.

20°. In the latitude of Englewood, near the east base of the ridge, the loam is found covering till (?) at an elevation of about fifty feet.

21°. Still further south, at Edgewater, the loam covers the surface of the gentle slope above the level of stratified drift, up to the vertical trap face. Something very similar covers the stratified drift

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at lower levels. Trap talus of post-glacial origin sometimes conceals the loam near the base of the bluff.

There are other deposits of yellow loam in similar situations west of the Palisade ridge. While it is no part of the purpose of the present paper to discuss these latter deposits, reference may be made to the fact that they are well developed at various points in the vicinity of Newark, up to altitudes of 200 feet.

There are other surface formations on the Palisade ridge and adjacent to it which resemble the yellow loam more or less closely. At the western base of the ridge, on the low flat or flattish land, there is frequently a fine yellowish sand bearing some resemblance to the loam, but often differing from it in showing stratification, and in being more sandy. This does not rise above the levels of stratified drift. The plain at Highwood and south, has a coating of three feet of loam, closely simulating the type of loam under discussion. Its texture is loose. Except at its base, where it grades into the stratified drift of the plain, it contains few pebbles. Just below Edgewater there is sandy loam at low levels, down to twenty-five feet, which is comparable to that at higher points. It is here less clayey, and much more loess-like, so much so, indeed, that one instinctively looks about for loess fossils. None, however, were found. Again, the surface of the trap till, after it has been weathered, sometimes resembles the yellow loam in color, but is essentially heterogeneous in composition, contains more stony material, and is more compact.

The origin of the loam.—The origin of the loam is problematical. Several hypotheses have suggested themselves, and the material has been examined with reference to them. It might be conceived—1°, that the weathering of the surface of the subglacial till gave rise to it; 2°, now and then a patch of it is in such a situation as to suggest that it may be the result of accumulation from post-glacial wash; 3°, some of it is of such a character as to suggest the possibility of its being a post-glacial deposit made by the wind; 4°, its relations are sometimes such as to suggest that it is a deposit made by water on the surface of the drift after the ice retired. This would involve a submergence of the land up to such elevations as loam having such an origin exists; 5°, it may be that the yellow loam is of superglacial origin, consisting of material which was accumulated on the ice, and which was let down upon the surface of the subglacial drift when the ice melted.

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The facts which have already been enumerated respecting the loam under consideration are such as to eliminate several of these hypotheses, if the loam be a unit in origin. But it is quite possible, so far as present knowledge goes, that different parts of it originated in different ways, and that all these various suggestions concerning its origin may be true for limited areas. In considering its origin it should be remembered—1°, that it is discontinuous; 2°, that the altitudes at which it occurs are variable; 3°, that it is not found at the greatest altitude at either end of the ridge, and that it is much better developed at low altitudes at the south end of the ridge than at corresponding altitudes farther north; 4°, that it occurs in various topographic situations, being sometimes on slopes, sometimes on flat surfaces, and sometimes in depressions; 5°, that it rests, now on till, with perfect indifference to the constitution of the same, now on stratified drift, and now on the surface of rock; 6°, that the line of demarkation between it and the subjacent drift is often sharply defined; 7°, that this line of junction is sometimes such as to indicate that the underlying surface was affected by the action of water before the deposition of the loam at that place; 8°, that it sometimes contains stony material; 9°, that this stony material is generally (*a*) unworn, and (*b*) predominantly foreign—that is, much of it has come from beyond (north and west of) the Palisade ridge, and from beyond the valley which lies immediately west of it.

The lack of continuity of the loam bears against the suggestion that it is the product of post-glacial weathering of subglacial till. There is no manifest reason why till should be weathered at one point in a certain way and to a certain depth, while at other adjacent places nothing of the same sort has taken place. Furthermore, at many points where the drift has been manifestly weathered and leached of soluble ingredients, mainly calcium carbonate, the surface till is not manifestly different in color from that beneath. Again, the sharpness of definition between the loam and the underlying till at many points is not what would be expected if the loam were the product of the weathering of the till beneath. The lower limit of weathering is not so sharply defined. The loam is much the same whether it lies on solid rock, on trap till, or on red sandstone till. This could hardly be the case if it were the result of post-glacial weathering of subglacial till. Still again, its stony material, where such exists, is often markedly unlike the stony material of the underlying subglacial till.

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The stony material of the loam is in stronger contrast to that of the till below, than is the stony material of different horizons of a continuous bed of till, so far as seen anywhere within the whole State. The absence of striæ upon the stony material of the loam, and such striæ were not seen in a single instance, might be explained on the basis of post-glacial weathering, were not the stones so frequently of durable material. On the whole, it must be concluded that the loam has not originated from post-glacial weathering, for it does not bear the marks which must serve as the criteria of such an origin. It is, nevertheless, quite possible that superglacial weathering of certain portions of the till may have given rise to a loamy material which has some resemblance to the loam here under discussion.

The fact that in many cases the loam contains coarse, stony material, even though the amount of it be small, is fatal to the suggestion that it is a deposit made by the wind in post-glacial time. Apart from its constitution, there is nothing whatsoever in its distribution, or in its topography, to strengthen this hypothesis as a general explanation of the loam. In proximity to areas of fine, sandy material, it is still possible that deposits of loamy material may have come into existence at the hands of the wind.

If all the yellow loam be one in origin, its topographic distribution is such as to preclude the idea that it is a post-glacial deposit made by the sea, unless there have been much more considerable post-glacial changes of level than we yet know. It is nevertheless true that this may have been its origin in certain situations, especially at low levels, for there seems to be good evidence of submergence to the extent of twenty or thirty feet during the closing stages of the ice epoch. But no submergence of which there is independent evidence can account for the loam at the higher levels at which it occurs.

The especially-good development of loam on the lower part of the ridge near its southern end seems consistent with its marine origin at this point, though it often lacks the stratification which might be expected in a deposit thus made. On the other hand, it is to be said that the loam is often too shallow to have retained distinct stratification, even if it once existed, for its thickness frequently does not exceed the depth to which weathering is effective. The uppermost three or five feet of material of any stratified drift deposit does not generally give evidence of stratification. From the facts cited on page 208 *et seq.*, it would seem that much of the area below Jersey City,

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now covered by loam, may have been temporarily below the sea as the ice was disappearing. Since the loam is the uppermost material over some parts of the territory which may have been below sea-water, the conclusion that the loam in such situations may be of marine origin is not irrational, if this low-level loam only be considered. The loam at low altitudes, too, is more likely to show signs of stratification than those at higher.

While, therefore, the marine origin of some of the low-level loam seems possible, when this part of the loam only is considered, a difficulty is encountered in the fact that the high-level loam and the low are so similar as to suggest community of origin; and of post-glacial submergence sufficient to account for the marine origin of the high-level loam we have not only no independent proof, but no independent evidence.

None of the foregoing objections with reference to the origin of the high-level loam can be urged with equal force against its superglacial origin. The fact that the stony material is mostly of distant origin, that it is largely unworn, that the pieces are often slab-like in form, and that they commonly lie on their flat sides, is favorable, so far as it goes, to the hypothesis of the superglacial origin of the drift. In an earlier report * it was indicated that the rock material of superglacial drift should have many of the characteristics which are here found. It was further indicated that fine earthy material and sand might accumulate in abundance upon the surface of the ice, carried thence by winds from the region outside the ice. This process of dust and sand accumulation on the ice must have been co-extensive in time with the development and movement of the ice itself. Such parts as escaped removal at the hands of superglacial drainage would be likely to be in patches. This loamy material would be likely to be mingled, finally, with such stony material as may have become superglacial during the process of the dissolution of the ice sheet.

When the ice finally disappeared, this mixture of material, the sand and dust which had been blown upon the ice, and the unworn stony material which had been englacial, and finally became superglacial by reason of surface-melting, would be let down upon the surface of the subglacial deposits. Under such circumstances, the superglacial loam might have such a distribution as that of the yellow loam under

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* See Annual Report 1892, page 50.

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discussion. It might rest on slopes or on flat surfaces, and it would be found in patches only.

If it be thought that the amount of material is an objection to this hypothesis, it should be remembered that in addition to the dust blown upon the ice directly, rain and snow, both of which helped to make the ice sheet, bring down dust from the atmosphere. It is believed that not less than 100 tons of meteoric dust daily enters our atmosphere.* Much of the earthy material embodied in the ice during its accumulation by one or another of these processes, must finally have become superglacial. This would be true of all that which was imbedded in the ice which disappeared by surface melting. In confirmation of the possibility of such an origin, it may be mentioned that existing glaciers often have a considerable covering of comparable material upon their surfaces. Nordenskiold found dust in considerable quantities in circular cavities on Greenland ice, near the edge, and for considerable distances inland.† He was convinced that the dust in the isolated patches could not have been washed down from the mountain regions above, since the same sort of dust was found somewhat uniformly over the surface far inland, at elevations greater than that of projecting masses of rock, and since it was frequently as thick upon the tops and slopes of ice knolls as on the more even surface between them. He concluded also that it could not have been distributed over the surface of the ice by running water, and that it could not have arisen by being pressed up from the bottom of the ice, and that it must therefore have been deposited by the wind. Metallic iron was found in this dust, indicating that part of it had a cosmic origin. The fact that near the edge of the Greenland ice the dust was found in abundance at certain points only, is of moment. Were the ice to disappear, the dust would be left in patches, just as is the yellow loam under consideration.

It will be readily seen that the conditions for accumulating dust upon the ice sheet of North America in glacial times were very much better than those for the accumulation of dust upon the Greenland ice-sheet to-day, since in the latter case there is relatively little land uncovered by ice, in proximity to it.

The hypothesis of the superglacial origin of the loam would involve the following sequence of events:

* Langley, "Nature," Vol. 29, page 324, 1884.
† "Nature," Vol. 38, page 304; Vol. 29, page 39.

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As the snow which was to make the ice accumulated, dust was accumulated at the same time. This entered the snow mass which was to become the ice mass, partly in the flakes of snow, partly in the drops of water, and partly by being blown upon the surface of snow more or less constantly, even if in but small quantities. To the dust arising by these processes was added such cosmic dust as fell upon the snowfields. As the snow was compacted into ice, these materials found themselves within the ice. They were carried forward with the ice as it moved. Conditions for the rapid accumulation of dust on the surface were better near the edge of the ice than elsewhere, because the edge of the ice was in proximity to land surfaces which were free from ice, and which could have contributed the dust. The fact that the climate must have been cold near the edge of the ice would have hindered the growth of vegetation in the marginal zone, and the lack of vegetation, or its paucity, would favor the transportation of surface materials by the wind. The differences in temperature along the margin of the ice, as the result of its presence, would be likely to occasion a considerable degree of atmospheric circulation along this zone, which would be favorable for the accumulation of dust upon the ice so far as currents were toward it.

As the surface of the ice melted, the dust of the part melted became superglacial. When a hundred feet of the surface had melted, the dust, together with the stony material which had been contained in this layer of ice, was at the surface—superglacial. Though the ice was probably never very thick at its edge, the dust which was upon it may have represented the dust which had been in a considerable body of ice which had been melted during the progress of the ice through the zone of wastage.

Superficial streams, and superficial drainage which did not organize itself into streams, no doubt transported much of this superglacial material from the surface. The stream may likewise have concentrated much of it in favorable localities, as observed in Greenland. Wherever it was not carried away, it must have been let down upon the surface when the ice melted. Some of it must have been destroyed by extra-glacial drainage, immediately after its deposition, but some of it would be likely to have remained to the present time, distributed somewhat irregularly, and with some measure of indifference to topography, upon flat and sloping surfaces.

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Comparable material which is believed to have a similar origin is found overlying drift in other places, as in the vicinity of Madison, Wisconsin.*

This hypothesis seems to fairly account for the indifference with which the loam lies upon the rock, red till, or trap till. It seems to account fairly well, or at least not to be inconsistent with, the sharp line of demarkation which often separates it from the drift beneath. It does not explain the presence of the loam on stratified drift. The loam in such positions may have another origin. It does not appear to explain the failure of the loam upon the crest of the Palisade ridge, and it does not, as thus far stated, explain such involutions of loam in the till as are noted on page 213. But this difficulty may be more apparent than real. It is quite within the range of possibility that after the loam was deposited at a given point a temporary advance of the ice might bring about such relations as those indicated.

Apart from this loam, and from some materials which have not been described in this connection, but which somewhat resemble it, nothing has been found upon the ridge which has been confidently interpreted as of superglacial origin, though it may be that some of the loose, sandy material often present along the lower slope of the western face of the ridge is to be put in this category. The till of the ridge is for the most part compact, generally contains an abundance of striated material, is frequently foliated, and in general has the characteristics of subglacial till, except for two or three feet, more or less, at the surface. This thin surface layer is believed to have assumed its present form in post-glacial time, as the result of weathering.

The extremely-thin body of drift which covers the crest of the ridge in many cases—indeed, its almost complete absence at many points on the crest of the ridge—is in itself proof that at such points at least there was little or no superglacial material. It may be here added that the frequent barrenness of the rock in other parts of the State, notably in Sussex county, is likewise proof of the absence, or extreme paucity, of superglacial material in that region, and this is true in spite of the fact that both the Palisade ridge and Sussex county, considering the country over which the ice which operated

*See note by the senior author. Proceedings of the American Association for the Advancement of Science, 1893, Vol. 42.

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there must have come, are favorably situated for the existence of superglacial drift. If superglacial material had any such development as has been sometimes supposed, it is not easy to see why it should have been so completely absent from areas especially favorably situated for its presence.

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SECTION VI.

LAKE PASSAIC.—AN EXTINCT GLACIAL LAKE.

BY ROLLIN D. SALISBURY AND HENRY B. KÜMMEL.*

INTRODUCTORY STATEMENT.

In his annual report for 1880 Professor Cook made mention of a glacial lake which existed in the upper part of the Passaic drainage basin during the later part of the glacial epoch. The lake was stated to have covered the area of the Great swamp, the Black meadows, the Troy meadows, the Lee meadows, the Hatfield swamp, the Great Piece swamp and the contiguous low land. A number of localities where evidences of the lake's existence were thought to occur, were cited. Concerning these Professor Cook says:

"The upper portion of the terminal moraine from Morris Plains to Summit has been modified by the action of water and has assumed the form of a long and broad, level-topped bank, dividing the valley on a northwest and southeast line. * * * The upper level, corresponding to that of the moraine in the Morris plains, and the level from Morristown to Madison has a mean elevation above tide of 385 feet. It is recognized in the flat-topped hills northeast of Boonton and south of Montville, in the beautiful terrace cut by the Boonton Branch railroad, north of Montville and on the eastern side of the highlands at the west border of Pompton Plains. It has been traced around the mountain to Bloomingdale; the sand hills near the rubber works are near the same height, and they are, probably, part of the same formation. The high terrace near the Ponds Reformed Church and Oakland, in Bergen county, is also nearly as high and may belong to it. On the Second mountain, two miles southeast of Pompton Furnace and at Upper Preakness, it has a mean elevation of 340 to 360 feet. There are indistinctly-defined levels at the same elevation at Cedar Grove, at Caldwell and at Centreville, in Essex county.

* In his annual report for 1892 the senior author made a brief statement with reference to Lake Passaic. Most of the facts brought to light since that report was published have been worked out by the junior author. Many of the inferences embodied in this report are based upon this more recent work, which exceeds, both in amount and importance, all that had been done before.—*R. D. S.*

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These latter are also on the western slope of the Second mountain. Terraces have been observed at the same height on the Hook mountain from ten to fifty feet below the crest line. No attempt has been made to trace out fully this high terrace."

After speaking of certain terraces and drift hills at lower levels, Professor Cook says, referring to both the higher and lower terraces:

"In explanation of their origin we may consider these levels or terraces as marking the successive heights at which the waters stood in this great valley after the retreat of the glacier had begun, during the Champlain epoch, and continued through the Terrace epoch. The melting of the ice in the valley and on the highlands north and west produced an enormous volume of water which filled the great basin, forming a lake thirty miles long and eight miles wide. The top of the terminal moraine was leveled off and a part of its material was carried southward and silted on the bottom of the lake, where are now the Great swamp and the Dead river flats. The gaps through the trap-rock ranges at Paterson and Little Falls were filled with drift by the glacier. The excavation of these drift-filled gaps began as it disappeared, and the outlet again followed the line of the old channel into the red sandstone country on the east. * * * The upper terrace is most plainly marked on the surrounding hill and mountain sides. It was the broad, pebbly shore of a lake, into which poured torrents of water from the neighboring hills, carrying cobblestones and bowlders into it and depositing them so confusedly together as in places to resemble a glacial deposit. The accumulations of drift at Bernardsville and Basking Ridge may have come in that way. The lower level-topped hills mark the more quiet waters as they subsided and shrunk into narrower limits. Pompton Plains and the flats along the Passaic and Whippany rivers mark their further contraction into irregular-shaped ponds within the bounds of the old lake basin. The erosion through the drift at Little Falls was probably the gradual wear of the Terrace epoch until the hard trap-rock reef was reached. At that level the drainage stopped. The slow work of excavation through this barrier and the recession of the falls have been in progress since that time, and a gorge 300 feet wide at the east, narrowing westward to the falls, and between thirty and forty feet deep, has been cut back about 600 feet in the rock."

Because of its hydrographic position, the lake was called Passaic.* Although the boundaries of the lake were not traced out, its supposed level was determined at a few points. On the strength of these determinations, the area of the lake was represented on a map accom-

*Annual Report of the State Geologist of New Jersey, 1880, pages 61-64.

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panying the report referred to. The average altitude of the border of the lake was stated to be 385 feet.

Later, Professor W. M. Davis visited the region, and observed what he interpreted as shore features at a number of points, but never published his observations. At the commencement of our work, he kindly made known to us three several localities near Morristown, where phenomena which he regarded as shore features had been seen by him. In his further studies, Professor Davis encountered what seemed to him grave difficulties in the way of the hypothesis which Professor Cook had put forth.

Other geologists have visited the region at one time and another for the purpose of studying the supposed lake. Some of them at least remained sufficiently long to convince themselves that, if the lake existed at all, its relics were difficult of discovery. So far as we are aware, no publication was made concerning the lake between the date of Professor Cook's and our own.

Through the detailed survey made in the process of mapping the surface geology of this region, many new facts readily explicable upon the hypothesis of a glacial lake were brought to light. Some of these facts were gathered during the field season of 1892, and in the annual report for that year * they were presented and discussed by the senior author of this paper. From this report it will be seen that data then at hand were sufficient to demonstrate, beyond reasonable doubt, the existence of Lake Passaic. But while the data published in 1892 were sufficient to demonstrate the existence of the lake, they were hardly sufficient to afford a clear insight into its history. That the lake existed was known, that it had a complex history was surmised, but its details had not been worked out.

Further study of the lake was undertaken during the summer of 1893, more especially by the junior author of this paper, for the purpose—1°, of gathering new data; 2°, of correlating more perfectly the data already known; 3°, of explaining certain apparent contradictions and deficiencies; 4°, of working out the different stages in the lake's history, and 5°, of determining the possible changes, especially deformations, which the lake basin may have undergone since the water disappeared from it. Two months of field work during the autumn of 1893 were given to this work. During a part of this time, assistance was received from Mr. C. F. Sproul, an experienced sur-

*Pages 126–144.

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veyor and topographer, by whom were drawn the topographical sketches of shore features accompanying this paper, and with whose aid the heights of the various shore features were determined.

PRELIMINARY CONSIDERATIONS.

The trap ridges known as the Watchung or Orange mountains rise in long crescentic curves three and four hundred feet above the general level of the Triassic sandstone lowland on either side of them. The crescents are convex towards the southeast. The horns curve towards the northwest and connect with the crystalline schist or gneiss highlands. The basin which is thus formed between the highlands on the northwest and the trap ridges on the south, southeast, east and northeast, is now drained in a very roundabout way by the Passaic river, which finally escapes across the trap ridges at Little Falls and Paterson. The height of the river where it crosses Second mountain at Little Falls is 158 feet.

Leaving out of account the low line of drainage along the Pompton river at the north, there is no other break in the rim of the basin lower than 331 feet. At this height there is an outlet across the trap mountains at Moggy Hollow, about two miles west of Liberty Corner, in the southwestern part of the basin. The altitude of the Great swamp is about 230 feet, and therefore about 100 feet below the Moggy Hollow outlet. Within the basin thus inclosed, rise several smaller trap ridges, of which Long Hill, extending from Chatham to Basking Ridge, is the most important. The trap hills near New Vernon (south of Morristown), Livingston, and Whitehall and one or two hills of Triassic conglomerate or hard shale near New Vernon rise about two hundred feet above the surrounding lowlands. Between Chatham and Morristown the terminal moraine forms a ridge 100 to 250 feet above its surroundings. This ridge divides the topographic basin into two parts.

Such being the drainage and topography of this region, there is *a priori* reason for believing that when the ice sheet blocked the outlet of the Passaic at Little Falls or Paterson and filled the Pompton valley to the north, a lake was formed in front of the ice, in the basin between the gneiss highlands on the northwest and the crescentic trap ridges on the southeast, unless at that time there was a gap across the

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trap ridges south of Little Falls. As will be shown later, well borings prove that there is a deep drift-filled gap across the trap ridges near Short Hills and Millburn. The depth of the rock bottom of this gap renders it certain that a large part of the pre-glacial drainage of the present Passaic basin was across the trap ridges at this point. The pre-glacial drainage of the northern part of this basin probably escaped by the gaps at Little Falls and Paterson. The two drainage systems could have been separated by no more than a low divide.

A part of the drift in the Short Hills-Millburn gap may be first glacial. If any considerable proportion of it is of this age all the inter-glacial drainage may have escaped via Little Falls and Paterson. If this was the case, it is possible that the drainage held its course beneath the ice for a shorter or longer time after the edge of the same had reached the Little Falls outlet across the trap ridge; but it is difficult to believe that such could have been the case, after the ice had advanced any considerable distance beyond Little Falls. It is well-nigh incredible that such a sub-glacial drainage outlet could have persisted until the ice occupied the position marked by the terminal moraine at Morristown and Madison.

If, on the other hand, all or by far the greater part of the drift in the Short Hills gap is last glacial, as is more probable, the lake would not have been formed until the ice had closed this outlet. A small lake, however, might have existed in the basin of such stream as flowed through the Little Falls gap, after the ice had closed that outlet. Such a lake, if it existed, must have been shallow, as it would have overflowed the low divide into the basin of the river, which flowed through the Short Hills-Millburn gap. When the ice had advanced to the line of the terminal moraine it must have filled the Short Hills gap. It would seem, therefore, that Lake Passaic must have existed during and after the time when the ice held this position.

Barring the outlets at Little Falls and Paterson, the lowest point on the rim of the basin which inclosed the lake is a notch near Liberty Corner, at an elevation of 331 feet. Through this notch the lake, if it existed, must have drained.

As the glacier retreated from the position of the terminal moraine the lake must have increased its area by occupying those parts of the basin from which the ice successively withdrew, until at length its waters were able to escape either under the ice or through the gap at Little Falls. When the recession of the ice opened the Little Falls

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outlet again the water of the lake must have fallen promptly to the level of the outlet. If this outlet was much higher than now, the lake must have continued a diminished existence until the outlet had been cut down nearly to its present level.

If the lake existed, as above outlined, it was naturally divisible into two parts—the extra-morainic and the intra-morainic. The former occupied that part of the basin lying southwest of Morristown, Madison and Chatham, extending to Basking Ridge and Union Village. It included the Great swamp and the surrounding areas below the level of the outlet at Moggy Hollow. This part of the lake had a longer, or at any rate, a more interrupted history than the other, and so far forth the record of its existence should be more distinct. The intra-morainic portion of the lake extended from the moraine on the southwest to Boonton, Montville and Pompton Plains on the north, to Caldwell on the east, and to Summit on the south, including Black meadows, Troy meadows, Great Piece meadows and Hatfield swamp, besides considerable areas of higher ground.

If Lake Passaic existed, that fact ought to be capable of more or less complete proof. Even if its life were short, the lake must have left sufficient record of itself to place the fact of its existence beyond question.

This record would be expected to consist of (*a*) shore features, (*b*) berg deposits, (*c*) lacustrine deposits, (*d*) something of a difference between the pre-lacustrine surface formations within and without the lake area, and (*e*) a difference in the nature of the till within the lake basin and that without. These differences last mentioned may be very slight; they may not be recognizable at all points, and may be difficult of detection at most; yet they might reasonably be expected to exist. The presence of unmistakable shore features, even in the absence of the other lines of evidence, would prove the existence of the lake. If shore features were altogether absent, all the other lines of evidence might be inconclusive, since berg deposits, lacustrine deposits, lacustrine-like modifications of till and of other surface formations may be simulated more or less closely by other agencies. While no one of these other lines of evidence might be conclusive, their combined testimony might have great weight. Yet if the lake had so protracted an existence as to develop these various phenomena in such strength as to make them available in evidence, it could hardly have failed to develop recognizable shore features. The chief reliance

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must be placed on shore features. The other lines of evidence may have much corroborative interest and weight.

One of the principal conditions which control the development of shore features and lacustrine deposits is the time element. Other things being equal, a lake with a long life would bring about a better development of shore features and lacustrine deposits than one of briefer history. Relying on this principle, it is possible to make some inference concerning the length of life of an extinct lake from the degree of development of its shore features.

Another factor determining the distinctness of the shore features of lakes is their size. The larger the lake, the greater the sweep of its waves, and, other things being equal, the better the development of its shore features.

So soon as a lake is drained and its shore features are exposed to the ordinary agents of sub-aërial erosion, they may soon lose their distinctness. If, therefore, we find wave-cut cliffs and terraces sharp and distinct; spits, bars, beaches, and deltas with normal profiles, and but slightly gullied by post-lacustrine erosion, we may safely infer that post-lacustrine time has been short and that the lake was drained but recently. If, on the contrary, the shore features are indistinct, and if this indistinctness can be shown to be due not to lack of original development but to subsequent destruction, we must conclude that post-lacustrine time has been long.

If the history of an extinct lake was a complicated one, involving various stages during which the water stood at different levels, shore features may be preserved at various altitudes. From the nature and relations of these various sets of shore features, something of the history of the lake may be read. Under favorable conditions, the record of the events of a lake's life may be very complete. If shore features were distinctly developed at the successive levels of a lake, if they are well preserved, and if their relationship to each other is clearly and unequivocally shown, the history of the lake may be made out with great clearness and detail. In so far as the record is fragmentary, or in so far as these conditions are not all fulfilled, the history of the lake remains obscure in some or all its parts. It may be here added, in anticipation of that which is to follow, that the shore features of Lake Passaic are not, at most points, conspicuously developed, and that their obscurity is plainly not the result of subsequent erosion. We must infer that they were never well developed.

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Since the size of the lake was sufficient to have allowed of waves of several miles fetch, the meager development cannot be ascribed to the smallness of the lake. We therefore conclude that the life of the lake was short. The evidence is sufficient to show that the history of Lake Passaic was not a simple one, but the record is not sufficiently complete or definite to make it possible to decipher with certainty all its stages.

CLASSIFICATION OF SHORE FEATURES.*

Sea-cliffs.—Every impact of a wave upon the shore may break off some of the loose material. This is then swept away into deeper water by the undertow during the recession of the wave. Upon all but very incoherent material, the effect of the blow struck by the water itself is comparatively slight. But the wave is armed with cutting tools—the sand and gravel—which it hurls against the shore. By their help it is able to erode resistant shores. Vertically, the waves cut in a narrow zone like a horizontal saw. If the material above this zone of cutting is undermined, it may fall of its own weight, leaving a cliff at the shoreward margin of the cut. This cliff is called a wave-cut cliff or sea-cliff. The cliff is steep in hard, resistant rock, or may even overhang. In unconsolidated material, the slope is gentler, since in this case the retreat of the top of the cliff before the combined attack of wind, rain and frost, is more rapid in incoherent material than in hard rock. Since the cliff is determined by wave erosion, its base must be essentially horizontal, and must always stand at or about the level at which the waves are formed. Wave-cut cliffs are represented in figures 13 and 14.

The wave-cut terrace.—Bordering the cliff on the water side is the submerged bench, whose width measures the shoreward progress of wave erosion. This bench is called a wave-cut terrace. Its upper edge is coincident with the base of the cliff, and is therefore approximately horizontal. Its surface has a gentle inclination away from the cliff, and is frequently strewn with larger or smaller masses of rock which have fallen from the cliff. A portion of the eroded material

* In the following brief discussion of shore features, the classic discussion of the subject by Mr. G. K. Gilbert, has been freely drawn upon. Fifth Annual Report U. S. G. S., pages 75-123, 1885. Also Lake Bonneville, Monograph I., U. S. G. S., pages 23-89.

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may be deposited at the outer edge of the cut terrace, which is thus extended lakeward by a built terrace (Figure 15).

Cliffs and wave-cut terraces formed on a lake shore lose their distinctness when the lake becomes extinct. The base of the cliff is buried by debris falling and washing from above. The finer parts of such debris are carried out and deposited on the terrace. Thus, by

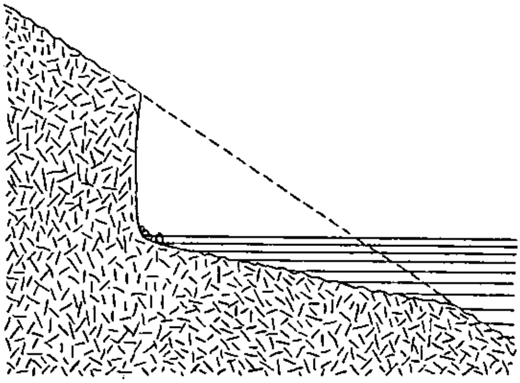

Fig. 13.
Represents a sea-cliff cut in resistant rock on a steep shore. (After Gilbert.)

virtue of the recession of the upper part of the cliff and by the accumulation of talus at its foot and further out on the terrace, the marks of wave action are gradually obliterated.

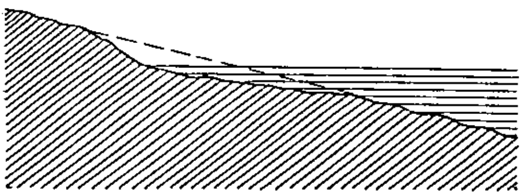

Fig. 14.
Represents a sea-cliff cut in less resistant rock on a gentle slope. (After Gilbert.)

In a lake, the principal movements of water are controlled by the winds. The tendency of the waves is to heap up the water against the shore. The surplus water escapes lakeward by an undercurrent, termed the undertow. In addition to the undertow, the waves, when striking the shore obliquely, set up a littoral current which tends in a

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direction harmonious with the movements of the waves. The finer portion of the detritus is kept in suspension by the agitation of the waves, and is carried by the undertow into deep water. The coarser material remains in the zone of agitation, and is transported along the shore by the joint action of the waves and littoral current.

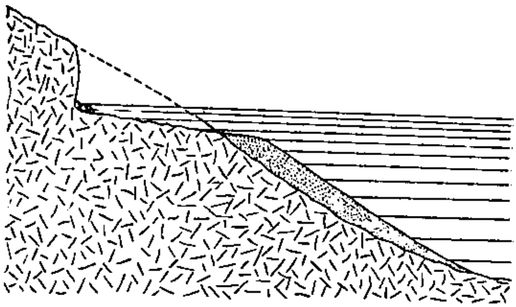

Fig. 15.

Wave-cut terrace extending outward from the base of the sea cliff, and bordered along its outer edge by a wave-built terrace. (After Gilbert)

The beach.—The shore drift in transit occupies a narrow zone, the upper margin of which is a little above the water-level. This deposit of shore drift is called the beach (Figure 16). It is the path along which shore detritus is constantly traveling. Sometimes the beach may encroach upon a wave-cut terrace, burying it by the drift which the waves and shore currents shift about under the varied conditions

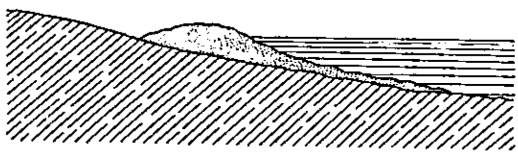

Fig. 16.

Cross section of a beach ridge (After Gilbert.)

of wind. The beach is continually receiving a fresh accession of shore drift, since it is within the zone of agitation by the waves. Were its supply of detritus cut off, it would soon be demolished by the waves which created it.

The barrier.—On gently-shelving shores, the zone of greatest agitation by the waves is not at the water's edge, but some distance out.

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The shore drift depending on the agitation for its transportation then follows the line of breakers, rather than the shore, and is built into a ridge at some distance from the lake's margin. The barrier (Figure 17) is to all intents and purposes a beach, save that it is separated from the shore by a strip of shallow water which may be transformed into a marsh and eventually silted up.

The littoral current which occupies the zone of shore drift and is an active agent in the transportation of shore detritus, is inseparably connected with an off-shore current, which occupies deeper water and is less impeded by friction. By reason of its momentum, the off-shore current does not follow all the minor curves of the coast but sweeps from point to point, dragging the littoral current with it. Wherever the littoral current, separated from the water-margin and therefore from the zone of agitation, passes into deeper water it is no longer

Fig. 17.
Cross section of a barrier. (After Gilbert)

able to move the shore drift. Deposition therefore takes place where shore currents diverge from the zone of wave action. This separation may occur in several ways.

The spit.—When the coast line turns abruptly landward, as at the entrance to a bay, the littoral current continues its direction and passes from shallow to deeper water. The zone of agitation follows the coast line, but the shore drift cannot follow this line because there is no littoral current to transport it. It cannot follow the littoral current into the deep water, for there is not sufficient motion to keep it in suspension. It therefore falls to the bottom. But the littoral current is continually bringing to this point a supply of detritus, and as a result a spit is constructed. So far as it is built, it serves as a road along which more detritus can be carried. Its direction is that taken by the littoral current. As soon as it is built up to such a height that the waves can move the particles of which it is composed, the forces which cause the construction of the beach and barrier become effective. Under their influence, the spit may be built above the mean water-level, when its cross profile corresponds to that of a beach.

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The distal end of the spit is always submerged. Its submergence is slight and its terminus abrupt, if the material of which it is composed be coarse, since coarse material is soonest dropped when the littoral current passes into deep water. Its submergence is greater and its terminus less abrupt, if the material of which it is composed be fine. The process of construction is very similar to that of a railroad embankment, the material of which is carted along the crest of the grade and dumped at the end. The proximal end of a spit connects with the shore and is continuous with a beach or terrace.

The bar.—If a spit is continued until its distal end reaches a shore, it is called a bar. The bar is continuous at either end with a beach or barrier. In all other particulars it is similar to a spit. It may connect an island with the mainland or with another island, or it may be built from one headland to another across a bay or the mouth of a small river. At the mouth of a river, the construction of a bar is antagonized by the outflowing current, and it is, therefore, largely submerged and more or less discontinuous.

The terrace.—The divorce between shore currents and wave action may take place by the divergence of the current rather than of the coast line. If the current diverging from the shore remains on the surface and retains its original cross section, and so its original velocity, a spit is formed. But if it remains on the surface and assumes a greater cross section, and therefore a diminished velocity, the shore drift is built into a terrace. The same result will be brought about if the littoral current descends as it leaves the shore.

The rate of transit of the shore drift depends upon the velocity of the current. Whenever or wherever the velocity is diminished, the supply of detritus may exceed the transportive power of the lessened current. In this event accumulation takes place. This accumulation does not occur at the end of the beach, as in the case of spits, but on its lakeward margin. In this way the beach is widened and advances lakeward. A wave-built terrace is the result. As already noted, a wave-built terrace may be formed on the lakeward margin of a wave-cut terrace by the accumulation of material cut from the retreating cliff, or from points in either direction along the shore. The internal structure of a wave-built terrace is characterized by a lakeward dip of the successive layers of sand and gravel (Figure 18).

The situation most favorable for the formation of wave-built terraces is the head of a converging bay up which the waves sweep with-

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out obstruction. Strong littoral currents are set up on each shore, which on meeting the strong undertow lose their velocity and deposit their load. At the head of the bay a curved bar is commonly first formed, to the lakeward face of which successive additions are made, and a terrace gradually produced.

The delta.—The beach, barrier, spit, bar and wave-built terrace are constructed mainly of shore drift. Small streams contribute a certain amount of detritus to the lakes into which they flow, but their contribution is frequently carried away by the littoral currents, and mingled with the shore drift proper. The result is different in the case of large streams whose volume of water is sufficient to overwhelm the littoral current, and whose load of stream drift is large compared to the amount of shore drift. In this case the stream drift is built into a delta at the mouth of the river.

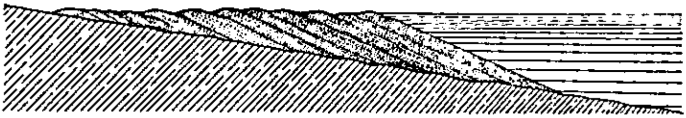

Fig. 18.

Cross section of wave-built terrace, showing its structure. (After Gilbert.)

The process of delta formation depends upon the principle that the amount of material which can be transported by a stream is diminished by any decrease in the velocity of the current. If the material carried be physically heterogeneous, diminution of velocity will also reduce the average size of the particles carried, since the coarsest are dropped first. So soon as a river empties into a lake, its momentum is communicated by friction to so large a body of water as to practically dissipate its energy. The coarse material which was being rolled along the bottom of the river comes to rest promptly at the shore. The finer particles are carried out further. When the deposit thus made in a lake bottom is built up to the level of the bottom of the river channel, it affords a road along which the newly-arriving sediment is carried further lakeward. The effect of this lakeward elongation of the river is to slightly diminish its velocity just above the earlier debouchure. With diminished velocity goes diminished carrying power. A part of the stream's load is therefore dropped at

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some point between its debouchure at the end of the submerged path and a steeper part up stream. Thus the channel is built up, and a new gradient is established sufficient to give the stream velocity adequate to its load.

The greater part of the load is always dropped at the point where the velocity of the river is lost in the still waters of the lake. On the lakeward margin of the deposit the slope is as steep as the material will lie. The slope of the top is very gentle, being controlled by the gradient of the river. As the delta is extended lakeward by additions to its steep frontal slope, deposits are made on the gentle slope in the channel of the stream. Since the river current is slower on the sides than in the middle, the deposition takes place on the sides rather more rapidly than along the bottom. Thus the sides of the channel are built up, and the river comes to flow down an elevated sluice of its own construction.

Such a condition of affairs is an extremely unstable one, and in time of flood the river breaks over the side of its sluice at some point, and finds a shorter route to the deep water. The process of deposition is repeated along this new channel, and another elevated sluice is constructed from which the river again breaks forth. Repetition of this process by all the numerous distributary streams which a delta-building river has, ultimately results in the construction of a gently-sloping plain with a more or less lobate margin. The general form of the plain is that of a sector of a circle, the margin being the arc. The up-stream part of this plain is above the mean water-level and passes into and is continuous with the flood-plain of the river above. The lower part is slightly submerged and is terminated by the steep slope of the delta front, which marks the point where the velocity of the river current is lost in the lake. The line joining the gentle slope and the steep slope is a little below the mean lake-level. Its distance below the surface is dependent upon the momentum of the river and the size and the amount of detritus carried. It is greatest when the momentum is great, the material fine, and the load a minimum. In small streams heavily loaded with coarse detritus, it must very nearly reach the lake surface.

The structure of the delta is indicative of its method of origin. The finest material which was carried in suspension sinks in essentially horizontal layers beyond the delta front. These may be called

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"bottom-set beds."* The coarse deposits slide down the delta front by their own weight and form steeply-inclined "fore-set" beds. As the delta grows lakeward, these steeply-inclined beds are superimposed upon the more level "bottom-set" beds of earlier deposition. The beds of the delta plain, laid down in the channel of the river, correspond with its gradient. They are gently inclined and rest upon the oblique edges of the fore-set beds. They may be called "top-sets." These various layers are shown in Figure 19.

The characteristic features of a normal delta are, therefore, its gently-inclined surface, its steeply-sloping front, its margin, which, although lobate, is the arc of a greater or less circle, and its tripartite structure, as shown in cross-section. The normal fossil delta, if a delta may be so called after the lake in which it was formed has disappeared, is usually divided into two parts by a channel extending

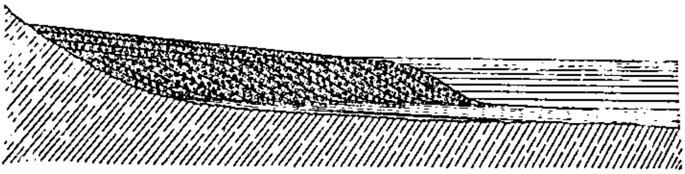

Fig. 19.

Showing structure of delta as shown in cross section. (Modified from Gilbert.)

from its apex to some point in its margin. This channel is occupied by the stream which, formerly the agent of its construction, has become the agent of its destruction.

In glacial lakes—that is, in lakes formed in part by glacier ice—modifications of the normal delta may be constructed. A river flowing from the glacier into the lake may build a delta at its mouth which, at the time of its construction, might not seem to differ from the ordinary delta in any essential respect. Its single peculiarity is that it heads against an ice shore, whereas the ordinary delta heads against a land shore. Later, this point of difference may become very obtrusive. After the ice has melted and the lake been drained, the delta which was built against the ice may remain unconnected with higher ground. It may itself constitute a conspicuous elevation.

* W. M. Davis, "Structure and Origin of Glacial Sand Plains." Bulletin of the Geological Society of America, Vol. 1, pages 195–202.

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Since the stream which constructed it disappeared with the recession of the ice, this form of delta is not subjected to partition, as is the other.

If a number of glacial streams enter a lake in close proximity, their deltas may coalesce, and the typical circular outline would be lost, but the lobate margin, the steep front, the gentle top slope and the tripartite structure would still be shown. If a moraine was being formed at the edge of the glacier at the same time that the numerous glacial streams were building their deltas in the bordering lake, the moraine would be bordered on its outer edge by an overwash plain having the characteristics of a delta, or of a series of coalescing deltas. For overwash plains or glacial deltas of this type the senior author has already proposed the name "subaqueous overwash plains."*

Distribution of wave-formed shore features.—Upon all shores certain stretches are undergoing erosion while certain others are receiving the detritus. The intervals between are occupied by the shore drift in transit. A few words need to be said as to the location of these various processes. Projecting headlands are usually being eroded, and salient curves almost always. This is true, since these points are most exposed to the direct attack of the waves, and since they are so situated as to allow littoral currents to carry off the shore drift as fast as it is formed. It is here, therefore, that cliffs and wave-cut terraces are usually found. Projecting from a headland, and often connecting it with an adjoining headland, there may be a spit or bar. Spits are also common at the leeward ends of long, narrow islands. Re-entrant angles are always places of deposition, and re-entrant curves are usually so. It follows that wave-built terraces commonly occur at the head of narrow bays, and well-marked beach deposits are found along the gentler re-entrant curves. Deltas are found only at the mouths of the larger streams, where the volume of stream drift was more than the littoral currents could handle. Glacial deltas and subaqueous overwash plains may occur at any point along the shore where the ice stood, or at any point along the line that was the shore, at any stage of the glacial lake's existence. If the edge of the ice at

* Geological Survey of New Jersey, Annual Report for 1892, pages 99-102. For similar plains Professor Davis earlier proposed the name "glacial sand plains." But there are so many sorts of sand plains associated with glacial deposits that this term does not seem especially appropriate. For Professor Davis' instructive discussion of the formation of these plains, see Bulletin of the Geological Society of America, Vol. 1, pages 195-202.

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one time stood at a place which was subsequently in the middle of the glacial lake, subaqueous overwash plains may even be found in the middle of such a lake basin, where temporary glacial streams entered it.

CLASSIFICATION OF LACUSTRINE DEPOSITS.

In glacial lakes there may occur two classes of deposits quite diverse in origin—berg deposits and true lacustrine beds.

Berg deposits.—Icebergs breaking off from the glacier and floating out over the surface of the lake might carry debris either on their surfaces or frozen into their mass, particularly in the basal portion. Some of this material would be dropped as the bergs floated freely over the surface, but the most of it would be deposited in the shallower waters where the bergs grounded and melted. The deposits might consist of materials of any and all sizes, such as are carried by the glacier. They may be bowlders alone, or more commonly bowlders and much finer material. They would be unsorted or show but slight traces of stratification. Where the deposit was more than scattered cobbles and bowlders, it might resemble more or less closely glacial till. It is believed that berg till can generally be distinguished from glacial till "(1) by a more homogeneous clayey base; (2) by a more uniform distribution of imbedded erratics; (3) by occasional traces of indistinct lamination; (4) by its surface expression; (5) by its distribution; (6) and by its stratigraphical relations." * A pronounced tendency to crack upon drying, a glazing on the cut face, and a tendency of the fine clayey particles to adhere to the surfaces of the stones and to coat them with a film not easily removed,† are further characteristics readily discernible at the surface.

Lacustrine clays and silts.—Such deposits would be expected to be more abundant the longer the life of the lake, and, other things being equal, to be more abundant in those parts which for any reason have the longer history. The clays and silts accumulating in a glacial lake "should possess certain characteristics by which they may be recognized. They should be finely laminated, as are similar deposits of more recent origin. They should be of such materials as could be furnished by the waters draining into the lake in glacial

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*Chamberlin, Third Annual Report, U. S. G. S., pages 297-8, 1881-2.

†Salisbury, New Jersey Geological Survey, Annual Report for 1892, page 142.

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times. The finer silts and clayey deposits should be found especially at some distance from the shore line, where the water was relatively deep, and where waves did not greatly disturb the bottom. They should be especially abundant, it would seem, toward that end of the lake which received the glacial drainage."* Toward the shore, in shallower water, we should expect to find them giving place to coarser deposits—sand or berg till. It may not always be altogether possible to differentiate true lacustrine silts and clays from the silts and clays accumulated in swamps and along streams after the lake had mainly disappeared, or at least after it had ceased to be a glacial lake.

THE SHORE FEATURES OF LAKE PASSAIC.

When search is made for shore features about the borders of the supposed Lake Passaic, they are found to exist, but not in so many localities nor in such strength of development as might have been anticipated. They are absent from some localities where their presence might have been expected, and they are sometimes well developed where there seems to be no good reason for their distinctness. Careful study has demonstrated that their absence at certain points and their indistinctness at others is due primarily to failure of original development, not to subsequent destruction. Nevertheless, indubitable shore features are found at so many places as to prove the existence of the lake. In many instances the features found are not so distinct as to be indubitable. But here, as in the study of very many geological questions, the effect of the evidence is cumulative. As each new fact or series of facts touching the existence of the lake was found, it was seen, not only to accord with the hypothesis of the lake, but to be demanded by it. Two concordant and corroborative facts, or series of facts, have a value much more than twice as great as that of one, so far as their bearing on any particular hypothesis is concerned. On the same principle, four corroborative facts, or series of facts, are worth much more than twice as much as two. As corroborative facts concerning Lake Passaic were gathered, though some of them were not in themselves indubitable, their cumulative force became such as to compel belief in the existence of the lake.

* Salisbury, New Jersey Geological Survey, Annual Report for 1892, pages 138-9.

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In describing the various shore features of Lake Passaic, the extra-morainic portion will first be considered. The various classes of shore features will be taken up in succession, and their nature and geographic distribution noted. This can best be done by beginning with that part of the basin near Summit, and passing around the lake to the southwest.

The elevations which are given in the following pages were in most cases determined by two men working with a surveyor's level and rod. From the original sheets of the topographical atlas of the State, the heights of the centers of road intersections, of road summits, of brook crossings and of cols were obtained. As taken from the map, these are supposed to be correct to within fractions of a foot. From these bench-marks, which were usually at intervals of not more than half a mile, lines of levels were run to the desired points. Wherever it seemed possible that an error might creep in through inaccuracy in locating the bench-marks, the levels were continued to the next bench-mark, or sometimes to several bench-marks. In this way possible errors in the heights of the bench-marks because of grading or filling of the roads since the topographical survey was made, were guarded against. The elevations thus determined are believed to be correct to within one foot. In a few cases the heights were determined from a bench-mark close at hand, by a hand-level, and here the possible error may be as much as three or four feet. Unless otherwise stated, the heights given are those determined by the more accurate method.

A. THE EXTRA-MORAINIC PORTION OF THE BASIN.

I. Possible Wave-cut Terraces and Cliffs.

1. *On Second mountain.*—A 1.* *Murray Hill.*—In the timber a short half mile southeast of Murray Hill station, there is a narrow bench more or less strewn with small trap bowlders and fragments. From its upper edge rises a steeper slope which has some slight resemblance to a wave-cut cliff. It can be traced northeastward through the woods for some little distance, apparently holding an approximately constant level, but it finally fades out. The upper edge of the cliff is about 364 feet, and the lower about 354 feet. Its topographic form

*The designations A 1, A 2, B 1, B 2, &c, refer to the accompanying map of Lake Passaic, where the exact location of the features here described may be seen.

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is not sufficiently distinct or characteristic to warrant the positive assertion that it is a wave-cut terrace and cliff, but the probabilities are in its favor. No evidence of wave action could be found in this vicinity at a higher level. No accumulations of water-worn pebbles could be found on the terrace or on its outer slope.

A 2. Westward, across the road leading over the mountain from Murray Hill depot, is a suggestion of a rock terrace, but it is not accompanied by a marked cliff. Its upper edge has an altitude of about 363 feet. It has such a form as one would expect the waves to cut on a very gently-sloping shore. Since these terraces correspond in elevation with undoubted shore features, they may be regarded as probable shore terraces, although taken alone they prove nothing.

A 3. *Mount Bethel.*—A quarter of a mile north of the hotel at Mount Bethel an ill-defined cliff and terrace may be observed. Water-worn trap gravel was noted in a number of places along the road near the outer edge of the terrace. The height of the terrace is 350 feet.

A 4. *Liberty Corner outlet.*—A mile and a half west by north of Liberty Corner, at Moggy Hollow, is the notch in the trap ridge, at an elevation of 331 feet, by which the waters of the lake drained into the valley of the North Branch of the Raritan. A full discussion of the outlet will be made the subject of a later section, but here attention is directed to the probable wave-cut terraces in this vicinity. In the peach orchard of Mr. Henry Apgar are numerous small outcrops of trap, around which it is evident the waves of the lake beat. The trap rock is covered by only a thin layer of soil, and around the knolls of rock slightly but certainly water-worn trap pebbles are found. To the observer whose eye is focused to catch the slightest trace of horizontal cutting by the waves, the terrace is distinctly visible. By another it may be readily overlooked, since it is not accompanied by a distinct cliff. The phenomena are such as would be produced on a gently-sloping, rocky shore against which the waves had beaten but a short time, and where the finest material had been carried off, leaving the ill-rounded pebbles just where they originated. They are not the phenomena of a shore where any marked terrace and cliff had been cut. Both above and below the zone thus affected the rock is covered by a much deeper layer of residuary soil. No well-marked beds of wave-worn gravel could be found in the imme-

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diate vicinity. The height of the mean lake level at this point was between 351 and 356 feet.

A 5. Two miles north of Liberty Corner, a little west of and above the road to Bernardsville, is another terrace along whose upper edge are numerous trap outcrops and broken trap fragments. The phenomena here are those which would be developed at the foot of a trap knoll covered with debris, where the waves were strong enough to carry away the finest material, but had not rounded the coarser to any notable extent. The height of the upper edge of this terrace is 365 feet. No indications of wave action could be found in this vicinity at higher elevations. Another and lower terrace—not certainly due to wave action—was observed just below the above at a height of 346 feet. At intervals for three-quarters of a mile northeast of this point, there are more or less well-marked terraces, but so far as observed they were unaccompanied by any specific evidence of wave work. Their heights were not accurately determined, but from the topographical map they seem to accord with that of the higher terrace cited above.

A 6. *Near Bernardsville.*—Just north of the road, about half way between Bernardsville and Madisonville, is a clearly-marked bench, at the upper edge of which is a cliff twenty or thirty feet high, with a slope of thirty degrees. Angular trap fragments are abundant at the immediate foot of the cliff, but no water-worn pebbles were found in connection with the terrace. The height of the upper edge of this terrace is 350 feet, but since within half a mile of this terrace well-marked wave-built terraces are found, whose elevation is 369 to 371 feet, this terrace could not have been cut by the waves during the maximum stage of the lake. This headland of trap, however, undoubtedly supplied part of the material of the gravel beds near at hand. The apparent absence of water-worn gravel at the foot of the cliff and its slightly inharmonious altitude raise a serious question as to whether this is really a lake cliff. It is not impossible that it is due to differential degradation.

2. *On the gneiss highlands.*—B 1. Half a mile northwest of the last locality, on the gneiss highlands, there is a narrow bench which can be referred with much certainty to wave action. It is distinctly marked, and passes southward into a wave-built, terrace-like spit of sand and gravel, derived by the cutting of the waves. This sand and gravel will be described later. It can be traced north-

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ward for three or four hundred yards. The height of the terrace averages 370 feet.

B 2. *Near Morristown.*—For a mile and a half southwest of Morristown, along Mount Kemble avenue or the Mountain road, there is a narrow terrace which in places is fairly distinct. The road is located upon it for some distance. This terrace forms a bench in the steep slope of the hillside. The slope rises rather abruptly above its upper edge, and falls off with almost equal abruptness at its outer edge. In places, the distinctness of the terrace has been increased by grading and filling, and in other localities, as shown by cuts, it has been obscured by post-lacustrine wash. It is partly wave-cut, and partly wave-built. In a number of places a thin layer of sand and water-worn gravel was noted, and at one cut the following section was seen, commencing with the surface:

3. Clay, containing some grit and sand, with a few gneiss fragments, very compact, glazing slightly when cut, and cracking on the dry face; thickness, three to four feet.

2. Rounded gravel, mostly gneiss, but with a few foreign pebbles; pebbles generally small and more or less imbedded in a clayey matrix, but sometimes very loose; thickness, six inches.

1. Gneiss residuary, containing angular, unworn fragments.

The upper member of the section was such as might well be derived from the finer clayey part of the gneiss residuary of the higher slopes by post-lacustrine wash. The thin gravel layer between this and the unmodified gneiss residuary is believed to be due to wave-action. The few small foreign pebbles could readily have been derived from the overwash plain and carried along the beach by littoral currents and waves.

The height of this terrace is about 365 feet, but, as will be seen later from other evidence, it does not mark the maximum level of water at this locality.

3. *On Long Hill.*—C 1. On the north end of Long Hill, half a mile south by west of Chatham depot, is a strongly-marked wave-cut cliff and terrace. This part of the hill is covered with till, and, as it was exposed to a long sweep of the waves from the north and northwest, the terrace and cliff are well developed. The cliff rises by a steep slope from the terrace, on which are strewn a number of large trap, gneiss and quartzite bowlders, evidently washed out of the till. Some of these are four or five feet in diameter, but the average

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size is two to three feet. At several points on the terrace the bare trap is exposed, indicating that the terrace was a place of erosion rather than of deposition. The upper edge of the terrace has an altitude of 369 feet, and is sharply defined; the lakeward margin passes gradually into the general slope of the hill below and cannot be definitely located.

This wave-cut terrace can be traced southward along the eastern side of Long Hill. Its surface there becomes sandy, and it soon passes into the prominent wave-built terrace seen in the lower part of Chatham cemetery. The clearly-defined cliff, the bowlder-strewn terrace, its association with and transition into the prominent wave-built terrace, make this one of the best-marked shore features of the extra-morainic basin.

Along the southeastern or front face of Long Hill, terraces and cliffs may be observed in several places, but probably not all of them, and perhaps none of them, are to be connected with the lake. The upper part of the hill is composed of trap which is underlain by the Triassic red sandstone and shale. The face of the trap is generally marked by a steep slope which changes abruptly to a more gentle one a little below the contact with the softer red shale. The junction of the shale and trap is frequently near the level at which the waters of Lake Passaic stood. The benches and cliffs on the south face of Long Hill may therefore be benches and cliffs of differential degradation. Such topographic features may simulate very closely ill-defined wave-cut cliffs and terraces, and it may not always be possible to distinguish between them. In studying the possible wave-cut terraces of Lake Passaic, terraces which were not directly traceable into wave-built terraces, spits or beaches, were regarded as probably wave-cut when they corresponded in elevation with neighboring shore features about which there was no doubt. Even this accordance cannot be said to prove their lacustrine origin, but only to render it probable. It is possible that a cliff and terrace due to differential degradation in pre-lacustrine times should occur at the lake-level, but in this case we should expect it to have been more or less re-shaped and intensified by the action of the waves. This would also be the case with all differential degradation benches which occur at any level at which the lake stood for any considerable period. It may be, therefore, that some cliffs and terraces at the maximum shore-line, as well as at lower levels, owe their location primarily to other than lacustrine

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factors, but have been more or less altered by the waves. This may be the reason why in some localities cliffs and terraces are so prominent, while in other places, apparently equally favored, they are obscure or altogether wanting.

C 2. *New Providence.*—Along the face of Long Hill, northwest of New Providence, there is a narrow but well-marked bench, at the upper edge of which is an abrupt change to a steeper slope. The bench has been cut in the red shale, the contact of the trap and shale being at least thirty feet above the bench. It does not seem, therefore, that the bench is due to contrasts in hardness between the shale and trap. Since its elevation is 367 to 369 feet, and it can be traced almost continuously into a well-marked spit a mile west of New Providence, it can, we believe, be safely referred to the lake, although no deposits of wave-worn pebbles or sand could be found along its outer margin. At the lakeward edge of the bench foreign pebbles and cobbles occur, but since we have good evidence that a tongue of the glacier stretched down this valley a few miles beyond the moraine, these erratics and accompanying sand are probably due to the ice rather than to the lake. This bench can be well seen from Murray Hill station, its upper edge in general corresponding with the lower edge of the woods.

C 3. *Berkeley Heights.*—On Long Hill north of Berkeley Heights there are in places indications of a bench in the trap. Where best developed, this bench is about thirty feet wide. In the absence of any positive evidence, it is doubtful whether it is due to wave action.

C 4. About half a mile farther southwest there is another faint bench in the trap, with which are associated a few trap pebbles apparently water-worn. As its height (350) is somewhat below the level of the lake (360) at this point, as shown by other data, it is questionable whether the bench is due primarily to wave action.

C 5. The same conclusion is true of another terrace on Long Hill between Stirling and Gillette, whose height is only 339. Its connection with the lake is very doubtful.

C 6. North of Stirling depot there is another bench and cliff in the trap at a height of 358 feet, an elevation which accords very closely with that of water-worn trap gravel beds in the vicinity. This terrace may be due to the lake, or at least may have been shaped to some extent by the waves.

C 7. *Millington.*—A quarter of a mile east of Millington depot,

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there is a very marked cliff and terrace. Seen from the east its profile stands out sharply against the sky, with all the appearance of a wave-cut cliff and terrace. But when measured it was found to be below (342 feet) the level of the waves (361± feet). Furthermore, the line of contact between the terrace and cliff is not a horizontal line but a curve, convex upward. It therefore cannot be due primarily to wave action.

C 8. Three-quarters of a mile west of Millington there is another clearly-defined bench on the south slope of a trap hill. The height of this bench was found to be too great for its reference to the lake.

C 9. *Liberty Corner.*—A mile and a half northeast of Liberty Corner are two trap hills which were islands in the lake. On the south side of each of them there is a terrace and cliff, a distant view of which can be had from the Liberty Corner-Millington road. The eastern one is at an elevation of 350 feet, and is developed in the shale. Forty or fifty feet above it is another bench, along the contact of the shale and trap, which is clearly due to differential degradation. On the surface of the lower terrace traces of water-worn shale and trap gravel were observed, generally more or less buried by a red clay, which may be, in part at least, post-lacustrine wash. Although the upper edge of this terrace is six or eight feet below the level of well-marked water-worn trap gravel found in the immediate vicinity, it still seems referable to the action of the waves. The cliff rises about twenty feet above the terrace and is marked by a number of shale outcrops.

C 10. The other cliff and terrace is half a mile west of the one just described. Its height is 349 feet, and, as in the other case, traces of water-worn shale and trap pebbles were found upon it, beneath a thin layer of clayey material. Since this terrace is located near the line of contact between trap and shale, the terrace may be due, in part at least, to differential degradation and only emphasized by the waves.

C 11. On the northern and northwestern sides of Long Hill no cut terraces of indisputable lacustrine origin were noted. The most marked is found northwest of New Providence, south of and above the road leading from Long Hill village to Chatham. Some rounded trap pebbles and apparently water-worn trap outcrops were noted at one end of the terrace. Although its height was not accurately determined, it seems to be about 365 to 370 feet, according well with the terrace on the opposite side of the hill.

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4. On the New Vernon trap hills.—D 1. Near the road from Morristown to Green Village, and about two and a quarter miles north of the latter, there is a very indistinct terrace which may be due to wave action, since its height (383 feet) corresponds with that of a spit near at hand. Further than this there is no evidence that it is wave-cut.

D 2. In the woods a mile north by west of Green Village is a distinct cliff of varying height along which the trap outcrops. At the foot of this is a terrace of varying width which seems to be on the shale. No traces of water-worn pebbles could be found, but this may be due to the complete absence of exposures. The height of the terrace is 362 feet, which, judging by the nearest wave-built deposits, is ten to fifteen feet below the maximum lake-level at this point. The reference of this terrace to the lake is very questionable.

D 3. About a mile northwest of the above terrace, on the property of Mr. F. F. Lippmann, is a strongly-marked bench, with a steep cliff rising above it. The surface falls off steeply from the outer or lakeward edge of the terrace, which is sixty to ninety feet wide, sloping gently away from the cliff. The terrace, which is cut in the red shale, can be traced through the woods for half a mile or more to the northward, where it gradually disappears. Its surface is practically bare rock throughout most of its extent, but towards its northern end it becomes somewhat sandy. Southward, it is indistinctly traceable into a bed of water-worn shale, gravel and sand, which forms a wave-built terrace. Its height, 357–9 feet, suggests that it may not belong wholly to the maximum lake stage, since its elevation is about twenty feet below the highest level of the water in this vicinity. Even if it is due to wave action it is difficult to understand why so marked a terrace should be developed in this part of the lake, for the terrace and cliff face a bay of the lake which could not have been more than two miles broad. The fetch of the waves at this point must therefore have been short.

Summary.—Of the terraces above mentioned and described some may be classed as probably lacustrine, some as doubtful, and some as due to other causes. The terraces designated, both in the text and on the map, by A 4, B 1, B 2, C 1, C 2, C 9, and C 10 are probably of lacustrine origin. Terraces A 1, A 2, A 3, A 5, A 6, C 6, C 11, D 1 and D 3 are referred to the waves of the lake with more or less doubt, since the evidence of such origin is not conclusive. Terraces C 3, C 4, C 5, C 7, C 8 and D 2 are probably due to other causes.

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The supposed wave-cut terraces and cliffs are so few and so poorly developed that they are not regarded as in themselves demonstrative proof of the existence of the lake. Especially is this true since such terraces are so closely simulated by terraces formed in other ways. But since, by other lines of evidence, the lake is known to have existed, the presence of these cliffs and terraces becomes important corroborative evidence.

II. Wave-built Shore Features.

The wave-built shore features in the extra-morainic basin of Lake Passaic are more readily and more certainly recognized than the wave-cut features. They consist of spits, terraces, certain beds of water-worn gravel which do not possess marked topographic form, and scattered water-worn pebbles. These, except the last, will now be considered in detail, the deposits on Second mountain, the gneiss highlands, Long Hill and the New Vernon hills being taken up in order.

1. *On Second mountain.*—a 1. One mile due south of Berkeley Heights station, on the property of Joseph Frazer, is a deposit of trap gravel whose upper limit, so far as can be determined in the absence of good exposures, is 357 feet. The gravel is not well rounded, but is nevertheless distinctly water-worn. The surface indications of the gravel are best observed in the middle of the peach orchard, but it is more widespread than appears on the surface, as is shown by two gullies which reveal layers of gravel beneath and between beds of stony clay, and also layers of gravel in a clayey matrix. Traces of gravel were noted eastward to the corner. No data could be obtained as to the depth of the gravel, which does not form a distinct topographic feature.

a 2. A third of a mile south of Union Village, in the woods west of the road, on the property of John F. Schwalb, there is a deposit of trap gravel of considerable extent. About 100 yards from the road is a pit which has been opened to obtain road gravel. The pebbles are commonly two or three inches in diameter, poorly rounded, but distinctly water-worn. The deposit is certainly more than four or five feet thick. It reaches a height of 355 feet at least, and perhaps reaches 360 feet. Just southwest of this deposit of gravel is a very pronounced headland of trap, from which this material was probably derived, and in the lee of which it was deposited, forming a

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faintly-developed wave-built terrace. In the woods between this deposit and the one south of Berkeley Heights, traces of water-worn gravel were found, but, in the absence of exposures, no well-defined beds of gravel could be located.

a 3. One mile southwest of the above locality is another deposit of trap gravel which forms a broad, flat-topped bench or wave-built terrace. A pit of some size has been opened, exposing the gravel to a depth of three or four feet. The material varies from fragments of the size of a pea to cobbles six or eight inches in diameter. The pebbles are water-worn, but not well rounded; are fresher in appearance than the residuary trap fragments, yet are weathered one-quarter to one-eighth of an inch. They seem to be water-worn cores of deeply-disintegrated trap fragments. The gravel is used for road purposes. Although beyond the shallow pit exposures no data could be obtained as to the thickness of the gravel, yet there is enough in sight for many miles of road. The elevation of this gravel bed is 344 feet, but the gullies along the road show that water-worn pebbles in a clayey matrix reach up to 358 feet, which is probably nearer the maximum lake level at this point. This pit is owned by the Old Home Life Insurance Co.

a 4. A mile southwest of the above pit, and two miles due south of Stirling station, are more or less clearly-marked indications of trap gravel at an elevation of 344 feet, although as a shore feature it is not topographically distinct. A well dug in the gravel and sand struck rock at a depth of seven feet. The gravel is almost wholly of trap, but with the trap pebbles there are a few fresh erratics, probably contributed by floating ice. This gravel is probably a little below the maximum lake level.

a 5. Half a mile west of the above locality, in the peach orchard of Clement Eskesen is still another deposit of trap gravel which, topographically, should be classed as a wave-built terrace, although it is not well marked. There are no exposures, and beyond two or three feet no accurate data as to the depth of the gravel could be obtained. This deposit reaches a height of 344 feet, about ten feet below the probable maximum lake-level at this point.

a 6. One-third of a mile west of Mount Bethel corner, traces of water-worn trap pebbles were found on an ill-defined terrace. From well data there seem to be several feet of sand and gravel beneath the clayey surface layer. The height of this terrace is 350 feet.

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Scattered water-worn pebbles were also observed along the road near the wave-cut terrace south of the corner. (A 3.)

a 7. One and two-thirds miles west of Mount Bethel, on the property of J. H. Moore, is a flat-topped, gently-curving ridge, slightly resembling a spit. Where the road to Basking Ridge crosses its western end, there is a cut three or four feet deep which shows the material to be mainly poorly-rounded trap gravel, with occasional pebbles of gneiss and quartzite. A well dug near the southern end, about twelve feet from the top of the ridge, penetrated eight feet of gravel. The top of this ridge is a little below 300 feet, at least forty-five to fifty feet below the maximum lake-level in this locality. This is an extensive gravel deposit and contains material enough to macadamize many miles of road. Along the road between this point and Mount Bethel, water-worn trap pebbles were observed in a number of places, although not in well-defined deposits.

a 8. One and a half miles south of Liberty Corner, near the house of John Dougherty, is a pit opened in the southern end of a small steep-sided spit. The gravel is trap, coarse, water-worn and loosely stratified, with but little fine material in the interstices. Foreign pebbles are rare. A well twelve feet below the top of the spit penetrated eighteen feet of gravel, reaching sand, into which it was not dug. If these figures are reliable, we have a maximum thickness of gravel of about thirty feet. Traced northward through the woods one-third of a mile, the gravel seems to extend continuously to the road, being there exposed along the stream in a cut ten feet deep. In this cut the gravel contains a noticeable element of clayey matter. Gravel is also found in the orchard across the stream to the west. A channel fifteen feet deep and about forty yards wide here seems to be the measure of post-lacustrine erosion. The highest point of this deposit is at the south end, where it has an altitude of 345 feet.

a 9. A mile and a half southwest of Liberty Corner, near the fork of the roads, is a small spit extending southward from a knoll of trap. The gravel is exposed to a depth of three or four feet by the roadside, where it is seen to be very similar to the trap gravel found at the other localities. Its height is 344 to 347 feet, but water-worn pebbles were noted southward along the road at an elevation of 350 feet. This deposit is on the property of Thomas Maddock.

a 10. A mile northwest of the above deposit, near the house of B. Anthony, there is a small deposit of loose trap gravel. It has

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accumulated at a height of 349 feet, on the side of a 385-foot hill of trap. The gravel on the surface is small and water-worn, and as shown by a well, is eight feet thick where penetrated. Its location at one end of a small trap hill is very significant of its wave origin.

a 11. A mile and a quarter south of Bernardsville three or four feet of water-worn trap gravel is exposed for fifteen or twenty feet along the road just north of the brook. The gravel is open, the interstices not being filled with fine material. The gravel is so covered by a layer of clay (one foot thick) that it is impossible to trace it beyond the exposures. Its height is a little below the maximum water-level as indicated by the terrace A 5.

a 12. In the vicinity of the corner, a half mile east of Bernardsville, and one mile north of Basking Ridge, is an extensive (for Lake Passaic) wave-built terrace of gravel. Its greatest length, 2,400± feet, is along the road to Basking Ridge, and its greatest width is 1,500± feet. The gravel reaches a maximum elevation of 367–9 feet. Along the roads north, east and south of the corner there are exposures which show considerable variation in the constitution of the gravel. In the cuts north and south of the corner the gravel is made up largely of flat, disk-like pebbles of red shale, the once-angular corners entirely rounded. A few pebbles of trap, gneiss, slate and quartzite are also found. In the cut along the road toward Madisonville the gravel contains much less red shale and a much larger percentage of trap pebbles. The gneiss, slate and quartzite pebbles are also found. The gravel from this part of the terrace affords much better road material than that which is made up largely of red shale.

This terrace is built at the head of what was a small bay, the headlands of which were, on the northeast, trap, and on the south, a surface covered by earlier glacial drift and red shale. We find, therefore, materials from each of these sources in the terrace. The great development of this deposit, compared to most of those found about the borders of the lake, is due (1) to its favorable situation for accumulation—the head of a bay (see page 240), (2) to the prominence of the headland of trap, (3) to the erodable character of the drift and red shale, (4) to the wide sweep of the waves from the east. A well near the corner penetrated fifteen feet of more or less compact gravel and then struck "red clay," which may have been nothing more than clayey shale. A depth of thirty feet of gravel has been

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reported.* This gravel lies mostly on the properties of James V. Blazer and Calvin D. Smith.

a 13. Half a mile north of the above corner, in a shallow bay north of the trap headland, is a small deposit of water-worn gravel, mostly trap, but with some shale and gneiss. It is exposed to a depth of six feet along the road, and, in the amount of rounding and wear which its constituent pebbles have suffered, it is in marked contrast to the angular trap fragments above the lake-level. The gravel does not appear at the surface above 360 feet, but its upper limit is obscured by post-lacustrine wash. It is on the property of Mr. Childs.

2. *On the gneiss highlands.*—b 1. A little northwest of the above deposit, near the head of a small bay between the gneiss and trap, is a small but distinct spit, whose shoreward margin has an altitude of 371 feet, and whose distal end is 365 feet A. T. The gravel is composed almost entirely of gneiss, with occasional pebbles of Triassic red shale, Hudson river shale and quartzite, but it contains practically no trap. Since the trap hill is but a few rods away, the absence of trap is significant of the direction of the waves, which must have been from the northeast along the gneiss highland. The littoral current set along this side of the bay, and, dropping its load nearly at the head of the inlet, built this spit, which reaches almost to the trap hill on the other side. Traced shoreward the spit is continuous with a wave-cut terrace (B 1) thirty yards wide, the outer edge of which is marked by a few gneiss bowlders, but upon which no trace of gravel could be found. A pit has been opened in the end of the spit, which is on the property of Mr. Childs.

b 2. A mile and a half northwest of New Vernon, near the prolongation of Mount Kemble avenue, Morristown, there is a wave-built terrace near the head of a small bay. The material was supplied from both sides of the bay; from the gneiss on the northwest more rapidly, because of the greater sweep of the waves along this shore; from the Triassic conglomerate on the south less rapidly, for the opposite reason. Consequently the terrace is longer and wider on the northwest side of the bay than on the southern side. Its greatest length is 600 feet, its width 450 feet.

The constitution of the terrace shows to some extent the derivation of its material. On one side, gneiss sand and gravel predominate, with occasional pebbles which were derived from the Triassic con-

* Annual Report, 1892, page 133.

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glomerate. On the other side, the quartzites from the conglomerate are more abundant and the gneiss pebbles proportionately less, but since there is gneiss in the conglomerate, it is certain that a part of the gneiss in the south portions of the terrace came from it. Definite data as to the thickness of this deposit could not be obtained, but there is certainly a considerable body of it. The height of the upper edge of the gravel is about 380 feet, which in a small bay of this size could hardly be more than two or three feet above the mean lake-level. This terrace is about three-quarters of a mile northeast of the McAlpine-Pyle property.

There are no other well-marked gravel deposits along the gneiss highlands, although in a few localities scattered water-worn pebbles or thin layers of sand and gravel have been noted. The best marked of these have already been described in connection with the wave-cut terrace along Mount Kemble avenue. (B 2.)

3. *On Long Hill.*—If water should rise to a height of 360± feet about Long Hill, there would be formed a series of nine long, narrow islands, rising to heights not exceeding 125 feet, and in general separated from each other by narrow, shallow straits. Debris carried by the waves and currents along the shores of these islands would accumulate at their ends as spits, bars, or beds of gravel and sand. By these deposits the islands would in time become connected, or at least the channels between them would be diminished both in depth and breadth. When the cols of Long Hill are examined, beds of trap gravel, or at least water-worn trap pebbles, are found at accordant heights between each pair of the former islands. The presence of these water-worn beds of locally-derived gravel in just the positions where they might be expected to accumulate as the result of wave action if the lake existed, at the proper height, and where their origin by any other means seems impossible, is in itself a strong proof of the existence of Lake Passaic. These beds, with a few others on the sides of the several islands, will now be considered in detail.

c 1. In the lower part of the cemetery of Chatham, and just north of the paper mills on the Passaic river, is a high, well-marked wave-built terrace of sand and gravel. At its northern end it is continuous with the wave-cut terrace at the north end of Long Hill. (C 1.) Towards the south it terminates in a short, spit-like projection. It is composed of glacial gravel, derived from the till which covers this end of Long Hill. At its upper edge it is 369 feet A. T. From

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this point there is a gradual slope to 351 feet, where it falls off more steeply. This terrace can be traced for more than a third of a mile along the side hill; it varies in width, being widest opposite the cemetery (440± feet), and narrowing northward. A good view of this terrace can be had from the southeast, across the river.

c 2. Along the road half a mile further southwest there is another but much smaller wave-built terrace, whose height is 372 feet. A pit shows the material to be glacial sand and gravel. At intervals along the road between this terrace and the last, traces of a wave-cut bench in till, at an elevation of 369 to 370 feet, were observed.

c 3. A mile and a quarter west of New Providence is the sag which separated the first island of Long Hill from the second, counting from the northeast. At the southwest end of the first island is a short but pronounced spit. Northeastward it is con-

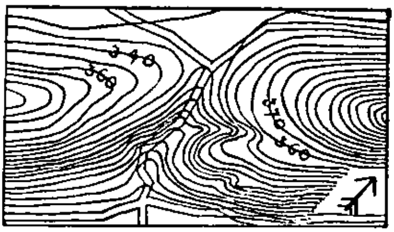

Fig. 20.

Durie spit and surroundings represented by contour lines. The spit is near the center of the map, extending just south of west from the 360 line. Scale, three inches to the mile.

tinuous with the wave-cut terrace (C 2); southwestward, the free end terminates just back of Mr. Samuel Durie's house. From its upper edge, about 350 feet, it slopes gradually to 335, and then plunges off steeply for seventy or eighty feet. From the low hill, half a mile to the southeast, a good profile view can be obtained. In the pit which has been opened near Mr. Durie's house, the material is seen to range from fine sand to pebbles six inches in diameter, with rarely a small bowlder a foot to a foot and a half in diameter. The finer constituents are very largely of red shale, which also comprises much more than one-half the larger pebbles, although fresh gneiss, red sandstone (unidentified), quartzite, trap, greywacke and slate pebbles are more or less common. The shale pebbles are disk-like in shape, and,

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owing to their abundance, the gravel as a whole has this characteristic form. Since the pit is in the end of the spit, the structure is well shown. Along the axis of the spit the beds are seen to dip in the direction of the free end, whereas on the sides they dip outward, forming what may be called anticlinal stratification.

Some of the layers are of fine, clean sand; others are of loose gravels, the interstices between the pebbles not being filled; others are of pebbles which are coated with a film of clay, and by this means loosely cemented together. The clayey layers are in the upper half of the gravel. The gravel of this spit is used locally (within a radius

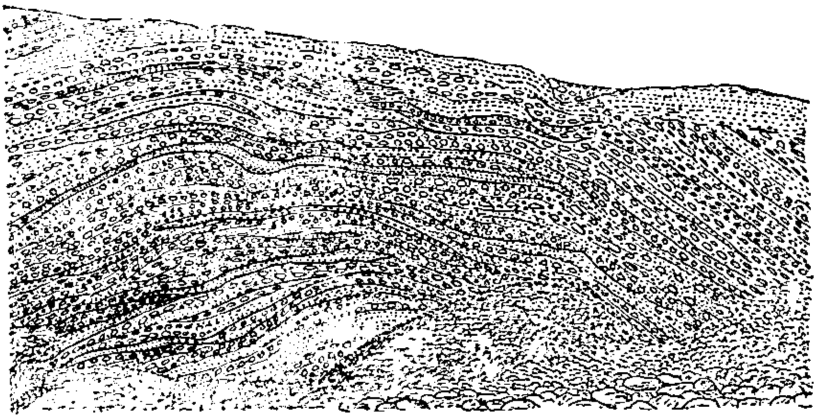

Fig. 21.

Cross-section of the Durie spit, showing the general tendency to anticlinal structure. (Drawn from a photograph.)

of two or three miles) for road material, but, owing to the great abundance of red shale, which crushes easily, and then forms, in wet weather, a sticky mud, it is not so good as the trap gravel.

c 4. Across the road from the spit just described, more or less water-worn trap gravel is found up to a height of 363 feet. Faint indications of a terrace were noted at about this height, but in the absence of exposures it is impossible to make any definite statement as to the amount of gravel.

c 5. Rounded trap pebbles can be found more or less continuously along the inner (northern) slope of Long Hill for nearly a mile southwest of this locality. Within this distance a ditch was found, which, by chance, had been dug for several hundred feet directly across the

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old shore line. This exposure was the more valuable in that the surface did not show any topographical evidence of wave action, nor were wave-worn pebbles abundant on the surface. Above an elevation of 361 feet the material exposed in the trench was trap residuary, the rock fragments being deeply decayed, angular, or but slightly rounded by exfoliation. At 361 feet there was a change. The trap residuary was succeeded laterally (lakeward) by coarse, water-worn, rounded, more or less fresh-looking trap pebbles, the whole somewhat stratified and containing occasional foreign pebbles. Farther out, the gravel passed beneath fine sand, which was succeeded by gravel, and that again by sand. A thin layer of clayey loam covered the whole, effectually concealing the gravel, except where exposed in the trench.

This exposure was valuable for several reasons. (1) It proved conclusively that some agent had been at work upon the lower part of the slope, re-working and re-arranging the trap residuary up to a certain definite point, above which it did not reach. The element of height was the only controlling factor. Waves working at this height could produce the observed phenomena; running water, either as streams, causing surface wash, or percolating water, causing creep, could not. (2) This exposure was valuable in that it furnished a definite point by which to fix the lake-level (361 feet). (3) It showed conclusively the fact that the absence in some localities of topographic shore features, and of rounded gravel on the surface, does not militate against the lake hypothesis; and (4) it furnished a strong presumption that shore gravel has a much wider distribution than at first appears, and that it has been buried in post-lacustrine time beneath a thin layer of surface wash, sod and vegetable mould.

c 6. A mile northwest of Berkeley Heights station is a second sag in Long Hill, in which there are ill-defined deposits of trap gravel, with some foreign pebbles. There are no exposures, so that the surface indications are the only guides. The foreign pebbles (berg or wave-transported) extend to 358 feet.

c 7. Half a mile south by west of this gap is a terrace at 311 feet, at the western end of which is a short but sharply-marked spit, whose upper edge coincides with the terrace, and whose distal end declines to 270 feet, where it terminates in a steep slope. The gravel is largely of red shale, but trap, gneiss, slate, greywacke and quartzite are by no means rare. As this spit and terrace are forty-five to fifty feet below the maximum lake-level of this vicinity, they must be referred

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to a stage in the lake's history when the water was below its maximum level.

c 8. On the road leading over the mountain eastward from Long Hill village, and a third of a mile from the same, is a small but typical exposure. By the roadside, at an elevation of 360 to 362 feet, are a number of large, rounded water-worn trap bowlders, in the crevices between which are sand and fine gravel—exactly what would occur where waves beat upon a rocky shore. Near here are also several outcrops of trap, the thin soil covering of which was probably removed by the waves. In the fields for some distance on either side of the road, scattered rounded pebbles were noted. The shore line here is not marked by any considerable accumulation of gravel.

c 9. Just below the corners, half a mile north of Stirling station, a road gully shows one or two thin layers of fine trap gravel, which seem to be referable to the lake. Their height (340) is below the maximum level.

c 10. A mile west of this last locality there is a pit in a trap-gravel deposit, on the properties of Patrick O'Rourke and Mrs. Thompson. A few foreign pebbles occur with the trap, which is poorly rounded, but nevertheless distinctly water-worn. It is in no wise different from the numerous other trap-gravel deposits already described. Its upper limit is at 361 feet, and it is said to be forty feet deep, but this could not be verified.

c 11. A little west of this locality, a few rods beyond the corner along the road to Basking Ridge, the trap gravel again forms a continuous bed at an elevation of 359 feet. The gravel can be traced along the north and west sides of the hill lying just north of Millington station. The gravel reaches a height of 361 feet, and in places forms an indistinct terrace. In the railroad cut on the west side of this former island, the gravel is seen to be distinctly stratified, to be about twenty-five feet thick, and to range from coarse sand to ill-rounded cobbles five or six inches in diameter. Nearer Millington station is an exposure of red shale. On the part nearest the trap, the shale is covered by one to three feet of trap gravel, which gradually changes to shale gravel as it gets further from the trap. Although this is one of the largest gravel deposits found, little of it is available for road material, since it is located mostly upon improved residence property.

On the hill to the west, across the gorge, rounded pebbles of trap

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were noted, together with a few of gneiss, as high as 355 feet, but there are no considerable beds of gravel.

c 12. Half a mile south of Lyons station, along the road which passes between two trap hills, is another pit in a bed of trap gravel which accumulated in the shallow water between the two islands. The deposit is not extensive, though its limits cannot be well made out for lack of exposures. In the pit, the gravel is seen to vary in thickness from three feet to more than eight feet. The pebbles under one inch in diameter are well rounded, but the angularity increases with the size. Where exposed, the gravel is obliquely stratified, though the stratification is not especially distinct and contains no layers of sand. It is now used to a large extent for road material. Its upper limit, which marks very closely the actual water-level, is 361 feet A. T. The deposit is on the property of Benjamin Runyon.

c 13. A mile southwest of the last, on the parallel road, is another bed of trap gravel, likewise in the narrow channel between two islands. Its greatest length is in the neighborhood of 1,200 feet, and its width about three-fourths as much. In a pit toward the northern end the gravel attains a thickness of over eighteen feet. Here it is almost entirely of trap, the pebbles ranging upward to six or seven inches in diameter, but averaging less than two inches. Towards its southern limits the gravel contains a noticeable element of red shale, which was derived from the wave cut terrace in the red shale a short distance to the east. (C 9.) This gravel reaches up to a height of 356 feet. It occurs on the property of Lawyer Zieglow and of Dominie Bowers.

c 14. Half a mile north of Liberty Corner are two small hills of trap, whose crests rose just above the surface of the lake. At the southern end of the northern one is a broad, flat-topped spit, about 300 yards long and 200 yards wide. In a pit near the road there is exposed twelve feet of coarse (constituents ranging up to one foot in diameter), poorly-rounded, obliquely-stratified trap gravel, the beds of which dip outward towards the periphery of the spit. This gravel pit is owned by Bernards township, and the material is used on the roads. This spit is 348 feet A. T. at its highest point. A few rods to the southeast is the other trap knoll, at the northern end of which is another spit, which, at its end, coalesces with the one already described. This spit is owned by Charles Greulock. Its greatest height is 342 feet A. T. Judging by the heights of the gravel

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beds to the east, mentioned above, and by the phenomena at the outlet, these beds are eight to fifteen feet below the maximum lake level in this region.

c 15. A little north of Lyons station, south of the fork of the roads, is an extensive deposit of trap gravel, forming a wave-built terrace, 100 to 150 yards wide. This is at the southern end of what was a peninsula, and is a favorable point for the accumulation of debris transported along its eastern and southeastern sides. The deposit is best shown in the pit at the crossing of the Basking Ridge-Liberty Corner road and the railroad. Here coarse trap gravel is seen overlying and horizontally inter-stratified with coarse sand. The pebbles average two to three inches in diameter, but range upward to ten inches. Ninety-nine per cent. of the material is trap, the foreigners being gneiss, slate and quartzite. Five per cent. of the larger and probably thirty per cent. of the smallest material might be called well rounded. Most of the pebbles not included in this class show signs of wear. Those showing no signs of rounding vary from fifty per cent. of the largest pebbles to only five or ten per cent. of the smallest. The gravel here reaches a height of 364 feet.

Northward from this terrace, through the timber and in the cultivated land along the foot of the trap escarpment, rounded pebbles of local origin were observed in considerable numbers. As the red shale at Basking Ridge is approached, the shale pebbles become more numerous, and the trap pebbles become proportionally less abundant. Water-worn shale pebbles were noted around newly-set fence posts, just back of Moore's hotel, although on the surface no signs of gravel were to be seen.

c 16. Southwest of Moore's hotel, Basking Ridge, is a broad wave-built terrace at the head of a small bay. From this point the terrace can be traced for half a mile northward on both sides of the railroad track. The gravel was derived largely from the local shale, the pebbles being flat, disk-shaped and covered with a thin film of fine clay. Nothing is known as to its depth save that it exceeds six feet. Northward from this terrace rounded pebbles were noted at heights varying from 360 to 365 feet, and in a ditch near the railroad station the reworked upper part of a bed of till belonging to an earlier ice invasion was seen. The lake level in the vicinity of Basking Ridge was very nearly 367 feet A. T.

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Three other small deposits of shore gravel should be mentioned in this connection, although strictly they do not occur upon Long Hill.

c 17. One of these forms a small terrace along the road to Madisonville, half a mile northeast of Basking Ridge. The gravel is largely of red shale material, and its height is about 285 feet A. T.

c 18. A quarter of a mile nearer Madisonville is an exposure of red shale gravel twenty-five feet thick which probably owes its origin to the lake, but which does not form a topographic shore feature. Its height is about 291 $\pm$ 3 feet. Both of these deposits are significant because of their relationship to the height of the gorge of the Passaic at Millington.

c 19. The third bed of gravel referred to above not connected with the higher stages of the lake, if, indeed, it is to be attributed to the lake at all, is about one and one-third miles southeast of Basking Ridge station, at an elevation of something like 260 feet. It is difficult of exact location on the map.

On the hills near New Vernon.—d 1. A quarter of a mile west of New Vernon is a wave-built terrace ending in a small spit extending southward nearly across what was, in the days of Lake Passaic, a small bay.

The material is largely red shale gravel with some pebbles, which may be from the drift or from the Triassic conglomerate of the vicinity. The top of the spit has an elevation of 372 feet, and at its end it falls off abruptly twenty feet. The terrace extends northward to the road, where it is interrupted by a deep gully, beyond which it can be traced more or less clearly for half a mile in a slightly sinuous course to the northeast. In this direction it departs slightly from the shore, and assumes something of a spit-like appearance, at the same time declining a few feet in height. Much of the material is quartzite from the Trias conglomerate, and where not too largely mixed with red shale gravel, is valuable as road-making material. This deposit lies partly on the Fairchild property, and partly on that of N. S. Benbrook.

d 2. Along the road half a mile east by south of New Vernon is a small bed of red shale gravel at an elevation of about 370 feet. It is not significant topographically, nor does it seem to be of great extent.

d 3. A mile east of New Vernon are five more or less topographically-distinct constructional terraces, which are clustered about a small

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hill of red shale rising ten feet above the lake-level. They are within an area less than a quarter of a mile square, but nevertheless show slight variation in altitude, their heights being 370, 371, 373, 376 and 376 feet, respectively. This gives an average height of 373 feet. There are no exposures, but from surface indications the material seems to be well rounded. It is composed of disk-shaped red shale pebbles and sand.

d 4. At the three corners a mile north of these terraces is another deposit of fine red shale gravel and sand. This is on the property of F. F. Lippmann and is nearly continuous with a wave-cut terrace just north (D 3), its elevation being 362 feet. There are no good exposures, but the depth of the gravel is known to be at least eight feet. It is somewhat lower than the maximum lake-level at this point.

Along the southern faces of the New Vernon trap hills occasional water-worn pebbles were found at altitudes of 360 to 370 feet, but so far as could be made out in the absence of exposures, the shore line is not here marked by beds of gravel.

d 5. A mile and three-quarters due south of the Morristown depot is a spit-like deposit of trap gravel, at the northern end of the trap ridge which extends northward from Green Village. Occasional fresh gneiss and quartzite pebbles, derived either from the drift close at hand, or borne in by floating ice, are found in the gravel, which otherwise is composed entirely of poorly-rounded trap pebbles. The gravel was noted on the surface up to a height of 381 feet, but the indications from the topography are that the lake-level was about 376 feet. If this was the case, the height of the lake at this locality is brought into accord with the heights of the nearest shore features to the west. The longitudinal profile of this deposit is interesting. From the highest point (381 feet) at which gravel was noted, the surface declines thirteen feet in the first seventy-five yards (1 in 17), fifteen feet in the next twenty-five yards (1 in 5), eighteen feet in the next 125 yards (1 in 21), and then thirty-five feet in the last seventy-five yards (1 in 6), beyond which the gravel is not present. This profile seems to indicate a lake-stage twenty to twenty-five feet lower than the maximum level of 375 feet. This spit is on the property of G. E. Taintor.

d 6. A mile and a quarter south by west of the center of Morristown two hills, one of trap, the other of Triassic conglomerate, rise to a maximum height of about thirty-five feet above the old lake-

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level. In the narrow strait separating them, there was laid down a deposit of gravel whose flat surface is now 373 feet A. T., and whose length is about 175 yards. The greater part of this deposit of gravel was derived from the trap hill to the east. The Triassic conglomerate hill at the west supplied comparatively little. The quartzite pebbles from the conglomerate are abundant only where the gravel bed joins the conglomerate hill. A large pit opened in the trap gravel shows that the material is ill-rounded, obliquely-stratified, coarse—the pebbles averaging two or three inches in diameter, but ranging up to eight inches—and more than twelve feet thick. This bed of gravel is on the Spring Brook farm, and is a valuable body of road gravel.

d 7. At the western end of the Triassic conglomerate hill just referred to, there is a deposit of gravel having a rude resemblance to a spit in its early stages of growth. This deposit is well exposed along the road in the gravel pits owned and worked by the city of Morristown. The gravel is almost entirely of quartzite pebbles, which have been derived from the hill of conglomerate. They are well rounded, but this is due primarily to pre-Passaic wear. Those pebbles which were broken in the process of disintegration of the conglomerate, show little evidence of wear during their lacustrine history. The upper layers are horizontally stratified, forming the "top-set" beds. Beneath these, the strata are inclined westward towards the end of the spit, forming "fore-set" beds. This structure clearly indicates the method and direction of growth of the spit.

The stratified material certainly extends up to a height of 376 feet, and possibly a little higher. The surface of the hill at heights much above any possible wave action is strewn with quartzite pebbles, resulting from the disintegration, in place of the Triassic conglomerate. These pebbles are in every respect similar to those found upon the wave-built spit. Beyond the limits of the exposures, therefore, it is impossible to determine positively the extent of the wave-worked gravel. Judging from slight topographic evidence, it probably does not extend higher than 380 feet, and the lake-level was probably 377$\pm$ feet. The testimony of the three beds of gravel last mentioned, considering both their material and their position, shows conclusively that in this part of the lake the prevailing direction of movement of the shore drift was a little north of west.

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III. Subaqueous Overwash Plain Bordering the Moraine.

The terminal moraine crosses the lake basin between Summit and Morristown, forming a ridge which in places rises twenty-five to seventy-five feet above the lake-level, but which in other places falls below it. Between Chatham and Stanley there is a break in the moraine a mile and a half wide, in which lies the northern end of Long Hill and the valley of the Passaic river. Along its course across the lake basin, the outer margin of the moraine is bordered by a subaqueous overwash plain of goodly proportions. From what has already been said concerning the process of delta growth (page 237), it will be remembered that the especial characteristics of deltas and subaqueous overwash plains are a flat top, sloping gently from the head to the front, a steep front slope, a lobate margin with deep re-entrant angles and projecting cusps, and a tripartite structure, as seen in vertical sections, consisting of nearly horizontal beds at the top, these underlain by beds dipping steeply towards the front, which in turn rest upon horizontal layers of fine material. (See Figure 19, page 239.)

Near West Summit there are three prominent marginal lobes on the subaqueous overwash plain. West of Madison, the flat top of the plain is a third of a mile wide, and has a fall of about ten feet, whereas the steep front falls off sixty feet in one to two hundred yards. As will be seen from the accompanying contour map, which was prepared from a careful survey of the plain, the cusps and re-entrant angles are here very pronounced. (Plate V.) Southwest of Convent station the plain is half a mile wide, declining twenty to twenty-five feet from its upper edge at the moraine to its outer edge, where it ends abruptly in a steep slope of about fifty feet in 125 to 150 yards.

Kettle holes, varying in size from shallow, saucer-like depressions to huge sinks fifty feet in depth occur, although such large ones are not abundant. Travelers on the Delaware, Lackawanna and Western railroad have a fine view of the largest kettle, which lies just west of the track, a third of a mile northwest of Convent station. The railroad runs on this plain from Convent northwestward for a mile or more.

The material varies from very coarse gravel containing large cobbles down to fine sand. Layers of sand are often intercalated between beds of coarse gravel. Lithologically the material is similar

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Plate V.

Subaqueous overwash plain from Madison to Morristown (southwest of the railway), with a part of the moraine (mainly to the northeast of the railway).

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to that found in the moraine, and was derived from the melting ice. No exposures were found which showed the complete tripartite structure, nor were there found any extensive exposures showing both fore-set and top-set beds, although one or the other were seen at a number of places.

To fix the exact water-level in which these subaqueous overwash or glacial delta plains were formed, is a matter of considerable difficulty. In a general way it may be said that the line marking the junction of the gently-sloping upper surface of the plain with its abrupt front, marks the water-level. This general statement is certainly very near the truth. But when it is desired to fix the level of the water exactly, or even within two or three feet it seems to involve many inconsistencies to assume that this line marking the change of slope corresponds accurately with the water-level. There are several reasons for supposing that it does not.

1°. It has been found that even where the change of slope is most marked and can be accurately fixed, its heights vary three, five or even seven feet within comparatively short distances; that is, the line of change from the top to the front is not a horizontal line but a more or less irregularly-curved line. The water could not stand five or six feet higher at one point than it did at another less than a hundred yards away.

2°. But more than this. A consideration of the manner in which a delta is formed shows that the pronounced change of slope must mark the point where the bottom current of the running water which is rolling the coarse gravel along its bed loses its momentum when it reaches the deeper water of the lake. It would seem, therefore, that the steeper slope cannot, at a maximum, be built nearer the surface of the lake than the depth of the current which at that particular spot is supplying debris. Since the depth and velocity of each stream supplying the detritus is different at different points in its cross-section, and since a subaqueous overwash plain or a glacial delta plain is built by a number of streams or by the distributaries from a single stream, the several streams having various depths and velocities, we should expect the upper limit of the frontal slope to be of various heights on adjoining lobes, and even to vary in height on the same lobe. We must conclude, therefore, that the lake-level was somewhat (perhaps several feet) higher than the highest of the "fronts," and that the water submerged the outer and lower part of

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the gently-sloping top. The depth of the submergence at different points would depend on local conditions.

Just how far above the frontal slope the lake waters reached in the area under discussion is problematical. Its position is not marked by any line on the surface of the plain. It must be fixed rather by the interpolation of data from this and adjacent regions than by any specific mark. On this basis, bringing in data from neighboring wave-cut and wave-built features, it seems probable that (*a*) west of Madison the lake stood at an elevation of about 373 feet, covering nearly all of the plain whose outer edge is 362–5 feet; (*b*) that west of Convent it stood at about 374 feet, the lower edge of the plain being 356 to 364 feet and the upper edge 382 feet; (*c*) that at Morristown it stood at about 376 feet, the greater part of the plain here being but little below this level. Likewise, by the interpolation of data drawn from other sources in the immediate vicinity, it is believed (*d*) that the lake-level at the subaqueous overwash plains near West Summit was at about 367 feet, whereas here the outer edge of the plain is only 345 to 350 feet, from which height the plain rises gently to an elevation of about 380 feet.

Summary of Shore Features in the Extra-Morainic Basin.

The wave-cut terraces and lake cliffs are in general but poorly developed. In numerous localities ill-defined terraces have been observed at about the supposed lake-level, some of which, by their close connection with more decisive and more definite forms, are probably of lacustrine origin. The best marked of these are upon Long Hill and the gneiss highlands, but, with all possible allowances, it must be admitted that were the proof of the existence of Lake Passaic dependent upon its wave-cut terraces, the theory of its existence could not be stoutly maintained. There is not a terrace in the extra-morainic part of the lake basin the wave-cut character of which, taken by itself, can be said to be beyond question.

The constructional forms are much more satisfactory. In a number of localities there are small but distinctly-formed spits, bars and terraces, whose heights are closely accordant one with another. In many more localities stratified beds of poorly-rounded, but nevertheless of distinctly water-worn gravel of local origin exist, which, although not possessing a distinct topographic form, agree in height,

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material and structure with the better-defined forms. Where the gravel is not present in beds, scattered water-worn pebbles of local origin have been found at numerous places at the proper levels, and there is good reason to believe that the shore gravel is much more nearly continuous about the lake basin than the surface traces indicate. Nowhere have shore forms, beds of local gravel or scattered water-worn pebbles of local origin been found above the limit at which the waters of the lake could have been confined.

The composition of these gravel beds, considered in relation to the underlying and adjacent indurated formations, is most significant. On Second mountain—a great trap ridge—the gravel deposits attributed to shore action, are composed almost wholly of fragments or pebbles of trap, with only occasional foreign pebbles. The same is true in the main of Long Hill. But on the south side of this ridge the red shale occasionally rises to the former level of the lake. Where gravel beds are found at such points, the shale has made the principal contribution to the gravel. The Durie spit (c 3) west of New Providence is an instance in point. Where the supposed shore of the lake was against a drift-covered surface, the gravel beds are composed of drift gravel. The terrace (c 1) back of the paper mills at Stanley is an illustration. In the vicinity of Basking Ridge deposits of trap gravel grade into those of shale, as the supposed shore line passes the contact of the trap with the shale. Along the gneiss highlands only two gravel beds were found, both of which were largely of gneiss gravel and sand, and local sources for the other constituents are at hand. The gravel deposits on the trap hills about New Vernon are mainly of trap; those on the shale are composed chiefly of shale, and those on the Triassic conglomerate of quartzite pebbles, derived from the conglomerate itself. Waves and shore currents are the only known agencies which can develop beds of water-worn, stratified gravel sustaining this definite relationship to the adjacent and subjacent formations. The few foreign pebbles in the gravel are not difficult to explain, though their absence would be. They were derived from several sources. A few may have been transported along the shore from the moraine, or from the ice front, when it formed one side of the lake, by the combined action of waves and shore currents. This would probably apply only to the fresher pebbles found not far from the moraine. Others were probably carried by floating ice to the various parts of the basin. Where the ice melted or grounded near shore, they were incorporated

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in the shore deposits. The occasional large, fresh-looking bowlders which are now and then associated with these gravel deposits seem by this means to find adequate explanation. At a number of localities about the lake basin, reaching considerable heights above it, deposits of sand, gravel and till are found which present evidence of great age. Beds of drift similar in composition to these and sometimes continuous with them are found within the lake basin. These are believed to belong to the invasion of an ice-sheet much earlier than that which formed the moraine.* This pre-morainic drift was a third source of the foreign material found in the shore deposits.

The topographic situation of some of these shore deposits of gravel, taken in connection with their composition, is such as to admit of no second interpretation. Generally speaking, they occur along a horizontal belt at a definite elevation, either (*a*) on the slopes of higher lands, or (*b*) in the passes and cols between them. Above this definite level gravel such as is here described does not occur. Below this level such beds of gravel occur at various points as might have been formed during the later stages of the lake's history, when its level was sinking and its area diminishing. The gravels under consideration were deposited by waves and shore currents. Since they do not occur outside the Passaic basin the waves and currents must have been those of a lake.

There are certain deposits of gravel about the lake basin which are not to be confused with those here discussed. These gravels are so distinct from those of the lake shore, that even the tyro need not be confused in their discrimination.

A careful study of the shore deposits, particularly their relations to headlands of rock and wave-cut benches, gives us some knowledge of the general direction of the waves and shore currents. On Long Hill the shore drift traveled in general southwestward, as is shown by the high terrace near Stanley (c 1), the Durie spit west of New Providence (c 3), and the spit northeast of Gillette (c 7). On Second mountain a general direction cannot be made out. Some of the deposits, notably the one south of Union village (a 2), were derived from the southwest; others are found to the west or southwest of the sources of supply. Near Basking Ridge the material was carried southward, as shown by the red shale deposit south of the depot

*Annual Report of the State Geologist of New Jersey for 1891, pages 102-111; 1892, pages 60-72.

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(c 16), and the trap gravel at the south end of the ridge near Lyons (c 15). The three deposits (d 5, d 6 and d 7) a mile and a half south of Morristown were clearly formed by westward-moving currents.

Three particularly favorable classes of localities for deposition can be made out. These are—1°, in the shallow, narrow straits between islands, the numerous deposits along Long Hill being the most marked examples; 2°, at the ends of islands or peninsulas where the shore currents (*a*) kept their course and velocity as the island was passed, spits being the result, the Durie spit west of New Providence (c 3) being a good example; or (*b*) where the shore currents lost their velocity by spreading, in which event terraces were formed; the terrace just north of Lyons station (c 15) may serve as an example; 3°, at the heads of small converging bays, where terraces of considerable extent were sometimes formed. The terraces west of Basking Ridge (c 16), east of Bernardsville (a 12), and a mile and a quarter northwest of New Vernon (b 2), are good examples. Other instances may be seen upon the map accompanying this report.

Finally, the subaqueous overwash plain along the whole outer margin of the moraine, so far as it lies within the lake basin, is indisputable evidence that a large body of standing water once occupied the low ground to the southwest, the height to which it rose being approximately marked by the outer edge of the gently-sloping upper surface of the plain. The depositional shore features of the extra-morainic part of Lake Passaic are therefore regarded as demonstrative of its existence in this part of the basin. In view of this demonstration, much weight may be attached to the possible wave-cut terraces and accompanying cliffs heretofore described.

The extent to which most of the extra-morainic constructional features of the lake are developed, and they still retain essentially their original form, is so moderate that the conclusion seems certain that the history of the lake was a brief one. The spits, for the most part, are no more than well started. The terraces are narrow and often ill-defined. The beds of gravel are nowhere very thick or extensive. The very considerable subaqueous overwash plain along the moraine might be of very rapid construction, so that a long period of time is not demanded for its growth.

Deltas in the extra-morainic part of the lake.—Apart from the glacial drainage, the streams which emptied into Lake Passaic were

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generally small and short. Those on Second mountain could not have been more than a mile long. On the gneiss highlands they were larger, but nevertheless were of slight importance. Whippany river was probably the largest of these. Careful search failed to show any traces of deltas at the mouths of any of these streams. The Whippany valley, from Morristown to Brookside, was examined with great care. This valley was either filled by an independent lake, if the ice blocked the mouth of the valley at Morristown, or by an arm of Lake Passaic. No traces of shore lines are to be found, nor were any remnants of a delta observed.

The absence of fossil deltas, not only here, but at the mouths of all the tributaries to the lake, seems to substantiate the conclusion reached from other lines of evidence that the lake was short lived. The drift supplied by the streams was not more than could be handled by the waves and incorporated in the shore drift.

B. INTRA-MORAINIC PORTION OF THE BASIN.

The intra-morainic portion of the Passaic basin differed from the extra-morainic in certain essential features. Since it was occupied by ice for a portion of lacustrine time, its lake history, if such there was, must have been briefer than that of the extra-morainic portion. If shore features were formed in the interval between the closing of the pre-glacial outlet and the advance of the ice to the line of the moraine, they stood good chance of destruction by the ice as it advanced to its extreme position. Only those shore features which were formed after the ice retreated from the moraine, and before the old outlet across the trap ridges was re-opened, could be expected to remain. In so far as this period was shorter than that of the lake as a whole, we should expect the shore features to be less strongly developed than outside the moraine. On the other hand, since the glacier left thick deposits of sand, gravel and till on the sides of the basin, upon which the waves could readily work, and since an enormous amount of loose material was furnished to the waves directly from the melting ice, constructional terraces, spits, bars, &c., could have been rapidly constructed under these favorable conditions. The abundant supply of shore and glacial stream drift might even more than compensate for the short life of this part of the lake.

There is another and essential difference between the two parts of

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the lake basin. Since the ice filled the intra-morainic part of the basin, and covered all the surrounding country, deposits of more or less rounded and water-worn gravel are liable to be found at any and all elevations. The mere presence, therefore, of such deposits, even at elevations accordant with the shore lines, cannot be regarded as evidence in favor of the existence of the lake. Unless they possess the structure and the topographic forms characteristic of shore deposits, they cannot be of value in the present discussion. With these general considerations in mind, the possible shore features of this part of the basin may be considered in detail.

I. Possible Wave-cut Terraces and Lake Cliffs.

1. *On the moraine.*—F 1. Three-quarters of a mile south by east of Madison station is a broad terrace on the inner face of the moraine, above which the morainic topography, although gentle, is more strongly marked than below. This terrace is covered by a few feet of fine sand, which in a shallow road cut is seen to rest upon till. This bench, whose upper edge is 352 ± feet, and whose lower limit is about 340 feet, is probably about twenty feet below the maximum water-level. This terrace can be readily traced for half a mile or more to the southeast, being most distinctly marked upon the slightly-projecting headlands of the shore. In places the terrace is strewn with bowlders up to four and five feet in diameter. The bowlders are most abundant near its upper edge.

F 2. One mile northwest of Madison, also, on the inner face of the moraine, there is a bench which can be traced for three-quarters of a mile. It is generally more than a hundred yards wide, and is marked at its upper limit by a distinctly-steeper slope, which, however, is nowhere developed sufficiently to be called a cliff. In places the distinctness of the bench has been increased by grading and terracing. Above this terrace, whose upper edge has a height of 354 feet, the morainic topography is generally distinct, although often not strong, whereas it is very obscure or altogether wanting below this level. This same terrace was observed a mile further north on both sides of the east and west road, but it cannot be traced across the interval. Continuing northward, the bench is lost in the morainic topography in the woods, but it begins again some distance south of the Morristown-Afton road, and can be traced to this road. Here its upper

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edge has an elevation of 356 to 359 feet, about twenty feet below the maximum lake-level.

F 3. North of the Morristown-Afton road a higher terrace begins. This can be traced, with but little interruption, to the Morristown-Monroe road, a distance of more than a mile. This terrace varies from 100 to 300 yards in width, and is bordered much of the way by a lake cliff, fifteen to thirty feet high. Above it the moraine topography is strongly developed, while below it is almost entirely wanting. The upper edge of the terrace varies from 372 to 369 feet, averaging fourteen or fifteen feet higher than the lower terrace to the south, and being four or five feet lower than the estimated water-level at Morristown.

The 354-foot terrace, so clearly marked towards Madison, could not be made out on the outer face of this higher terrace, nor was the higher terrace observed further south above the lower. The terraces do not pass into each other, but on the contrary are distinctly at different levels, where their ends most nearly approach each other.

F 4. Across Whippany river, a mile west of the end of the higher terrace just described, another terrace occurs. Along its upper edge, which has a height of 360 to 362 feet, it is bounded by a steep, cliff-like slope, ten or fifteen feet high. The surface of the upper part of the terrace is strewn with bowlders. Its lakeward slope has a gradient of one foot in sixty. Above the summit of the cliff the country is nearly flat, and during the maximum lake stage was at lake level, so that the waves here had no opportunity to cut a terrace.

The width (100 to 300 yards) of these terraces on the inner face of the moraine is considerable for so small a lake, and for one having so brief a history. But there were several favoring conditions for their rapid development. The waves worked upon incoherent materials, largely sand and gravel. The terraces are so situated as to have been exposed to a considerable sweep of waves, particularly towards the later stage of the lake period, when the ice had almost withdrawn from the lake basin; and finally, when waves cut a terrace upon a gently-sloping shore, the lower edge of the terrace may pass almost insensibly into the original slope, and so the width of the wave-cut portion may seem to be much greater than it really is. It is quite probable that only the shoreward parts of the above terraces are really wave-cut.

F 5. Half a mile north of the terrace last described and at the

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south end of the high hill between Morristown and Littleton is a gravel-covered terrace at a height of 378 feet, and a steep cliff above. The terrace is fifty yards wide, declining fifteen feet in this distance. It is terminated lakeward by a much more abrupt slope. Westward this terrace ends in a spit to be described later. It can be traced eastward around the end of the hill and northward through the woods for a mile and a half. For much of this distance the cliff is steep and clearly marked, but it declines in height as the general slope of the hill in which the terrace was cut diminishes in steepness. The terrace at the same time becomes wider and less distinctly marked. Its continuity is several times interrupted by ravines and valleys. Half a mile south of Littleton the cliff is again well marked, facing a broad, gently-sloping till plain, the upper edge of which is thickly bowlder-strewn. Its height here is 376 feet, a little less than the height further south. Not far from the northern end of this terrace, and undoubtedly closely associated with it in origin, is a small spit at 382 feet. To this reference will be made later. Just east of this spit is a gently-sloping, bowlder-strewn till flat, whose height, 365± feet, bears the same relation to the top of the spit as the lower terraces between Madison and Monroe bear to the upper benches.

From Littleton northeast to Pompton no wave-cut cliffs or terraces exist, but constructional forms are present in great abundance. Neither were any wave-cut features found upon the curving trap ridge near Whitehall. Between Summit and Caldwell a few obscure benches of doubtful lake origin were noted. These will now be briefly described. North of Caldwell no wave features could be found.

2. *On Second mountain.*—H 1. Three-quarters of a mile southeast of Northfield, above the house of Mr. Christian Rimback, is a sharply-marked bench possessing many of the characteristics of a wave-cut terrace. It is one hundred yards wide with a lakeward slope of twenty feet between its lower and upper edges, which are at heights of 340 and 360 feet respectively (hand-level). The accompanying cliff is conspicuous, and bowlders large and small are scattered on the surface of the terrace at its foot. The outer edge of the bench is marked in places by accumulations of sand and gravel. Its length is about 750 yards. Southward it ends abruptly, without apparent cause, and northward it falls away to a lower and wider flat. This failure to hold a constant level casts doubt upon its lacustrine origin. Just

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north of the road leading east from Northfield a faint bench and cliff were noted, the height of which is about 360 feet (hand-level).

H 2. Beginning three-quarters of a mile east of Livingston, just south of the road, a bench can be traced southward more or less continuously for more than a mile, to the next road. For part of this distance it is limited by a distinct cliff, at the foot of which the terrace, fifty to one hundred yards wide, is more or less strewn with bowlders. As determined with a hand-level from the nearest bench-marks, its upper margin has an elevation of 358 to 360 feet.

K 1. Southwest of Livingston, along the eastern face of Riker's hill, there is a bench which is perhaps referable to the lake. It appears first in the Livingston cemetery, where it has a height of about 375 feet. Southward it increases in distinctness, and its surface is covered with sandy loam. At the same time it decreases somewhat in height, being only 367 feet half a mile south of the cemetery. Since these measurements were made with a hand-level there is a possible error, but making allowance for this, the bench seems to depart too much from horizontality to be confidently referred to the lake.

Summary.—On the inner face of the moraine between Chatham and Littleton there are discontinuous terraces in the drift, often of considerable width. In places they are bowlder-strewn, and limited above by sharply-defined cliffs. These benches belong to two sets of elevations—the one fourteen to eighteen or even twenty feet lower than the other. The upper is generally the most sharply defined, and has the steeper cliff. It is well shown at the southeast end of the high hill between Morristown and Littleton, and also south of Monroe. The lower set is developed midway between Chatham and Madison, between Convent and Madison, and also northeast of Morristown. These are probably lacustrine in origin. On the eastern shore of the lake, between Summit and Caldwell, particularly east and southeast of Livingston, benches have been observed which in some respects resemble wave-cut terraces. Even if lacustrine, they can hardly belong to the maximum stage of the lake. Elsewhere, save the doubtful case on Riker's hill, no benches were observed which can be regarded as lacustrine. These possible wave-cut terraces would in themselves be an insufficient basis for affirming the existence of a lake in the intra-morainic part of the Passaic basin. Taken in connection with other lines of evidence to be hereafter adduced, the foregoing terraces have corroborative value.

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II. Constructional Shore Features Within the Moraine.

1. *On the moraine.*—f 1. During the lake period the high hill midway between Littleton and Morristown formed the northern headland of a curving bay a mile in width. At the head of this bay is a small, wave-built terrace, sloping gently to the southeast, and connected with higher ground to the northwest. Its upper limit is 375 feet, and its lakeward slope is eight or ten feet in a hundred yards. A few hundred yards east of this terrace is a spit two hundred yards long, forty yards wide at its free end, but increasing in width northward to its junction with a wave-built terrace, which rapidly passes into the wave-cut terrace at the south end of the hill.

The spit rises eighteen or twenty feet above the low ground around it. At its free end the height of its surface is 369 feet, which increases to 378 feet at its upper limit. This spit, which is on the property of John Pearson, furnishes much gravel for use on the roads. The material, as is the case in all the constructional shore features of this half of the lake, is glacial sand and gravel. This spit is shown in Figure 23.

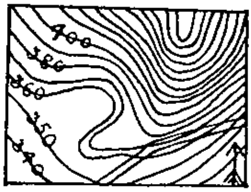

Fig. 23.

Spit on the face of the moraine midway between Morristown and Littleton. Scale three inches to one mile.

f 2. Just west of the three corners, half a mile south of Littleton, is a flat-topped spur of sand and fine gravel, having an elevation of 382 feet. Its form strongly suggests a lacustrine origin. Its height, and its close association with the wave-cut terrace along the side of the hill to the southeast, gives weight to the suggestion. The association of these two spits with the wave-cut terrace, the first (f 1) at the southwestern end of the terrace and the second (f 2) near its northern end, is a characteristic combination of shore phenomena.

f 3. A mile northeast of Littleton, along the road to Boonton, is a gently-undulating plain of sand and gravel, containing some bowlders, and passing, at its upper edge, into the moraine. The elevation of this plain is about 380 to 385 feet, and although its form does not point positively to a lacustrine origin, it seems most probable that it is the result of the combined cutting and building action of the waves working upon stratified drift. Towards the northeast this plain

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merges into a broad, flat-topped, spit-like ridge of gravel and sand, over a mile in length. Its crest is followed to its end by the road to Parsippany and Boonton. Where the road to Tabor turns off from the Boonton road, the ridge is broken by a gap which does not appear to be due to erosion subsequent to the development of the ridge, but to lack of development at this point. The average height of the part connected with the terrace is 360 to 370 feet, while that of the isolated portion is ten feet higher. In front and beyond the distal end of the isolated portion there is a lower terrace, about 350 feet in height, or eighteen to twenty feet lower than the higher ridge at this point. In view of the fact that this ridge is many times larger than any well-defined spit in the lake basin, and in view of the fact that it is interrupted by a gap across which material could not be transported by waves and littoral currents, it is not probable that this ridge is a spit, in any proper sense of the term. It does not seem to have been due primarily to lake agencies. It may, however, well represent a ridge or kame, or line of kames, more or less re-shaped by the waves. Unfortunately, the structure is nowhere well exposed, so that this hypothesis could not be tested.

2. *On the gneiss highlands.*—g 1. A mile north of Parsippany there is a gently-sloping, slightly-undulatory plain of sand and gravel, having an area of a quarter of a square mile. It has the lobate margin, steep front and re-entrant angles, characteristic of a glacial delta, *i. e.* a delta formed in standing water in immediate connection with the ice, the detritus being supplied by a glacier stream. The lobes of this glacial delta rise abruptly thirty feet above the lower land to the south and west. Northward the plain passes into an irregular kame area, the site of which, it is believed, was occupied by the ice during the formation of the delta. To the south there are a number of large kames, which were probably formed before the ice had retreated to the kames north of the plain, and which, therefore, antedate the plain. The southern limits of the plain seem to have grown out to, and to have partly encroached upon the nearest of these kames. The general level of the plain is 396 feet. The ends of the lobes vary from 390 to 394 feet. From these figures the water-level would appear to have been about 394 or 395 feet. The kames south of the plain must therefore have all been submerged during the maximum lake stage. On some of them, traces of terraces at about 362 feet were observed, although they were not very definite.

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g 2. Between Boonton and Montville, southeast of the canal, there is another glacial delta having an average width of three-eighths to one-half a mile, and a length of two miles. The surface is gently undulatory but perhaps not more so than is possible for a plain built in immediate connection with the ice front by a number of streams of varying velocities and volumes. The ice, too, may have co-operated, at least passively. The height of the outer margin of the plain at the top of the steep frontal slope varies between 381 feet and 399 feet, with variations of ten or twelve feet within thirty rods or less. In general, however, there is a rise of the margin towards the northeast. The general level of the plain is under 400 feet, and the water-level, so nearly as it can now be determined, was about 394 or 395 feet at the Boonton end, and probably a little less than 399 feet at the Montville end. Towards the upper limits of the plain, near the canal, bowlders become more numerous and the surface is more irregular. Patches of till are also present, apparently indicating that the ice lay on the higher ground to the northwest during the formation of this delta plain. If this were the case, the general slope of the surface of the plain would be away from the ice towards the lake, and the internal structure should have a lakeward dip.

A single small pit was found on the Boonton plain, which showed that the beds at that point dipped northward, nearly opposite to the direction which would have been expected, if the plain was built from the northwest as supposed. But it is unwise to assume that this is the normal dip for all the beds, or indeed that it is the usual direction of dip. Particularly is this true since other features of the plain, *i. e.*, for example, its surface slope and its lobate margin, and the unmistakable structure of neighboring plains, all agree in the supposition that the ice lay upon the high land to the northwest, and that the plains were built from the edge of the ice outward into the lake. The difficulty presented by the direction of dip at the observed exposure may be met hypothetically as follows: If the plain was built around and over a number of pre-existent kames, its surface might be more or less hummocky provided the kames were not completely buried. In this case the internal structure of the plain might be more or less confused and discordant, as the material was washed irregularly into the depressions between the kames. Besides this, the beds of a kame might dip steeply in a direction opposite to the general dip of the beds of the delta plain proper, and a single small

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excavation might reveal only the kame beds. From such an exposure it might seem that the plain had been built towards the highland, after the manner of a terrace formed in the angle between the side of a valley and stagnant ice occupying the low ground, even though this was not the fact. If this were the case the general dip of the beds would be towards the hillside if the material was derived from the melting ice.

The lobate front of the Boonton delta plain is well developed, the projecting lobes being sharply defined, falling off steeply fifty to seventy feet. The re-entrant angles also are clearly marked. Post-lacustrine erosion has in some cases undoubtedly increased their distinctness, but at many points they seem to preserve essentially their primitive forms. Along much of the front of this delta plain, there is a lower terrace, the height of which is about 320 feet (hand-level). At various other points along the lake margin, a series of terraces about seventy feet below the maximum shore line have been observed. These will be mentioned in their appropriate geographical position, but their exact relationship to the higher terraces, structurally and chronologically, will not be considered until the history of Lake Passaic is considered.

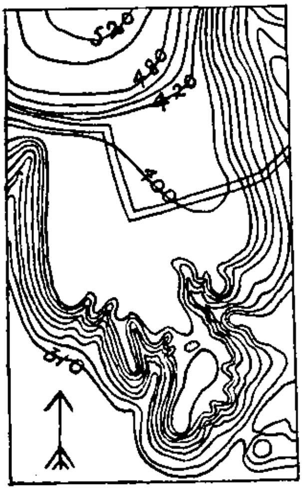

Fig. 24.

Topographic map of the Montville delta. Scale three inches to the mile.

g 3. Just north of Montville there is as perfect an example of a glacial delta as could be desired. It is represented in contour in Figure 24. Its area is about a quarter of a square mile. Its surface is nearly flat save for an occasional shallow, saucer-like depression, and a gentle slope from north to south. Its distinctly-marked lobes rise seventy to ninety feet above the irregular kame areas toward the south. The Delaware, Lackawanna and Western railroad skirts its southern edge at the foot of the lobes, cutting directly across the end of the southernmost projection. The upper fifty feet of this section shows cross-bedded sand and gravel dipping towards the end (south) and sides of the lobe. This exposure

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is so large that there is no hesitation felt in asserting that this lobe and the delta of which it was a part, were built from the north. Beneath this fifty feet of gravel is one to six feet of clay and fine sand. The laminæ of the clay are thin, one eighth to one-sixteenth of an inch in thickness, and separated by thin, sandy partings. As seen in section the clay and sand layers are horizontal, but they may have a slight southward dip. The clay, to all appearances, is exactly similar to that found at numerous low places in the lake basin, and regarded as undoubtedly lacustrine. Towards the sides of the lobe, the clay layer is succeeded by coarse sand and gravel stratified parallel to the side slope of the present surface. Beneath the clay there is more sand and gravel, the fine sand being stratified horizontally, the

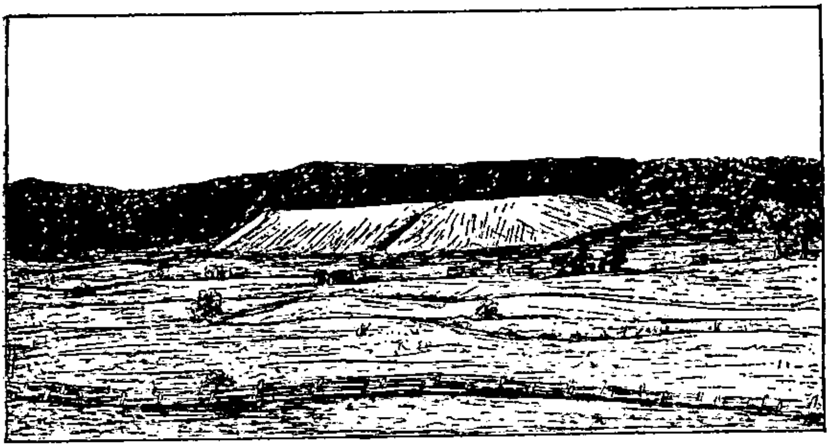

Fig. 25.

Montville delta, as seen from the southeast, three-quarters of a mile distant.

coarse materials irregularly bedded as in a kame. The coarse, irregularly-bedded gravels probably represent a kame, around and over which were deposited the finer materials supplied by the glacial drainage which entered the lake half or three-quarters of a mile to the north. In time, the margin of the lake was so filled up by the coarser materials deposited nearer shore, that the streams came to drop their coarse material further out on top of the fine deposits, made at an earlier time. Since there are no stratified deposits on the slope of the hill north of the delta plain, and since the slope of this hill shows no signs of river channels cut in the till, we conclude that the streams

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which built this delta must have been short, and that the edge of the ice must have been very near the head of the plain.

The heights of the margins of the different lobes vary from 388 to 395 feet, and the plain ascends gradually to a height little above 400 feet. The water-level seems to have been about 397 or 398 feet. On one of the lobes there is a faint indication of a terrace at about 325 feet, but no corresponding signs were found on the others.

Across the road just west of the northern end of this plain there is a small lobe whose height corresponds very closely with that of the larger plain. This may properly be considered as a part of the larger plain isolated in construction, and further separated by erosion. Figure 25 is a sketch of this delta drawn from a photograph taken from a hill three-quarters of a mile to the southeast.

g 4. Half a mile northeast of the Montville delta is a small and not very well-defined terrace, which may have been built in standing water. It is more or less kame-like in places, and its origin is not

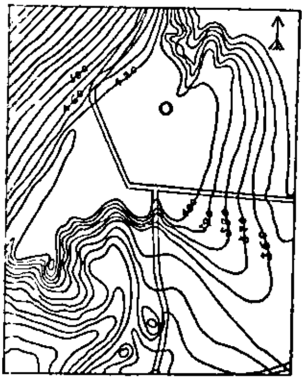

Fig. 26.
The delta near Jacksonville school-house, one and three-fourth miles north of Whitehall, shown in contour. Scale three inches to the mile.

certain. If it is to be referred to the lake, which may be fairly questioned, it seems to indicate a stand of the water at about 370 to 380 feet. There is also a faint indication of a terrace on the northeastern side of the Montville delta, at about the same level.

g 5. With the above exceptions there are no traces of shore lines in the first two miles northeast of the Montville delta, but at the three road corners, a mile and three-quarters north of Whitehall, there is a

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small and well-formed glacial delta, represented in contour in Figure 26. This may be called the Jacksonville delta, from its proximity to the Jacksonville school-house. In some respects this delta is the most significant in the lake basin. The top has very little slope until the brow of the lobes is reached, where there is a sudden change, and on the south an abrupt fall of fifty feet. Northward, towards the head, the surface becomes slightly undulatory, and at length breaks up into low kames north of the sink represented in the figure. The northern margin of the delta plain is marked by wide re-entrants between which are narrow, cusp-like lobes of gravel and sand. The slopes are kame-like and bowlder-strewn. The limit of the bowlders towards the front of the delta is nearly coincident with the limit of undulations of the surface, although an occasional bowlder is found upon the plain proper. The topography of the head of the delta makes it clear that the ice stood at this point while the delta was being formed, and that when the ice melted, the head of the delta was left unsupported, and the sand and gravel slipped and settled down irregularly.

It is only for a narrow strip on the northwest side that the delta abuts against higher ground. Directly south of the delta front are a number of kames which just escaped burial beneath the advancing delta.

The heights of the crests of the different lobes are 408, 407, 406 and 398 feet, the lowest lobe being as clearly and sharply defined as the higher ones. The general level of the plain is about 410 feet, and the height of water must have been between 408 and 410 feet.

No lower terraces were found upon the slopes of this plain nor upon the slopes of the neighboring kames.

g 6. A mile southwest of the intersection of the New York and Greenwood Lake railroad with the New York, Susquehanna and Western, near Pompton, there is a striking sand and gravel terrace built against the steep slope of the highlands. It is traceable for nearly a mile. Its height is between 335 and 340 feet (hand-level), and it rises by steep slope over 100 feet above the level plain to the east. The terrace varies in width from 100 to 150 yards. The face of this terrace is in part lobate, after the manner of the front of a glacial delta. There is, however, some question as to whether this terrace ought to be referred to Lake Passaic. It possesses certain features which make it seem probable that it was formed in the angle between the gneiss

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highlands and stagnant ice occupying the valley, the material being supplied by the ice. So far as could be determined with a hand-level, its surface, at least in part, slopes gently towards the highlands, whereas if it had been built out into a lake from the land, the surface slope should be in the other direction. Further than this, the topography of its eastern face strongly suggests, in places, the slipping and settling which would occur by the melting of a supporting wall of ice. Unfortunately the internal structure is nowhere exposed, and it seems impossible to decide definitely between the two possibilities of origin. The height, 335 to 340 feet, accords fairly well with the faint lower terraces near Boonton and Montville.

g 7. Half a mile southwest of this terrace there is a large, isolated kame of coarse sand, gravel and bowlders. On the east side, about forty feet below the summit, at an elevation of about 340 feet, is a narrow, wave-cut (?) bench, which at the south end of the hill passes into a short, narrow, flat-topped, steep-sided, spit-like ridge. The fact that this bench and spit are probably due to wave action would seem to make it probable that the terraces nearer to Pompton are also to be connected with the lake.

North of Pompton no traces of shore lines were observed, nor were any seen upon the trap hills on the east side of the Pompton plains. This is to be expected, since by the time the ice had melted back as far as Pompton the outlet at Paterson would probably have been open.

3. *On and near Second mountain.*—Shore features are not so well developed on the eastern shore of Lake Passaic as on the western, but there are enough to make it possible to fix the position of the shore line with some accuracy.

h 1. At Upper Preakness is the largest and most typical glacial delta plain found within the lake area. Its surface is nearly flat. Its margin is strongly lobate, falling off abruptly fifty to fifty-five feet. Its area is about a square mile. Its altitude at its front is from 330 to 335 feet, from which elevation its surface rises gradually for nearly a mile, to 360 feet. To the northwest, the plain abuts against a strongly-marked kame area, the knolls of which rise to 420 feet. On the northeastern side, the plain falls off very abruptly eighty feet, into a swamp. The margin here presents, to a slight degree, the concave, steep, and billowy appearance characteristic of deposits built against an irregular ice front. The material of which the plain is built

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varies from fine sand to coarse gravel and cobbles, but bowlders are uncommon, or altogether wanting.

Just north of this plain is a moraine-like kame belt half a mile in width. The hillocks are of coarse material, and in general thickly strewn with bowlders. During the time that the Upper Preakness delta was being built by glacial streams, which flowed into a lake whose waters stood at a height of between 335 and 340 feet, the kame belt would seem to have been forming just beneath and at the irregular margin of the ice. A large ice mass perhaps occupied the area of the swamp just north of the plain.

h 2. North of the kame belt is another but more irregular plain of sand and gravel. While it was probably not fashioned entirely beneath water, and perhaps not principally, its surface still seems to have been more or less modified by the action of standing water. But this is not beyond question; to have extended over it, Lake Passaic must have had an elevation of about 412 feet. The surface of this plain is not strewn with bowlders, and in this respect it is in marked contrast with the half-buried moraine-like kames which, near its southern margin, rise above its surface. The evenness of the surface of the plain is further broken by numerous sinks and hollows, which may find a partial explanation in the unequal settling of the sand and gravel, due to the melting of blocks of ice incorporated in the sand and gravel of the plain during their deposition. The height of this plain accords with the height of the Jacksonville delta, while that of the Upper Preakness plain corresponds to the terraces near Pompton, and the lower benches near Boonton and Montville. The relationship of the 412-foot plain, to the moraine-like kame area, on its outer margin, is such as to strongly suggest that it was formed after the lower plain at Upper Preakness.

h 3. On the slope of Second mountain, one and a half miles west of Haledon, there are terraces at two levels, the upper marking a water stage of 405 $\pm$ feet, the lower, one of 340 feet. In places the lobate delta margin is well developed, falling off steeply thirty to forty feet. These terrace plains are closely associated with kames, some of which rise steeply above the surface of the plain, while others are partially buried near the outer part of the plain. The surface of the kames is marked by many bowlders, whereas they are very rare upon the surface of the terraces. The terraces are composed of sand and fine gravel. Here again we seem to have a kame area,

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probably formed between or beneath the ice, as shown by the bowlders on its surface, and which was afterwards partly buried by the sand and gravel of a glacial delta, formed when the ice had retreated a short distance from the kame belt.

Traces of the higher plain were noted between the kames further north, toward the higher plain north of Upper Preakness, but they are not distinct. The relationship in time of the higher terrace to the lower, where they are both present, will be considered later.

h 4. There are no shore lines along the trap ridge between the terraces west of Haledon and Caldwell, a distance of seven miles, unless a small, spit-like form, half a mile north of Cedar Grove, having an elevation of 375 feet, is to be regarded as such. In the vicinity of Caldwell there is a somewhat extensive sand and gravel plain, whose evenness and regularity are more or less interrupted by kames and ravines. Those kame hillocks whose summits are of about the same height as the plain are somewhat flattened, as if more or less truncated by the waves. The plain is well developed near the school-house and cemetery of Caldwell, where its height is 385 to 387 feet. It rises towards the east, being about 410 feet at the Presbyterian church, half a mile east by south of the school-house. This plain indicates a lake-level of 385 to 390 feet.

In front (northwest) of the school-house and cemetery, this higher terrace falls off somewhat abruptly to a lower one, whose average height is about 363 feet, and whose width is from 150 to 200 yards. Half a mile north by west of the church, this lower terrace is better developed, its outer edge being 358± feet in altitude, and its upper margin 369 feet. Above, there is an indistinct bench at an elevation of about 400 feet. In front of the school-house, the outer margin of the lower terrace is more or less delta-like, and falls off steeply forty or fifty feet.

The higher plain (393± feet) about Essex Fells, one mile southwest of Caldwell, is a continuation of the upper part of the school-house level, while the poorly-defined level west of the depot at Essex Fells is about 360 feet high, and appears to correspond to the lower terrace at the school-house. Numerous pits have been opened in the kames about Caldwell, but there are no large exposures showing the structure of the plain surrounding the kames. The thickness of the stratified gravel is very great. A well near the school-house was sunk 120 feet, and one near Essex Fells station 145 feet, neither of them reaching bed rock.

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h 5. A mile south of Roseland a small terrace was noted on the slope of Second mountain. Its height is about 370 feet (hand-level), and it may be wave-built in origin, but no positive assertion can be made to this effect. At one or two other places, also, between Caldwell and Summit, faint traces of what might be wave-built forms have been seen.

4. *On islands.*—k 1. Near the northern end of the trap hill west of Livingston is a small deposit of gravel, largely trap, poorly waterworn and strongly resembling the trap gravel beds of the extra-morainic portion of the basin, save that there is a larger percentage of foreign pebbles. This deposit, which, where exposed, does not exceed five feet in thickness, lies between two hills of trap, which must have been islands in the lake. The height of the gravel bed is 378 feet (hand-level), agreeing very closely with the spit and wave-cut terrace northeast of Morristown, due west across the lake. This may probably be referred to the lake waves, although it is possible that it might have been formed beneath the ice.

k 2. Again on Hook mountain, half a mile northwest of Horse Neck bridge, is a small, spit-like deposit of fine gravel. Its entire length is less than 100 yards, and its upper edge has an altitude of 386 feet. Other than this rather indefinite feature, no traces of shore lines could be found upon Hook mountain.

Within the area of the lake, there are many hills 250 to 360 or 370 feet high. Some of these are of sand and gravel, others of till, and still others seem to be mainly of sand and gravel more or less thickly veneered with till. Careful search failed to show any unmistakable shore features upon the regular slopes of these hills. This indicates the rapid final draining of the lake, a point which will be discussed later.

Summary of Shore Features in the Intra-Morainic Basin.

In that part of the lake basin lying within the moraine, the chief constructional shore features are glacial deltas, built in immediate juxtaposition to the ice, by heavily-laden glacial streams. Under these conditions the supply of material was great, and the growth of the deltas rapid, resulting in the production of very considerable plains, in a comparatively brief time.

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These glacial deltas are numerous and decisive in character. They occur in greater numbers and better development on the west and northwest side of the lake than upon the eastern shore. In one case, at least, these deltas were built out into water seventy to eighty feet deep, and depths of forty to fifty feet are common. The plains north of Montville, west of Jacksonville school-house, and at Upper Preakness are the best examples.

In the two last-named cases, the northern margins of the deltas show the irregular form and the hummocky surface slopes characteristic of gravel beds which were originally built against the ice, and which have since slipped and fallen down as the ice melted, though retaining in part the irregularities of the ice mould in which they were cast.* Several of the other plains pass into kame areas which are believed to have been formed beneath and at the irregular edge of the ice, and to mark the position of the ice front, at the time of the formation of the glacial deltas. The surface of these kame belts is often strewn with bowlders, in marked contrast to the surface of the associated delta plain. In a number of cases, kames of an older generation have been partially buried by the advancing front of the growing deltas. This is true of the Caldwell area particularly.

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

In addition to the highest shore line indicated by the tops of all the glacial deltas except the Upper Preakness plain, two indistinct lower levels can be made out in several places. One of these is about twenty feet, the other between sixty-five and seventy-five feet below the highest. The time relationship of these inferior levels to the maximum will be considered later.

In addition to these glacial deltas there are a few small spits connected with what appear to be wave-cut terraces, and a few kames whose summits seem to have been somewhat truncated by the waves, but aside from the glacial deltas the wave-built forms are not conspicuous or decisive.

* This report, pages 152-6.

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As in the extra-morainic portion of the lake, the constructional shore features are much better developed than those fashioned by the destructive action of the waves. They are so numerous, and on the whole so distinct and so harmonious, that in themselves they constitute proof that the intra-morainic portion of the Passaic basin was occupied by standing water for a length of time sufficient for the accomplishment of the observed results. If the intra-morainic shore features seem disproportionately prominent when compared with the extra-morainic, it must be remembered that the conditions were far more favorable for the development of constructional shore features within the moraine than without, since in the former area the waves beat upon incoherent drift, while in the latter, except for the thin coating of residuary material, they beat upon solid rock. Deltas are the most conspicuous intra-morainic shore features. For the formation of deltas outside the moraine there was little opportunity. The largest deltas within the moraine may well have required far less time for their building than the gravel beds along the trap ridges for their accumulation.

THE LACUSTRINE DEPOSITS OF LAKE PASSAIC.

A. IN THE EXTRA-MORAINIC BASIN.

Iceberg deposits.—Iceberg deposits in the extra-morainic portion of Lake Passaic were discussed briefly in the Annual Report of the State Geologist for 1892.* Later field work failed to bring to light any further facts concerning them. They consist mainly of bowlders similar to those of the moraine, and are found frequently up to altitudes of 340 feet, and more rarely up to the maximum level of the lake. Although distributed more or less frequently over all the basin, they are particularly conspicuous on the low ground in the immediate vicinity of the Moggy Hollow outlet west of Liberty Corner.

In the vicinity of New Providence, Berkeley Heights, and Union Village there are considerable deposits of drift which at one time were thought to be possible berg deposits. But since a tongue of ice probably extended beyond the moraine, down the narrow valley between Second mountain and Long hill, this drift was more probably

* Page 136.

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deposited by this means. This drift, however deposited, bears the marks of subaqueous deposition, or of submergence subsequent to its deposition. We believe it to be till, subsequently covered by the waters of the lake.

As was stated in the report for 1892,* "bowlders of granite, gneiss, quartzite and conglomerate are sometimes found above the probable shore line on the trap ridges." As compared to the bowlders of corresponding material below the shore line, their greater age is shown by their greater decomposition. They are regarded as a part of a pre-morainic sheet of drift.

Lacustrine silts and clays.†—Clays and silts, which are believed to be lacustrine, have been observed at various points, and seem to occupy most of the low areas of the extra-morainic basin. They extend from Green Village, Pleasantville, and Logansville on the north, to the foot of the northern slope of Long Hill on the south, and to the foot of the subaqueous overwash plain on the northeast. They therefore underlie all the area of the Great swamp and the surrounding low ground. Within this area they do not occur above an altitude of 240 feet.

The clay of the eastern half of this area, as far west as the road from New Vernon to Gillette, is covered with fine sandy loam, which, east of the longitude of Green Village, changes into sand and gravel. Clay more or less buried by stratified drift which is continuous with the subaqueous overwash plain, has also been found south of Morristown, on the banks of the brook southwest of Convent, and at the bottom of deep wells southwest of Madison.

There seems good reason for believing that the ice during an advance, just preceding the formation of the moraine, extended at least as far as Green Village, forming the kame-like mounds of sand and gravel ‡ which in that vicinity overlie the lacustrine clay. The fine sandy loam, met with further west, is probably contemporaneous with these gravel knolls. This relationship shows that the lacustrine clay antedates the maximum advance of the ice.

The clay in the Great swamp area attains considerable thickness. In general, artificial excavations do not reach its bottom, except where it is very shallow. Wells twenty-five or thirty feet deep do not pass

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* Page 137.

†Annual Report for 1892, pages 137-140.

‡Annual Report of the State Geologist of New Jersey for 1892, page 86.

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through it, except along the edge near the higher ground. Clay is known to attain a thickness of over a hundred feet in at least one locality,* a mile and a half south of Green Village, although there is no positive evidence that all this clay is lacustrine.

Although the clay in the Great swamp area does not extend higher than 240 feet, similar clay has been observed at greater elevations outside the swamp. At the clay pits south of Morristown it has an elevation of 310 to 320 feet. Here it is overlain in places by two to three feet of stony clay, which closely resembles the clayey till in the vicinity of New Providence and Union Village. Fresh, glaciated cobbles and bowlderets of slate, limestone, gneiss, Green Pond mountain conglomerate, and trap are contained in this stony clay. A few glaciated pebbles were noted well down in the lacustrine clay. The stony clay is not separated from the underlying lacustrine clay by a sharp line, but passes into it by a transition layer of no great thickness. Here again the relationship is such as to indicate that the lacustrine clay antedates the maximum advance of the ice.

A mile southwest of Convent station, lacustrine clay, beneath a layer of stratified sand and gravel, is exposed along the brook near the Spring Lake Company's ice-house. The clay has an elevation of 270 to 280 feet. Here the brook has not cut more than fifteen feet in post-lacustrine times.

Again, three miles south of Morristown, near the red shale gravel deposit (d 4), on the property of Mr. F. F. Lippman, lacustrine clay is exposed along the road for 175 yards to a maximum depth of eight feet. Its vertical range is from 315 to 345 feet. This clay is somewhat stony, containing pebbles of red shale and trap. In this respect it differs from the clay at low levels, which rarely contains stony material. This is the highest point at which lacustrine clay, or clay apparently of lacustrine origin, has been noted.

Between Second mountain and Long hill, along the Passaic and Dead rivers, there is considerable clay. It does not reach elevations higher than 220 or 225 feet. In appearance it is similar to the clay of the Great swamp area, but it has not been shown to antedate the morainal accumulations. Indeed, as will be seen later, some of it at least, probably belongs to the closing stages of Lake Passaic.

The lacustrine clay at the lower levels is "fatty or greasy," and a little below the surface is finely laminated, the thin laminæ of clay

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*Annual Report of the State Geologist for 1892, page 139.

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being separated by fine partings of a more sandy nature. It is calcareous, much more so than the adjacent portions of the moraine.

It frequently contains concretions of carbonate of lime. These concretions are very abundant in certain layers of the clay. They sometimes occur in clumps in certain horizons rather than being regularly distributed. They have their flat sides parallel to the layers of clay. In shape they are curious and varied, ranging from slender cylinders five or six inches in length, and half an inch in diameter, to perfect spheres and round disks. Many of the disks are double, roughly resembling a pair of eye-glasses, and showing a marked degree of symmetry. The accompanying plate shows a number of typical forms taken from a well at a depth of twelve to twenty feet, on the farm of Mr. A. H. Baird, Pleasant Plains. Similar concretions occur in the clay pits south of Morristown. (See Plate VI.)

In addition to the evidence drawn from the shore features, the berg-dropped bowlders and the lacustrine silts and clays, there are other facts, or series of facts, which possess a corroborative significance. When compared with the residuary soils above the shore line, the soil and subsoil covering the trap ridges below this line often possess slight but significant differences. These differences were noted more particularly on the gentle slope of Second mountain, although it is not always discernible even here, and is occasionally conspicuous elsewhere. The difference is shown in several ways: (1) In addition to the fresh-appearing foreign bowlders, dropped by icebergs, trap pebbles, which have the appearance of wear, either because of partial rounding or by reason of freshened surfaces due to the removal of the weathered outer layer, are somewhat widespread. This is true even where there are no beds of shore gravel. (2) The trap pebbles are frequently in a clayey matrix, somewhat unlike the unmodified trap residuary clay. The exact difference is difficult of definition in words, but less difficult of recognition in the field. In general, the matrix seems more compact below the lake level, and the pebbles seem to be set in it somewhat differently. Below the lake level, too, there is not the same transition from greater to less oxidation from top to bottom as in the most typical residuary deposits. In many cases this re-working of the trap residuary is very slight, and the differences in appearance are not obtrusive. In some cases, careful search reveals the presence of a few foreign pebbles along with those of trap origin, in the matrix of clay. So far as observed, these characteristics are limited

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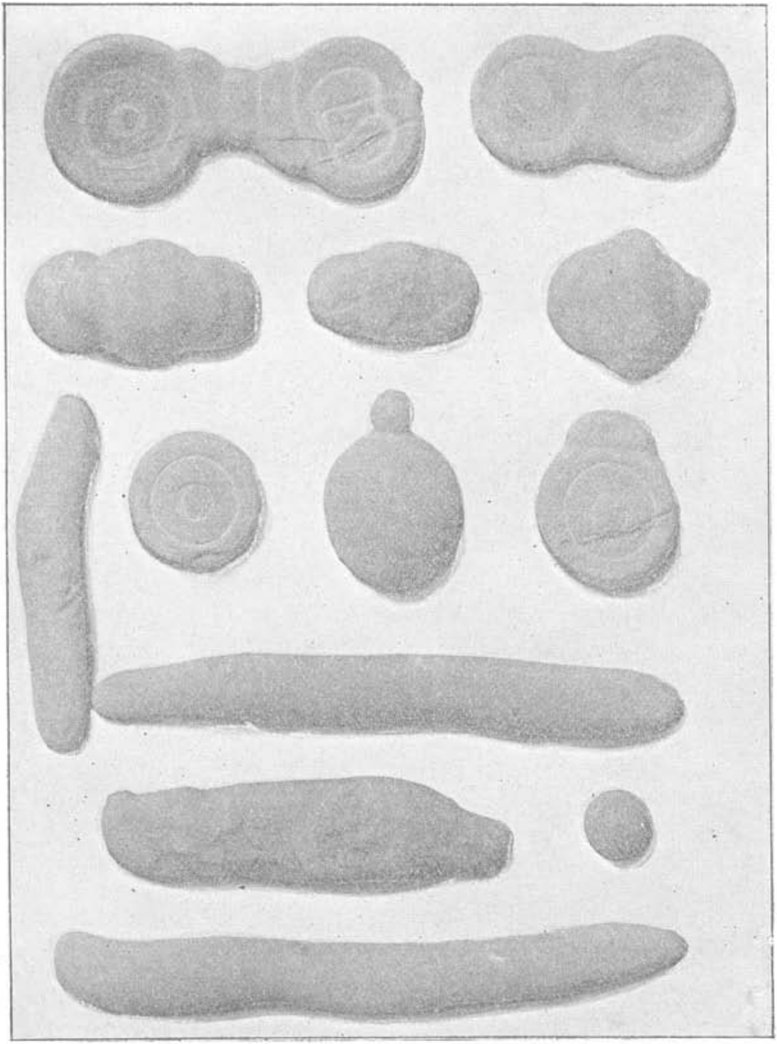

Plate VI.

Calcareous concretions from the lacustrine clay. About two-thirds natural size.

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to the trap soils below the shore line and are not found in the trap residuary above that limit.

In many places, also, the soil on the red shale within the lake basin possesses a waxy, clayey nature, not characteristic of unmodified red shale residuary. This waxy character is what would be expected in a shale residuary soil which had been submerged and more or less re-worked beneath the lake. In the case both of the trap soil and the shale soil, it is not easy to assert, positively, that these changes are due to lacustrine conditions rather than to any other, but since, so far as observed, they are limited to the lake basin and do not occur above the shore line, it is a rational inference that they are due to the lake.

B. IN THE INTRA-MORAINIC BASIN.

Iceberg deposits may have been formed in this part of the lake basin during the period of ice advance, before the glacier reached the limit now indicated by the moraine, and also during the period of ice retreat. The earlier deposits must have been overridden afterwards by the ice, and more or less buried by the later deposits formed in direct connection with the ice. It is, therefore, extremely improbable that any of this theoretical early berg till is anywhere exposed in the lake basin, or, if exposed, that it could be recognized. Berg deposits formed during the retreat of the ice may be present, but their discrimination would be very difficult, and in the majority of cases impossible.

Clays which are of the lacustrine type have been observed at several localities within this part of the lake basin. They are finely laminated, with thin partings of very fine sand. Like the extra-morainic lacustrine clays, they are waxy or greasy, more or less calcareous, and contain concretions similar to those found in the lacustrine clays of the Great swamp area. These clays are generally at low levels, and are associated with clays which may be post-glacial in origin. Such are the clays found in the marshes along the Whippany river. Brownish-blue clay, which is probably lacustrine, was noted on the hill midway between Whippany and Hanover, at a height of 230 feet—sixty feet above the river and marshes. Here it is overlain by several feet of stony, clayey till. North of West Livingston there is a low area, having an altitude of 200 feet, which seems to be covered with lacustrine clay, but there were (1893) no good exposures by

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which this point could be tested. Similar clay, containing concretions, is exposed on the right bank of the Rockaway river, a mile and a half northwest of the south end of Hook mountain. Here the river has cut through a thin coating of glacial sand and gravel into the underlying clay. Between Little Falls and Mountain View and north of the latter place is considerable clay which, where exposed in pits, is of the lacustrine type. It is all at low levels, 170 to 190 feet, and is overlain by stratified material, and in places by till. At one of the largest of these pits, half a mile north of Mountain View station, the laminæ of the clay are sharply crumpled and contorted into anticlines and synclines two to three feet in diameter. The crumpling is best marked in the upper layers, although all exposed layers, ten feet or so in thickness, are affected by it. The axes of these folds extend, as nearly as can be determined from the exposures seen, from northeast to southwest, or roughly speaking, parallel to the direction of glacial movement. The clay in this pit is overlain by six or eight feet of glacial sand, which is contorted very similarly to the clay, and which contains a few cobbles. The cause of this contortion is not known. Since many of these clays are covered, locally at least, by till, they would seem to belong to an early period of the lake's history, if they are lacustrine at all.

In addition to the lacustrine clays, there are certain peculiarities of the glacial drift in parts of the lake basin which may be due to lacustrine conditions. These were mentioned in the annual report for 1892.* In brief they are as follows: Between Parsippany and Madison, and eastward to the Passaic river, a thin but variable layer of till covers a great depth of sand and gravel. Over considerable areas, every excavation a few feet in depth penetrates the stratified material. This relationship is frequently seen in the deeper road cuts. Not uncommonly the stratified drift outcrops in small areas on the crests or steep slopes of a hill, while the greater part of the surface is covered with till, or with a stony clay which has not been distinguished from it. In some cases the topography seems to be determined by the underlying stratified gravel, no more than slightly modified by the thin veneering of till.

Much of the till is not of the normal type. This abnormal phase is stony, but not gritty. On the contrary, it is very clayey. It has a more or less greasy feeling, a waxy or glazing surface when cut,

* Pages 56, 57, 142.

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and a pronounced tendency to crack on drying. Many of the pebbles are coated with a thin film of clay, which is not easily removed. The color is dark red, tinged with brown. This clayey till occurs most commonly at low levels of the lake basin, 180 to 210 or 220 feet, but it is by no means limited to these heights, having been observed at a number of places at heights up to 270 feet. It is not possible to say to what extent this till was formed beneath the ice and afterwards submerged, and to what extent it was formed beneath water by the combined action of icebergs and water. Normal, gritty, stony, foliated till is not uncommon within the lake basin, and sometimes occurs in close proximity to the clayey, waxy till. This might suggest that the latter is due to iceberg action rather than to the modification of glacial till by submergence. On the other hand, the peculiar type of stony clay here referred to seems to be much too continuous over considerable areas, and too closely confined to the lower level, to make its reference to bergs plausible. Nowhere has this clayey till been found upon the sides of the basin up to the shore line. Something similar to it has been found on the low-lying (forty to fifty feet) Triassic areas outside the lake basin near the coast, where post-glacial submergence may have occurred.

THE OUTLETS OF LAKE PASSAIC.

Liberty Corner outlet.—A mile and a half west by north of Liberty Corner, at Moggy Hollow, is a notch in the rim of the basin, through which Lake Passaic drained during its maximum stages. The bottom of the notch has an altitude of 331 feet, and with the exception of the gaps at Little Falls and Paterson, and the low ground along the Pompton river, all of which were closed by the ice when the lake existed, this is the lowest point in the rim of the basin. That a large stream of water formerly flowed through this notch is at once evident (1) from the size and shape of the notch itself, and of the valley below the notch, (2) from the deposits in the North Branch of the Raritan at and below its junction with the lake outlet, and (3) from the deposits in the lake basin at the entrance to the outlet.

The notch is a flat-bottomed, steep-sided trench, sixty yards wide at the bottom and 157 yards wide at the height of the maximum lake level. Figure 27 is a sketch made from a photograph, looking down the outlet.

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The notch is cut in hard trap rock, which outcrops at many points on the sides and bottom. Just east of the entrance to the notch is a broad, ill-defined divide, at an altitude of about 331 feet, between a stream flowing eastward into Passaic river and another flowing westward into the North Branch of the Raritan. Westward from the divide the bottom of the notch falls sixteen feet in the first 1,100 feet, and then makes an abrupt fall of twenty-five feet. Below the fall the bottom of the gorge is marshy for some distance. The stream which at the present time flows from the 331-foot divide through the notch and over the fall is so insignificant that it is impossible to sup-

Fig. 27.

Moggy Hollow outlet, looking down the valley, which turns abruptly to the left in the background. (Drawn from a photograph.)

pose the notch, as we find it to-day, to have been cut by it. It is also impossible to suppose that the bottom of the notch has been lowered an appreciable amount by it since lacustrine times. It is equally inconceivable that the notch, in its present form, could be the col between the headwaters of two pre-glacial streams. Its form is altogether conclusive that it was the channel through which flowed a stream of water whose average width was over 100 yards, and whose depth was sufficient to give it great velocity. In pre-lacustrine times there may have been a col on the site of the notch, but the notch in its present form is due to erosion by the outflowing current.

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About a quarter of a mile below the falls, the gorge loses, to some extent, its flat-bottomed character, and the present stream has slightly eroded the bottom. Where the valley passes from the trap to the underlying sandstone and shale, three-quarters of a mile west of the first falls, another waterfall has developed. A short distance below the second fall the valley widens out into the broad flat which borders the North Branch of the Raritan. On this flat are strewn many trap cobbles and bowlderets up to one foot in diameter. These pieces of trap were quarried out of the notch, or out of the valley immediately below it, and were carried down to their present position by the outflow of the lake. They are far too large to be handled by the present stream, which, indeed, it has been necessary to ditch in order to get it across the deposits made by the outflow of the lake.

Below the junction of this valley with the North Branch, the flood-plain of the latter is a little wider than above the junction, and its materials are more than ninety per cent. of trap, many of them beyond the power of the present stream to carry. Above the junction, trap pebbles do not form more than ten or fifteen per cent. of the deposits of the valley plain. These deposits confirm the conclusions already drawn from the form and size of the outlet, that a stream of considerable dimensions, and of great velocity flowed through the notch in comparatively recent times.

A significant feature in this connection is the number of large, fresh gneiss bowlders, similar to those found in the moraine, which occur below the shore line near the entrance to the outlet. They are more abundant here than at other points in this part of the lake basin, and are taken to indicate that currents set towards the outlet, bringing to this point bowlder-bearing icebergs.

In juxtaposition to the outlet there is a considerable body of drift, some of which is glacial. It extends to a maximum height of 435 feet in this vicinity, and downward below the level of the lake. One phase of the drift is exposed in a pit a quarter of a mile south of the outlet. Here the drift is seen to be compact and stony, with a matrix composed largely of gneissic material. The stones are generally small, under eight inches, and consist of various quartzites, similar to those of the Triassic conglomerate, decomposed gneiss, Potsdam (?) sandstone, Hudson river (?) shale and slate, Triassic shale, flint and trap. A more satisfactory exposure of the drift occurs along the road toward Liberty Corner, where its till character is shown.

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At first thought, the presence of this body of drift about the outlet, at heights seventy-five feet above any possible lake level, might seem fatal to the lake hypothesis. But this drift has nothing to do with the lake. It is to be correlated with the bodies of extra-morainic drift found in other parts of the State, which are confidently believed to be much older than the moraine, and to have no chronological or genetic connection with Lake Passaic. That part of this drift, however, which is below the lake level was doubtless more or less modified by lacustrine agencies, and may be, in part, berg drift.

The Millington gorge.—The Passaic river escapes from the area of the Great swamp by a deep, narrow gorge through Long Hill, at Millington. The gorge is sixty to seventy feet deep, very steep-sided, and, so far as its shape is concerned, seems to be of very recent origin. If the gorge were to be filled up for sixty or seventy feet from its base, so that the top was 280 or 290 feet in height, a basin would be formed in the area of the Great swamp, the lowest point on whose rim would still be at this gorge. If this gorge has been eroded since the maximum lake stage, and some things may be said in support of this proposition, we must conclude that after the ice had freed the Little Falls-Paterson outlet, and thereby drained a large part of the lake, and brought the level of the remainder below the Moggy Hollow outlet, a small lake still occupied the area of the Great swamp, and that it persisted, with constantly-diminishing level and area, until its outlet across the trap ridge at Millington had been cut down nearly to its present level. Judging from the shape of the gorge, the maximum amount of post-lacustrine cutting might have been sixty or seventy feet, the bottom of the outlet being originally, in terms of the history of Lake Passaic, at an altitude of 280 or 290 feet. It certainly could not have been more than eighty-two feet above the present channel, for at Lyons station there is a sag in the rim of the basin at an altitude of 303 feet, that is, but eighty-two feet above the river at its entrance to the Millington gorge. If the gorge at Millington were filled up to a level higher than 303 feet, the hypothetical remnant of Lake Passaic would have been drained by way of Lyons station and Harrison's brook instead of via Millington. If the gorge at Millington was cut in post-lacustrine times, the Great swamp lake must have existed for a considerable period after the rest of the lake basin had been drained, for the gorge is cut in

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trap rock, and the stream flowing from the Great swamp lake must have been free from sediment, and so have had but slight cutting power.

If the Millington gorge be post-glacial, shore marks at heights corresponding to its top, and to levels below its top, might be expected to exist. A few beds of shore gravel have been found at heights varying from 285 to 295 feet. Two well-marked beds of red shale gravel occur along the road between Basking Ridge (c 17, 285 feet; c 18, 291 feet) and Madisonville, and traces of water-worn trap pebbles were found along the road three-quarters of a mile west of Green Village. But shore features at this level are neither so numerous nor so distinct as we should expect in a lake lasting the length of time necessary to cut the gorge in the hard trap. It should be remembered, however, that the lake was much reduced in size at this stage, and that its waves were correspondingly less efficient.

If the gorge be the result of post-lacustrine erosion, there should be considerable deposits of trap gravel along the Passaic just below the gorge. The material could not have been carried away, since beyond the gorge the stream is far too sluggish to carry gravel. Trap gravel is present in the bed of the stream and in the flood-plain, but apparently not in great quantity. From lack of exposure its quantity may be underestimated.

We cannot well suppose that the gorge was occupied by such a river as the Passaic in pre-lacustrine time. It seems to be too narrow and too steep-sided. A comparison of this gorge with the pre-glacial valleys of much smaller streams, such as Stony brook, which crosses the massive trap ridge of First mountain, back of Plainfield, seems conclusive upon this point.

It is possible to suppose that the gorge is located on the line of a narrow gorge or ravine which had just been cut by the headwater erosion of a small stream, when the lake came into existence, and that during and after the draining of the lake the ravine was deepened and widened, and its sides steepened by the larger stream draining the Great swamp country. The objection to this view, although it is not believed to be fatal, is that the profile of the gorge does not indicate recent cutting in an older valley. The only answer to this objection is that the older valley may itself have been young when the lake began its existence.

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When the Millington gorge is compared with the post-lacustrine gorge at Stanley, there seems to be good proof that the former is not, in the main, post-lacustrine. This evidence is given a few paragraphs below. The above conclusion is corroborated by the apparently small amount of trap gravel in the Passaic valley just below Millington.

In connection with the discussion of the history of the lake, the possibility of a lake having existed in the Great swamp area in inter-glacial time is considered. The outlet of this lake may have been across Long Hill at Millington, and the present gorge may have been partly eroded in inter-glacial time. As will be seen later, there is good reason for postulating the existence of this inter-glacial lake.

The Stanley outlet.—Near Stanley, the valley of the Passaic is much constricted, and the river has in post-lacustrine times cut a passage across a dam of drift. The amount of post-glacial cutting is here about twenty-five to thirty feet. Eighteen feet of it is in drift, the remainder in red shale. The passage which the river has cut here is much wider, less steep-sided and less deep than the gorge at Millington. The differences in width and slope are due to the difference in hardness of the materials through which the stream has cut. The difference in depth between the post-glacial gorge at Stanley and the gorge at Millington is most significant. All conditions seem to favor erosion at Stanley as compared with Millington—1°, the size of the stream is greater at Stanley; 2°, its gradient seems to be equally high, and 3°, the material in which it has had to cut is very much more easily eroded. If, under these circumstances, the post-glacial cutting at Stanley has been no more than the figure cited above, the amount of post-lacustrine erosion at the Millington gorge must have been much less. The altitude of the obstruction through which the river has cut was about 230 feet. It would seem that after the ice freed the Little Falls-Paterson outlet, a long, narrow lake must have existed, temporarily, behind this barrier in the valley between Second mountain and Long Hill. If the Millington gorge were as low as at present, the Great swamp must have been a greater swamp, hardly a lake, at this time. The lake between Second mountain and Long Hill must have been shallow, its greatest depth not much exceeding twenty feet. The lake must have been studded with islands. It must have been short-lived, since the upper part of the barrier at Stanley, down to about 212 feet, was composed of easily-eroded till. When the outlet was cut to this level, the lake would have mainly disappeared. A

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single bed of shale gravel, six feet thick, was found a mile southwest of Gillette station, at a height which permits its reference to this lake. It is interesting to note further that all the lacustrine clay between Long Hill and Second mountain lies below the level of such a lake as is here described, and furthermore, that most of the surface below this level is clay-covered. So small a body of water could not have had waves of much strength, and its deposits must have been, for the most part, of a clayey nature. The lacustrine clay seems to indicate very clearly that such a lake existed. It must have been ten to twelve miles in length, and a mile to a mile and a half in width. It was confined to the low area immediately adjacent to the Dead and Passaic rivers. Since the latter name has already been appropriated, this subordinate lake may be called Dead lake, an appellation which has a double fitness.

*Little Falls gorge.**—Second mountain is broken by a gap more than two miles wide, where it is crossed by the Passaic river at Little Falls. The bottom of this gap is nearly flat and is covered with a thin coating of till, clay and fine sand. At Little Falls the Passaic river has cut through this drift covering, which here does not exceed ten feet, and has eroded a channel in the trap beneath. On the glaciated ledges of trap on both sides of the river are many pot-holes of varying sizes. Most of them are shallow, and appear to have been more or less worn away by glaciation. The height of these pot-holes is 179 feet, and their presence on a glaciated surface seems to indicate that in pre-glacial times the river had here cut the trap down to this level. Above the trap, as indicated, the drift is not more than ten feet thick. It is, therefore, safe to conclude that when Lake Passaic was drained, after the retreat of the ice, the waters could not have been held here at a height of more than 190 feet, and must have been held to a height not more than 15 feet less than 190 feet.

The falls have within the last few years been blasted away, but their former position and height can be accurately determined. The top of the ledge over which the water fell in the main fall is 148 feet, and if, on the draining of the lake, the river flowed at a level of about 183 feet (the mean of the preceding limits), it appears that by erosion on its bottom the river has lowered its channel five to ten feet in drift and about thirty feet in trap. The falls have receded

* George H. Cook, Annual Report of the State Geologist, 1882, page 15.

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about 700 feet from the mural front of the trap where the contact between the trap and shale crosses the river. It is not positively known, however, that all of this recession is post-glacial. The breadth of the falls in their position at this mural front was about 300 feet and their height probably fifty feet. During their recession they lost in height, owing to the deepening of the channel in the trap above the falls. It is estimated that 434,000 cubic yards of trap rock were excavated by the river from the gorge below the falls, and an additional 181,000 cubic yards from the channel between the head of the falls and the ledges at the Beatty dam. Besides this, about 125,000 cubic yards of drift have been carried away between the dam and the end of the gorge. Below the gorge of trap the river is hemmed in for half a mile or more by steep walls of red shale, which diminish in height down stream from the trap front.

Midway between Little Falls and West Paterson the river, which is flowing northeast, makes a sharp turn to the southeast, and then, half a mile beyond, makes a sharp turn to the left, resuming its northeasterly direction. These turns are caused by two enormous kames, which are built, like a dam, almost across the valley. At its second bend, the river flows around the southeastern end of this dam, in a narrow valley between the drift and the trap of First mountain. At first sight it might appear that the drift once completely dammed the valley at this point, and that the river has since cut its way through it. In this case the waters of the lake must have been held for a short time at about 250 to 255 feet. Careful examination of the valley at this point, however, seems rather to show that the drift never completely filled it, but that the river found a passage around the end of the kame, being shifted by the drift to the right-hand side of its valley, against the trap of First mountain. The sides of the kames where the river makes its first bend to the southeastward are being eroded by the lateral cutting of the river, whereas the end of the kame around which the river swings at the second bend appears to have a constructional slope.

Passaic falls.—At West Paterson the Passaic river crosses First mountain through a gap two miles wide. In the bottom of this gap the river has cut a deep gorge, at the upper end of which the stream plunges over the side of a narrow cañon seventy feet deep. When the ice had so far melted as to open this outlet, the river must have

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flowed at an elevation not higher than 150 feet, and not lower than 125 feet, for at higher levels the water would have chosen some other channel. Since this height is at least twelve feet lower than the height of the lowest swamps in the lake basin, this rocky barrier could not have caused subordinate lakes within the Passaic basin.

Previous to the improvements for manufacturing purposes, the larger part of the river flowed into a side gorge, the "race," about 340 yards above the head of the present falls. Between this gorge, at the head of which were steep rapids, and the narrow cañon at whose head were the falls, was a long, narrow, rocky island. Originally the falls was probably located at the eastern front of the trap ledge about 630 yards north of the end of the "race" gorge, and was then 85 ± feet high, and 140 ± yards wide. It slowly receded about 275 to 325 yards, and then became divided into two parts, one of which receded up the "race" gorge, the other up the deep cañon at the head of which is the present falls. The head of the cañon has retreated 150 ± yards from the point of separation, and the "race" gorge was worn back about 300 yards. A very rough estimate, probably too small rather than too large, of the amount of trap rock eroded from these gorges, gives 1,493,100 cubic yards. This is equivalent to a column of rock 300 feet on a side and 447 feet high. No data are at hand by which to estimate the time involved in such excavation.

Great Notch.—Three miles south of Paterson, First mountain is cut by Great Notch, a deep, narrow, steep-sided gap, whose bottom has an elevation of 303 feet. It is conceivable that during the retreat of the ice, the gap in Second mountain at Little Falls was opened, before the gap in First mountain at West Paterson. In this case the lake must have overflowed through the Great Notch at an altitude of 303 feet, if the ice freed the Notch before it did the West Paterson outlet. Since they are so near together, the West Paterson gap would be expected to be opened very soon after the Little Falls gap, and therefore the outflow through Great Notch, if it took place at all, could not have been of long duration. If the water escaped there, even temporarily, it must have stopped the outflow west of Liberty Corner. Moreover, it is possible that Lake Passaic drained through a passage under the ice before its front melted back beyond the Little Falls gap. In this case the Great Notch gap may not have been used.

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Examination of the Notch failed to reveal data which could be regarded as indicating either that the lake did or did not drain through it at any time.

The drift-filled gap at Short Hills.—At Millburn, First mountain is broken by a gap a mile and a half wide. Although drift-incumbered, the lowest point in this gap has an elevation of 100 feet A. T. Opposite and west of this gap the moraine crosses Second mountain, between Short Hills and Summit. West of Short Hills the surface rises slightly above 380 feet. This elevation represents the lowest point of the gap in Second mountain, almost two miles west of the gap in First mountain at Millburn. From the bottom of this gap, at 380 feet, the surface descends westward towards the lake basin, and eastward towards the wide gap in First mountain. The average height of the trap crest of Second mountain northeast of this gap near Short Hills is 575 feet. Its average height towards the southwest is 550 feet. Since the morainal accumulations in the vicinity of Short Hills are very considerable, it is evident that the gap in Second mountain, opposite the gap in First mountain, is very much more considerable than it seems. Some idea of the size of this gap may be obtained when it is recalled that, even with the drift-filling, the surface is 170 to 200 feet lower than the average height of the crest of Second mountain.

A few years ago a deep well was dug about a mile north of the Short Hills depot, and nearly in the middle of the 380-foot sag. The elevation of the surface at the site of the well was about 370 feet A. T. The well was sunk *200 feet* without reaching the trap rock.* The rock bottom of this gap, therefore, must be below 170 feet A. T. That it must be considerably less than 170 feet is shown by the following data—1°. At the greenhouses of Mr. Jones, opposite the Short Hills depot, a well was sunk 150 feet without reaching rock. The elevation of the surface at the site of this well is about 200 feet. Rock at this point is, therefore, less than fifty feet above sea-level. The well is located in the shale valley between First and Second mountains, and in line with the gaps in First and Second mountains, respectively. 2°. A quarter of a mile east of this boring is the well which supplies Short Hills with water. This well has an elevation

* These data and those concerning the second well mentioned below were obtained from Mr. Stewart Hartshorn, Short Hills, N. J.

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of 200 feet A. T. and is 200 feet deep, at which depth rock was struck. Therefore the rock bottom of the gap in the shale between First and Second mountains is at one point known to be at sea-level, and this is not known to be the lowest point. The known deep gap in Second mountain near Short Hills, the deep gap in First mountain at Millburn, and the known deep buried valley between the two mountains, and in line with the two gaps, give strong suggestion that a pre-glacial stream flowed through these gaps to the sea. Apart from this gap in Second mountain near Short Hills, the lowest possible pre-glacial outlet of the basin was at Little Falls, and this, so far as known, was not lower than 180 feet (see page 328). The boring referred to, therefore, reached a level ten feet lower than any other known pre-glacial outlet of the Passaic basin. This seems to confirm the suggestion just made, that in pre-glacial time a stream flowed through the gaps in First and Second mountains, at Short Hills and Millburn, respectively, and thence to the sea.

This leads to another important inference. It will be remembered that the bottom of the rock valley between First and Second mountains is known to be as low as sea-level at one point, and that this is not known to be its lowest point. Now, if the rock bottom at the gap in Second mountain be no lower than 170 feet—the bottom of the boring—the pre-glacial stream must have had a fall of 170 feet on the south face of Second mountain. The width of the gap is such as to militate against this conclusion. It is so great as to indicate that the stream which occupied it was of considerable age. The chances against its being possessed of any such fall are good. It is probable, therefore, that the rock gap in Second mountain is very much lower than 170 feet, the height at which the boring ceased.

It follows that the main drainage of the Upper Passaic basin in pre-glacial times was almost certainly through the Short Hills-Millburn gaps. Manifestly, therefore, Lake Passaic could not have come into existence until the first of these gaps was closed.

The Summit Notch.—A little east of Summit station is a narrow, steep-sided notch in Second mountain. Its bottom is now at an elevation of about 320 feet. About Summit station and westward there are thick accumulations of drift. The elevation of Summit station is 387 feet. It would seem that the narrow notch east of the station must have afforded an outlet for the lake at a level of 320 feet before the drift

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to the west and westward was accumulated. No evidence of such overflow could be discovered. But since the ice afterwards covered this notch, such evidence could not be expected to exist. The possible existence of this outlet introduces another factor into the problem of the pre-morainic history of the lake, and renders the problem still more complicated. But the insignificance of this notch, in comparison with the gap at Short Hills, is such as to make it probable that this notch did not play an important role in the history of the lake. Nevertheless, the possibility that for a time at least the pre-morainic lake, if it existed at all, may have overflowed at this notch must be kept in mind.

THE HISTORY OF LAKE PASSAIC.

Study of the heights of the various gaps in the rim of the lake basin reveals something of the pre-glacial drainage of that region. Through the lowest gap, that at Short Hills and Millburn, the larger part of the present Passaic drainage escaped. Another stream of much less size, draining the northeastern part of the Passaic basin west of Little Falls, probably flowed through the gaps at Little Falls and Paterson. The drainage areas of these two streams could have been separated by no more than a low divide, as shown by the present topography. Apart from the gaps occupied by these two streams, there were no deep gaps in the rim of the basin. The next deepest was Great Notch, the bottom of which is now 303 feet A. T.

THE ADVANCE OF THE ICE

For a time after the ice sheet reached the gaps in the trap ridges at Little Falls and Paterson, the river which formerly flowed through these gaps may have been able to keep its channel open beneath the ice. So long as this was true, no lake could have been formed within the Passaic basin. But there came a time when such a sub-glacial outlet, if it existed at all, was closed. When this occurred the drainage which, but for the ice-blocking, would have escaped to the sea via Little Falls, must have accumulated in front of the ice in the northern drainage basin referred to above. Any lake which may have been formed at this time must have been

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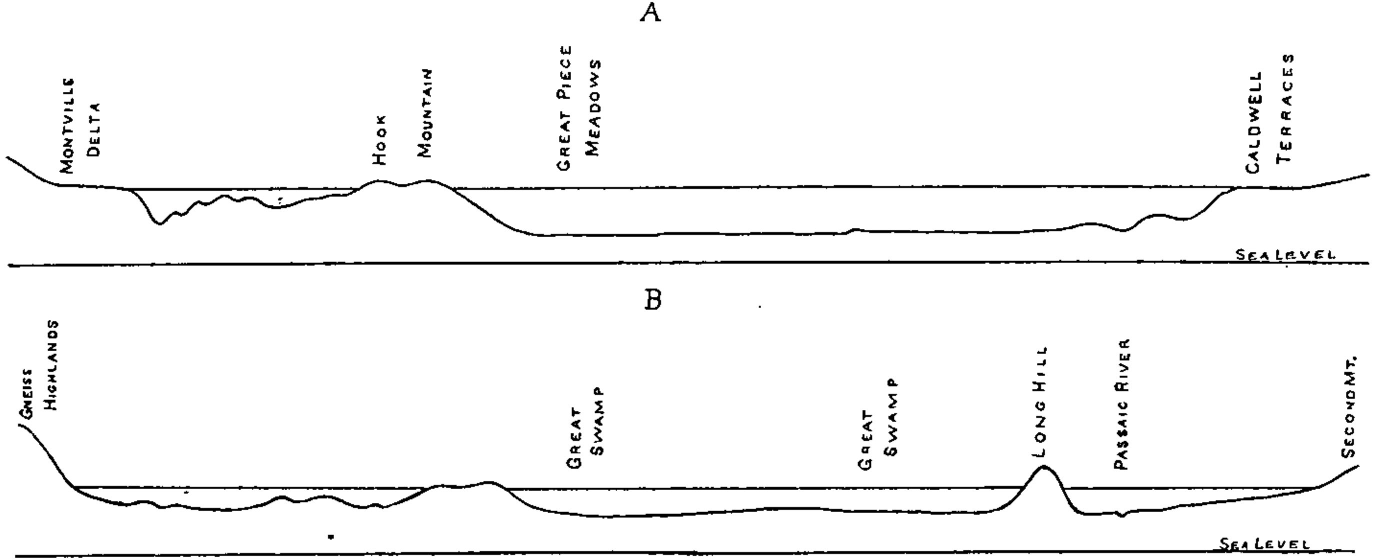

Plate VIa.

Sections of Lake Passaic Basin. A. From the Montville delta to Caldwell. B. Along a line a little northeast of New Vernon and Berkeley Heights. Horizontal scale, 1 mile to one inch. Vertical scale, one-eighth inch to 100 feet. Vertical scale about six and a half times the horizontal scale.

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small and shallow, for it must soon have overflowed the low divide, separating the drainage basin which had its outlet at Little Falls, from that which had its outlet through the Short Hills gap. This divide was in all probability lower than 303 feet, the height of Great Notch, which, therefore, could not have served as an outlet at this time. As the ice advanced it encroached upon this hypothetical early lake, displacing its water and diminishing its size. This process continued until the ice had displaced all the water, and so destroyed the lake. No lake could have been formed in the drainage area of the river which flowed through the Short Hills gap, until after the ice reached that gap and filled it. Then, and not until then, could a lake have existed in the basin south of Morristown. For a time the waters of this lake may have escaped through the narrow notch at Summit (height 320 feet), but since this notch is so close to the Short Hills gap, it must have been filled by the ice very soon after the Short Hills gap was occupied. The lake then drained through Moggy Hollow near Liberty Corner, where there is now a notch, the bottom of which is 331 feet above tide. It is not necessary to assume that when the lake first overflowed at this point the outlet was at this elevation. On the contrary, it was somewhat higher. During the period when this notch served at the outlet, erosion cut it down to the present level. From the evidence of shore lines in the immediate vicinity of the outlet, it is certain that the amount of erosion here cannot have been greater than twenty-five feet. It may have been a little less.

The sequence of events outlined above is based upon the assumption that all the drift in the Short Hills gap is late glacial, and that until the ice reached the line of the moraine, drainage escaped through this gap at the level of the rock bottom. On this assumption, no lake except a shallow one in the northern part of the present basin (see pages 229 and 306) could have existed until the ice reached the line of the moraine and filled this gap. But certain facts have been observed, which suggest the existence of a pre-morainic lake in the southern part of the basin. In the region of the Great swamp extensive deposits of clay are known to exist (pages 290–293). By their relationship to overlying deposits these are clearly shown to antedate the moraine and accompanying overwash plain. If this view be correct, and there seems no escape from it, a lake must have existed in the Great swamp

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area for a considerable period before the ice reached its maximum extension.

Three hypotheses concerning such an early lake may be considered—1°. Some part, perhaps a large part, of the drift filling of the Short Hills gap may belong to the earlier ice invasion which deposited much of the extra-morainic drift (page 270) found more or less abundantly about the lake basin. In this case Lake Passaic might have come into existence for the first time, when the ice filled the Little Falls gap. It would have overflowed through the drift-clogged Short Hills gap while the ice was advancing from Little Falls to Short Hills, if this gap were lower than Great Notch (303 feet) or Moggy Hollow (356 feet). Under this hypothesis, the Great swamp clays could then be referred to this part of the lake's history. Under this hypothesis, we must assume that the ice advanced very slowly, so slowly that more than 100 feet * of clay accumulated before the deposition of the overlying loam, sand and gravel, which is correlated with the greatest advance of the ice. The very general occurrence of these clays at levels below 240 feet might be taken to indicate that the Short Hills gap had this elevation. The clays north of the moraine, which are similar to lacustrine clays, are also in general at low levels, and so far as elevation goes, may have been formed in a lake draining as thus suggested. This hypothesis makes all the clay of the Great swamp, which may be lacustrine, later in origin than the closing of the Little Falls gap by the last ice advance.

2°. We may conceive that the earlier ice invasion wrought such changes in the pre-glacial topography that, after its retreat, a low-level lake occupied the area of the Great swamp, and perhaps also of the lowlands north of the moraine. In this lake much of the lacustrine clay may have been formed. We may suppose further that the lake was drained during inter-glacial time by the clearing out of the Short Hills gap. In this case we should expect to find the clays overlain by an old soil. Above this old soil would come whatever deposits were made in the lake of the later glacial invasion. So far as known, such an old soil does not exist. The upper part of the clay, including all that exposed in the various clay pits, and in one or two newly-dug wells, to a depth of twenty feet grades into the sand and silt or stony clay which overlie it. In comparison, however, with the whole

*Annual Report of the State Geologist for 1892, page 139. It is not certain that the great depth of clay and alluvium here cited is all lacustrine.

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area, the points at which observations can be made are few and the exposed sections shallow, and it is not certain that such a soil does not exist.

3°. The third hypothesis differs from the second only in the assumption that the inter-glacial lake lasted until the later ice invasion, and was continuous in time with the lake formed in consequence of that invasion. According to this hypothesis the clays may be all or nearly all early-glacial and inter-glacial. They would pass directly into the deposits of the later lake without the intervention of an old soil. In so far as there is no knowledge of such a buried soil this hypothesis is favored.

The first hypothesis makes the clays, so far as they are lacustrine, entirely late-glacial. The great objection to it is the very long time required for the advance of the ice in order to give so great a body of clay, compared to the time of its maximum extension and retreat. The silts and sands correlated in time of origin with the moraine are not buried by any later deposits.

The second hypothesis makes most of the clays early-glacial and inter-glacial, and seems to demand an old soil separating these deposits from the later ones. Such a soil is not known to exist, neither is it known positively that it does not exist. The third hypothesis makes most of the clays early-glacial and inter-glacial, and it demands their transition upward into the later deposits without a break. Against this hypothesis there do not appear to be fatal objections. But if the amount of inter-glacial erosion was as great, as it has sometimes been thought to be, it would hardly be expected that such a lake could have endured through all the intervals between the first and last ice invasions.

The clays about Mountain View and Little Falls, so far as they may be lacustrine, may be accounted for on either of the three hypotheses—on the third more readily than on either of the others. The presence of stratified drift directly beneath a more or less thin coating of till, over a large part of the area from Madison and Chatham north to Hanover Neck and Whippany, may find explanation on either of the three hypotheses, although it is difficult of explanation on the assumption that a lake never existed in the upper Passaic valley until the moraine filled the Short Hills gap.

Although there is much indefiniteness concerning the pre-morainic history of the lake, facts seem to indicate that there was such a his-

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tory. No such indefiniteness prevails concerning the post-morainic history. It is not implied that all the stages of the later history can be made out, but they are certainly clearer than the earlier stages.

The Madison stage.—When the ice had reached the limit of its maximum advance, the area of the lake was at a minimum, and at this time it must have overflowed through the Moggy Hollow outlet near Liberty Corner. The lake seems to have remained at approximately the same level during the time when the moraine and the subaqueous overwash plain were formed. During this period of maximum level there were formed, in part at least, the high-level shore lines in the extra-morainic basin. Correlated with these is the broad subaqueous overwash plain extending from Chatham to Morristown, and perhaps also the somewhat lower plains near West Summit. The pebble-strewn terrace in Mr. Apgar's orchard (A 4), at Moggy Hollow, the gravel deposits near Bernardsville (a 12, b 1), Basking Ridge (c 16), Lyons (c 15, c 12), Millington (c 11, c 10), Union Village (a 2, a 1), New Providence (c 3, c 4), New Vernon (d 1, d 2, d 3), and one and a half miles south of Morristown (d 5, d 6, d 7), together with the subaqueous overwash plain (see pages 266–8), are all referred to this stage of the lake. This may be called the Madison stage, from the fine development of the subaqueous overwash plain west of that place. It is hardly to be expected that the lake remained at absolutely the same level during this stage. There were undoubtedly minor oscillations of a few feet from time to time, due to varying rates of melting of the ice. Whatever may have been the ratio of drainage from the surrounding hills to that from the ice in the early history of the lake, during *this* stage, owing to the diminution of the land-drainage area, the melting ice must have supplied by far the greater part. Such oscillations of level would be best shown upon such shore features as were of rapid growth, as for example the subaqueous overwash plain. In this way perhaps many of the minor inequalities in the height of different lobes are to be explained. It will be remembered that the various shore features, described in detail in preceding pages, and correlated with the Madison stage of the lake, are not now at a constant elevation. These differences are too great to be ascribed to any minor oscillations. They are to be explained on the hypothesis of post-lacustrine warping of the earth's crust, a subject which will be more fully discussed a little later.

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THE RETREAT OF THE ICE.

As the ice melted back from the moraine, the lake increased in area by successively filling that part of the basin from which the glacier withdrew. During this period the lake must have been more or less completely divided into two parts by the moraine, which, for part of its course across the basin, rises above the maximum water-level. This barrier did much to prevent debris-bearing icebergs from reaching the extra-morainic basin, and thus limited the time, in which such deposits could be made, to the period of ice advance.

A study of existing glaciers, which have both a water front and a land front, has shown that when they remain in a condition of equilibrium or of retreat, the water front melts back more rapidly than the land front and an embayment is formed. This is shown in several of the Greenland glaciers and in the Muir glacier of Alaska.* That this was more or less true of the continental ice sheet, where it was margined by glacial lakes, is shown by the study of many of these lakes. The deltas of Lake Agassiz—a glacial lake in northern Minnesota and Dakota and extending into Canada—together with the terminal moraines of that region, show that "against this great lake the ice was melted back faster than on the adjoining land areas."† Mr. Upham states that the "extent of the indentation of the ice boundary was fifty to one hundred miles back from the lobed extensions of the ice sheet on each side."‡ To a less extent the same thing was true of the water front of the glacier where it crossed the glacial ancestor of Lake Champlain.§

The same thing seems to have occurred in Lake Passaic during the retreat of the ice. An embayment of several miles back from the ends of the land lobes marked the front of the glacier where it crossed the basin of the lake. The glacial deltas between Boonton and Parsippany, southeast of Boonton, north of Montville, at Jacksonville, Upper Preakness and Caldwell (see pages 279–287), were all formed by glacial streams, while the ice edge was in the immediate neighborhood. The ice seems to have remained upon the higher

*S. Prentiss Baldwin, Amer. Geol., Vol. XI., page 374, *et seq.*

†Warren Upham. Glacial lakes in Canada. Bulletin of the Geological Society of America, Vol. II., page 273, *et seq.*

‡Baldwin, *loc. cit.*, where Mr. Upham is quoted.

§Baldwin, *loc. cit.*

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ground above and back of these plains, after it had retreated from the lower ground in the same latitude. This is shown (1°) by the basinward slope of the surfaces of the plains, showing that they were built *from* the highland; (2°) by the forward-plunging strata, which, where seen, generally dip toward the lake and away from the highlands; (3°) by the frequent occurrence of bowlder-strewn kames at the heads of the plains, which, it is believed, mark the position of the ice while the plain was being formed; and (4°) sometimes by the forms of the margins of the deltas next the highlands above the lake. (See pages 279, 281, 283, 284 and 285.)

The other possibility, that these plains were formed in depressions between the highland on one side and the edge of the ice, which filled the lower ground of the lake basin on the other and supplied the material, was kept in mind as a working hypothesis in the field, but was finally abandoned, since it does not match the facts. In terrace plains formed in this way, the surface should slope towards the highland, not away from it; the beds should dip in the same direction, and the edge of the plain should, by the character of its slopes, indicate that the material had slumped down as the ice melted; or, in other cases, should preserve the knob-and-hollow type of irregularity which represents, in reverse, the irregularities of the surface of the ice, against which the sand and gravel of the plain were deposited. These criteria are wanting, except next the highland margins of the deltas, where they are explicable on the other hypothesis.

The Upper Preakness stage.—At a number of places, more or less well-defined terraces are present at elevations varying from sixty-five to seventy-five feet lower than the maximum water-level. These lower terraces are sometimes directly in front of the higher, which rise from the upper margin of the lower. In other localities, the higher are present without the lower, or the lower without the higher. The two are seen in close connection between Boonton and Montville, at Upper Preakness, and west of Haledon.

The following hypothesis may be framed to account for these terraces and their time relationship to those of greater altitudes: The fundamental assumption is, that the tops of these terraces represent the actual level of the water in which they were formed, just as it has been assumed that the surface of the subaqueous overwash plain marks the maximum water-level. Let us suppose that

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this assumption is correct and follow its lead. These terraces then mark a subordinate stage in the lake's history, which may be called the Upper Preakness stage, from the marked development of the delta plain near Upper Preakness. If this hypothesis be the true one, the time relationship of the upper to the lower terrace seems to be clearly shown at Upper Preakness, less distinctly south of Montville and west of Haledon. At Upper Preakness, the lower glacial delta plain at 335 to 340 feet was undoubtedly formed while the ice edge stood at the kame moraine belt, which borders the plain on the north. This kame belt rises forty to eighty feet above the level of the northern edge of the plain. At a later period, after the ice had melted back a mile or more, the upper plain, in so far as it was developed beneath the water, was formed in water standing at about 412 feet. According to the terms of this hypothesis, the lower flat clearly antedates the upper. It should be said, however, that the plain north of the kame or moraine belt, which lies just north of the Upper Preakness plain, is, in places, markedly undulatory. It is not believed that it is strictly a delta plain, though there seems to be evidence that its surface was, in some places, modified by the water of the lake.

South of Montville, the lower terrace is 150 yards wide, nearly a quarter of a mile long, and falls off steeply in a lobate front for forty or fifty feet. Save at one point, it is separated by depressions from the front of the higher terrace. At this one point, the flat rises to a bowlder-strewn kame, which is partially buried by a projecting lobe of the upper terrace. The relationship here is such as to render improbable the hypothesis that the lower flat has been cut by the waves from the upper terrace, or that the upper has supplied the material for the formation of the lower. No stream channels dissect the surface of the upper flat, as would be the case had the lower been formed after the upper, and of material supplied by streams which crossed the surface of the higher plain and emptied into water standing at 320 to 330 feet. The conclusion here is the same as that drawn from the Upper Preakness plains, that the lower terraces are older than the higher. Near Boonton the lower terrace is quite well marked along the front of the upper slope, but there the relative age is not clearly indicated. Although the data at that point do not show the younger age of the upper flat, they show nothing to the contrary. West of Haledon, the relationship of the terraces favors the hypothe-

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sis that the lower terrace is the older, but the evidence is not so strong as at Upper Preakness. Nowhere is the relationship between the two such as to necessitate the assumption of the greater age of the upper terrace.

On the assumption, therefore, that these delta plains mark the water-level at the time of their formation, it would seem that the front of the ice became deeply embayed as it retreated from the line of the moraine, and that the waters of the lake sank about seventy feet below the Madison level. During this lower stage, the 320–325-foot terraces from Boonton to Montville, the ill-defined flat between the first and second canal planes at Montville, possibly the terraces (340 ± feet) north of Jacksonville, the 335–340-foot plain at Upper Preakness, and the lower terraces (340 feet) west of Haledon were formed. Perhaps the red shale gravel beds between Madisonville and Basking Ridge, which are about eighty feet below the maximum shore lines, belong to this stage, though this is not at all certain. No other shore features were observed in the extra-morainic basin, which by any possibility can be referred to this stage of the lake. The Upper Preakness stage, if it existed at all, was probably a short one, since the terraces are not of great size, and deposits of this character were undoubtedly built very rapidly. In order to account for the lowering of the lake-level from the Madison stage to the Upper Preakness stage, it is necessary to assume that the lake had, at this time, a sub-glacial outlet. There could have been no surface outlet, as the present topography shows, and climatic changes, or possible changes in the rate of ice-melting, do not at all meet the case. There appears to be no difficulty in the way of supposing that a sub-glacial outlet might be brought into existence, as the ice retreated toward the Little Falls gap. But the difficulties involved in the assumption of such a sub-glacial outlet, as is necessary to account for the existing phenomena, are considerable. They will be considered after the next succeeding stage of the lake has been described.

The Montville stage.—The hypothesis under consideration renders necessary the assumption that the low stage of the lake postulated above was followed by a rise of the water approximately to the Madison level. The name Montville is proposed for this stage of the lake. During this stage there were formed the high-level plain north of Littleton (f 3) and the delta plains and terraces at corresponding levels north of Parsippany (g 1), between Boonton and Montville (g 2),

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north of Montville (g 3), at Jacksonville (g 5), north of Upper Preakness (h 2), west of Haledon (h 3) and at Caldwell (h 4). Some of these, especially those on the western side of the intra-morainic part of the lake, may have been partly fashioned during the earlier Madison stage. The ice retreated a little between the Upper Preakness stage and the Montville stage, and the plains of the latter were built a little back of and above those of the former. In some cases the higher plains reached and partially buried the lower ones, and the absence of the lower shore lines in some cases may be due to their complete concealment beneath the later-formed higher plains. Although of essentially the same height as the Madison stage, the Montville stage, according to this hypothesis, cannot be associated with it in time, as shown by the different positions of the ice edge at the two stages.

With the glacial delta plains of the Montville stage are correlated the higher wave-cut terraces on the inner face of the moraine between Madison and Monroe (F 3), the cut terrace and associated spits on the hill between Morristown and Littleton (F 5, f 1, f 2), the gravel bed at the north end of Riker Hill near Livingstone (k 1), the gravel bed on Hook mountain (k 2), and a few other features of doubtful shore origin. The Montville stage seems to have been a little longer than the Upper Preakness stage, but the wave-cut terraces may have been partly formed during the Madison stage before the water sank to the Upper Preakness level. The higher shore features, also, of the extra-morainic basin, particularly the local gravel deposits, may in part belong to the Montville stage, which is believed to correspond in height very closely with the Madison level.

In a few places possible shore lines have been noted at elevations between those of the Montville stage and those of the Upper Preakness stage. They range from fourteen to twenty-five or twenty-eight feet below the highest levels. It has not been possible to correlate them definitely with each other, or to make out their time relationship to the other shore lines. So far as known, they may either precede or succeed the Montville stage. They are best shown on the inner face of the moraine south of Montville, near Caldwell, and northeast of New Vernon.

In connection with the lowering of the water during the Upper Preakness stage of the lake, it was indicated that climatic changes, and changes in the rate of melting of the ice, seemed altogether inade-

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quate to account for the supposed drop in the level of the lake's surface. The same factors seem equally inadequate to account for the subsequent rise of the water from the level of the Upper Preakness delta to that of the Montville deltas. It would seem that the only cause which can account for this rise, is the blocking of the subglacial outlet by which the lake was lowered. It must be confessed that it is difficult to understand how such an outlet, once established during the retreat of the ice (and in the way of this there seems to be no difficulty), could again be closed *during the further retreat of the ice.* When the ice was advancing, as in the early stages of the last ice epoch, it is not difficult to see how an under-ice outlet could be closed. But it is not easy to see how an under-drain could be stopped when the ice was retreating, when its motion was probably diminishing in vigor, when its rate of melting was very likely increasing, and when it was becoming thinner. Nevertheless, the stopping of the outlet, even under these conditions, is not believed to be beyond the range of possibility.

The hypothesis that the Upper Preakness delta plain and its correlatives are older than certain other and notably higher delta plains, such as the Montville deltas, necessitates the following assumptions: 1°, that the lake secured a sub-ice outlet after the ice had receded as far as Upper Preakness; 2°, that by means of this outlet the lake was lowered from the level of the Madison stage to the level of the Upper Preakness delta plain (about seventy feet); 3°, that the water stood at the level of this and other corresponding delta plains, for a time sufficiently long for their construction; 4°, that the sub-glacial avenue of drainage was then closed, and that the water again rose to the Moggy Hollow outlet, where it stood during the building of the Montville and other deltas and certain other correlated shore features. If, in view of all the considerations, the hypothesis seems a difficult one, it nevertheless remains true that the hypothesis would explain the facts. It involves conditions which it is hard to believe existed; but if they existed, the observed phenomena would find adequate explanation. No other hypothesis of less or equal difficulty presents itself.

The drainage of Lake Passaic.—After the Montville stage had endured for a time, sufficient for the formation of the glacial delta plains which mark that level, but, nevertheless, brief compared to the whole period of the lake, the ice was so far

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melted back as to permit the escape of the lake drainage through the Little Falls and Paterson gaps. Whether for a short period the water flowed out through the Great Notch is uncertain. If it did, the lake must have been held for a time about ninety feet below the Montville stage. If this stage existed, it must have been very brief, since it has left no positive record. Upon the opening of the Paterson gap the intra-morainic part of the lake was drained to the level of the barrier at Little Falls, about 185 feet. This draining of the lake must have been rapid, since on the many hills within the basin, rising to heights of 200 to 300 feet, there are no shore lines, although many of the elevations are of loose sand and gravel, in which terraces could easily and quickly be cut by shore activities.

Although the intra-morainic basin was drained upon the opening of the Paterson gap, a small post-glacial lake remained in the low ground between Second mountain and Long Hill, in the valleys of the Passaic and Dead rivers. It was held at 230 feet by the dam of drift at Stanley, through which the river has since cut a passage. The greatest depth of this lake was not much more than twenty feet. It disappeared gradually as the Stanley outlet was cut down from 230 feet to its present level. If any considerable portion of the Millington gorge in Long Hill is post-glacial, the area of Great swamp also was occupied by a shallow post-glacial lake. If, when the Paterson outlet was opened, the bottom of the Millington gorge was higher than now, by so much as ten feet, the lower part of Great swamp must have been covered by water, and the limits of the swamp considerably extended.

Judging by the meager development of the shore features of Lake Passaic, save in those cases where the supply of material from the glacier was abundant, their indefinite form in many instances, and their entire absence in localities where they might rationally be expected to exist, we cannot but conclude that the entire life of the lake was, geologically speaking, brief. On the other hand, when we take into consideration the great thickness of lacustrine clay in the Great swamp basin, assuming for the moment that it is all lacustrine, and that it all belongs to Lake Passaic, a very much longer period of time seems necessary.

If, as was suggested above, a lake existed in part of the Passaic basin in the first glacial epoch, and during a part or the whole of inter-glacial time, much of the clay may be lacustrine and yet antedate Lake Passaic.

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Summary of the History of the Lake.

Whether a lake existed in any part of the basin in early-glacial or inter-glacial time is not definitely known, but the balance of evidence seems to favor the hypothesis that Lake Passaic had an ancestor. It is, however, certain that when the ice blocked the Little Falls and Paterson gaps, or at latest, when it blocked the buried Short Hills gap, Lake Passaic was born. If not sooner, at least by the time the ice reached its maximum advance, the lake had reached its maximum height, and overflowed its basin at Moggy Hollow west of Liberty Corner. The areal extent of the lake was probably at this time at a minimum. Its length could not have exceeded nine miles, and its greatest width was a little less than eight. This, the Madison level, was approximately constant during the formation of the moraine and the subaqueous overwash plain which fronts it. The greater number of the gravel beds, and the ill-defined terraces of the extra-morainic basin were in part at least formed at this time. The clays of the Great swamp area and vicinity antedate the maximum advance of the ice, since towards the east they pass beneath sand and gravel deposits formed at that time. Too little is known of the Little Falls clays to warrant any positive inference from them concerning the history of the lake. The interpretation of these clays can probably not be satisfactorily made until the whole body of clay in the north-eastern part of the State and up the Hudson has been carefully studied. Such study transcends the limits of the work which it has yet been possible to devote to this subject.

As the ice melted back from the moraine, it became deeply indented along its water front, the embayment apparently amounting to something like eight miles. According to the hypothesis presented to account for the lower terraces at Upper Preakness and other places, the lake sank, during the retreat of the ice, to the level represented by the delta plain at Upper Preakness, a level about seventy feet below a later maximum represented by the Montville delta and the other plains and terraces at corresponding levels. During this hypothetical stage, which is believed to have been brief, the lake could not have drained through the Moggy Hollow outlet. Its outlet must have been sub-glacial. After the Upper Preakness stage the waters rose about seventy feet to the Montville level, which is believed to be approximately the same as the Madison level. During the Montville

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stage were formed the higher terraces found on the shores of the intra-morainic basin, and the extra-morainic shore features were probably completed. Fourteen to twenty-eight feet below the Montville deltas there are ill-defined terraces and a few gravel beds at other points, the exact age of which is not determinable.

The final draining of the lake, which occurred after the Montville stage, must have been rapid, since no signs of wave action can be found on the sides of the many hills of loose materials within the basin of the lake. A small post-glacial lake in the Dead river valley, and perhaps another in the Great swamp area, remained until the barriers, which obstructed their outlets at Stanley and perhaps at Millington were cut away, but Lake Passaic may be said to have disappeared on the opening of the gap at Paterson. During its maximum extent, Lake Passaic must have been not far from thirty miles long, ten miles wide at its widest part, and over 225 feet deep in the intra-morainic part. This depth is indicated by the relative height of the Great Piece meadow and the highest shore lines near Boonton and Montville. The greatest depth of the extra-morainic part of the lake could have been little more than 140 feet. The preponderance of evidence seems to indicate very clearly that the life of Lake Passaic was brief.

DEFORMATIONS OF THE LAKE BASIN.

So soon as the heights of the highest shore lines of Lake Passaic were accurately determined, it was seen that they were no longer at a constant elevation in reference to the present sea-level. The most important of them are here given in tabular form, the maximum water-level in each locality being taken:

Northwest Side of the Lake Basin.

At Moggy Hollow	A 4.*	356 feet.
Two and a half miles northeast	A 5.	365 "
Basking Ridge	c 16.	367 "
Near Bernardsville	a 12.	369 "
Half a mile northeast of the above	b 1.	371 "
West of New Vernon	d 1.	372 "
One mile east of New Vernon	d 3.	373 "

* These designations refer to the descriptions, pages 243–288 of this report, and to the large map of Lake Passaic.

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One and a half miles northwest of New Vernon	b 2.	between 377 and 380	feet.
One and three-quarters miles southwest of Morristown	d 6, 7.	377	"
One and three-quarters miles south of Morristown	d 5.	between 376 and 380	"
Morristown		probably 376	"
Two miles north of Morristown	f 1.	378	"
South of Littleton	f 2.	382	"
North of Littleton	f 3.	385+	"
Glacial delta plain north of Parsippany	g 1.	394	"
South of Boonton	g 2.	394-5	"
South of Montville	g 2.	about 398	"
North of Montville	g 3.	397-8	"
Jacksonville	g 5.	408-9	"

South and East Shore of the Lake.

One mile south of Moggy Hollow (B. Anthony)	a 10.	349	feet.
One mile southeast of the above (Thomas Maddock)	a 9.	347	"
One and a half miles south of Liberty Corner (John Dougherty)	a 8.	345	"
Mount Bethel	a 6.	350	"
Two and a half miles northeast of Mount Bethel, near Old Home Life Insurance Co. pit	a 3.	358	"
Union Village (John F. Schwalb)	a 2.	355-360	"
One mile northeast (Joseph Frazer)	a 1.	357-360	"
West Summit deltas		probably 367+	"
North end of Riker Hill	k 1.	378+	"
About Caldwell	h 4.	385-390	"
West of Haledon	h 3.	405	"
North of Upper Preakness	h 2.	412	"

On Long Hill and the Moraine.

North of Lyons station	c 15.	364	feet.
Half a mile south of Lyons	c 12.	361	"
Millington	c 11.	361	"
Long Hill village	c 8.	361	"
One and a half miles northeast of the above	c 5.	361-3	"
Northwest of New Providence	C 2.	365	"
End of Long Hill near Chatham	C 1.	369	"
West of Madison		probably 373	"
West of Convent		" 374	"
Morristown		" 376	"

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These figures show that there is an increase in the elevation of the shore lines from the southern to the northern end of the lake from 345 to 412 feet, a total rise of sixty-seven feet in thirty miles, or two and one-quarter feet per mile. This increase is by no means regular. Within short distances, the gradient varies from nearly four feet per mile to less than one foot. In one or two instances, notably along the subaqueous overwash plain, the shore line, after making all possible allowances, seems to be slightly lower than at points further south and southwest. But in spite of these variations and apparent contradictions, generally speaking, the shore lines can be said to rise constantly from the southward to the northward end of the lake, at an average rate of two and a quarter feet per mile.

An outline map of the lake basin is given in Figure 28. On this map there have been drawn isobases at intervals of five feet. These isobases are lines drawn through points which have suffered equal amounts of deformation. These lines are necessarily hypothetical to a large extent, but they are useful in indicating, so far as can be determined, the nature and direction of post-lacustrine changes of level. The direction of these lines indicates graphically several important points. The great differences in the rate of rise of the shore lines in different localities is clearly shown by the varying distances of the lines from each other. Irregularities in rate of rise are also brought out by the curves of several of the lines. It is further seen that the shore lines do not rise most rapidly in the direction of the longer axis of the lake, but rather from south to north. Calculated in this direction, the rise is sixty-seven feet in twenty-five miles, or a gradient of two and two-thirds feet per mile.

The explanation of the greater northward elevation of the shore lines may be sought along two lines. 1°. The great mass of ice which covered all the country to the north of Lake Passaic must have exerted some attractive force upon bodies of water along its margin. The tendency of such attraction would be to draw away the water from the end of the lake furthest removed from the ice, and to raise its level at the other end. The shore lines, therefore, would not be horizontal in reference to the present sea-level, but would rise to the northward.

To what extent can the changing elevation of the shore lines of Lake Passaic be referred to this cause? If the northward rise of the shore lines were due solely to this cause, the rate of rise for each mile

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should be constant, or should increase by a regularly-changing increment. The northward elevation ought to be represented by an upward-slanting, straight line, or by a regular curve, concave upward. A study of the shore elevations as given above, or of the position of the isobases in Figure 28, will show that this is not the case, but that the

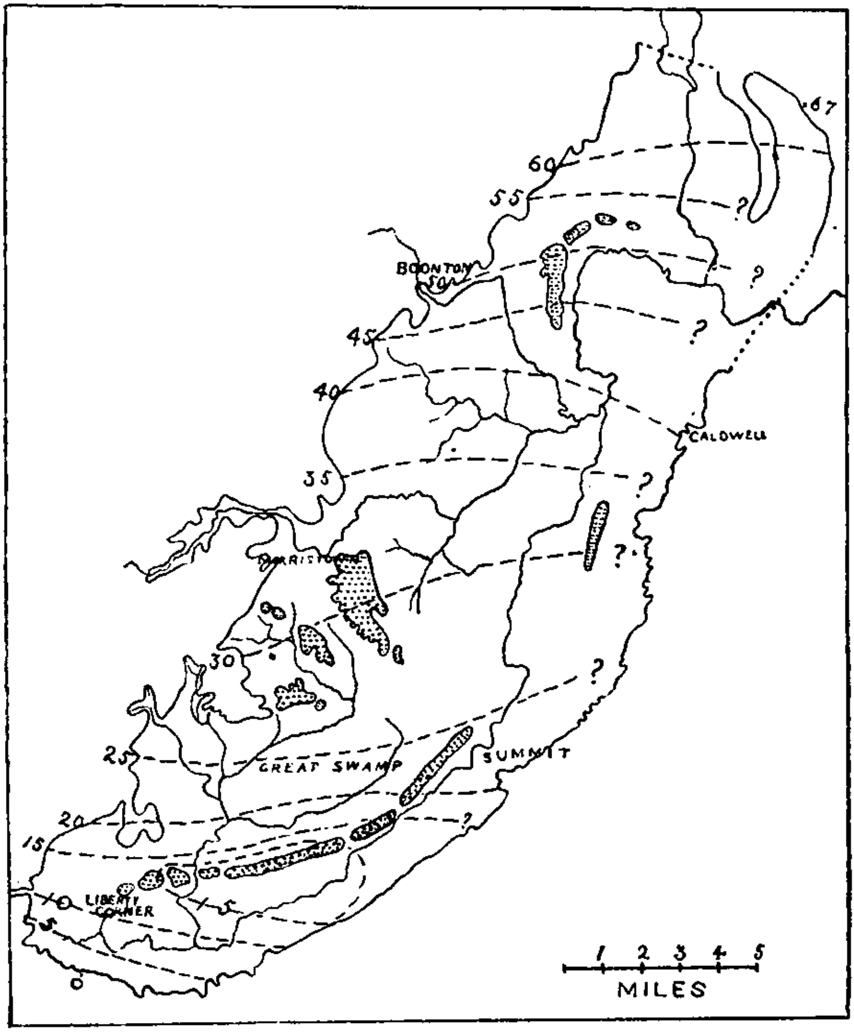

Fig. 28.

The dotted lines are isobases. The numbers upon them represent their height in feet, above the south end of the lake. Dotted areas represent islands.

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gradient changes irregularly from place to place. Further than this, it has been shown * that, under the most favorable conditions which could possibly have existed during the glacial period, as respects ice mass and bodies of water free to be attracted, the amount of elevation of the surface of the water could not have exceeded a half foot per mile. It is extremely probable that in the case of a small body of water like Lake Passaic the rise of the water towards the ice was much less than this. Manifestly, therefore, this hypothesis is quantitatively insufficient. Nevertheless, the ice mass doubtless had some effect in raising the level of the waters of the lake along its northern side.

2°. The other explanation of the present altitude of the shore line is to be sought along the line of crustal deformation in post-lacustrine times. According to the doctrine of isostasy, which has found much favor with geologists in recent years, the crust of the earth is in a delicately-balanced condition of equilibrium between forces, which are tending on the one hand to depress, and on the other to elevate it. It is believed that, in consequence of this balanced condition, changes in the level of the crust are somewhat readily brought about by the transference of sediments from one place to another, by the ordinary processes of erosion and deposition. The theory that the crust of the earth is much more sensitive to changes of load than we are accustomed to believe, seems to be borne out by many facts which have come to light in recent years, and by many others which have but recently been studied from this standpoint. Mr. McGee,† for example, believes that there is evidence to show that in the Gulf of Mexico the area of sedimentation is depressed one foot for each foot of sediments deposited, and that this depression takes place because of the weight of the sediments. Although all geologists do not accept this doctrine to the extent advocated by Mr. McGee, yet it seems to be well established that the crust of the earth is to a greater or less degree sensitive to changes of weighting.

With the advance of the ice at the beginning of the later glacial epoch, the northern half of Lake Passaic basin, together with all the country north of the moraine, was weighted down beneath the load of

* Chamberlin and Salisbury, Sixth Annual Report, U. S. G. S., page 291, *et seq.* The mathematical calculations are by R. S. Woodward.

† "The Gulf of Mexico as a Measure of Isostasy," Am. Jour. of Sci., 3d Series, Vol. XLIV., pages 177-192, 1892.

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ice, which, not many miles back from its margin, must have been many hundreds of feet thick. In addition to the load of ice there was the much lesser load of drift, which toward the ice margin, and particularly in the area of the lake basin, attained considerable thickness. In the extra-morainic part of the basin there was, in place of the ice load, the load of water and of the lacustrine deposits, which, as we have seen, are probably of considerable thickness. It is believed that beneath the weight of these various elements, but chiefly the mass of ice, the crust of the earth sank differentially, and that the amount of sinking was greatest to the north, where the load of ice was greatest. The area south of the ice, and south of the water of the lake, was probably depressed also, but to a less extent than the country further north, on which the load which caused the depression lay.

It is not to be supposed that these effects were confined to the area of Lake Passaic. They were widespread, influencing a wide area in the northern part of the United States and Canada.

On the removal of the greater part of this load by the melting of the ice, and for this particular region by the draining of the lake, the land tended to regain something of its original position. The resilience was probably differential, as the subsidence is thought to have been. On the doctrine of isostasy, the rise would be expected to be greatest at the north. This differential resilience must have deformed the shore lines, which, when formed, were horizontal. It is not to be expected that such an elevation would proceed with a constant gradient. It would rather be of the nature of an irregular warping, with the greatest rise to the northward. The irregularities of rise might well be such that locally there were areas, which failed to rise so much as other areas further south. This appears to have been the case in the basin of Lake Passaic. Although the average gradient from south to north is two and two-thirds feet per mile, it is sometimes as high as four feet per mile, while in one or two instances and for short distances the shore lines descend slightly to the northward.

The deformation of the shore lines occurred after the lake was drained, rather than during different stages of the lake. This is shown by the fact that the Upper Preakness shore line is everywhere about seventy feet below the Montville level, whereas, if any deformation had occurred in the interval between these two stages, their shore lines would not be essentially parallel.

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It must not be supposed that only the basin of Lake Passaic suffered post-glacial warping. All the surrounding country must have been similarly affected if the doctrine of isostasy is well founded; but it is only along the shores of lakes or seas that measurement of warping can be made, since it is only here that the former altitude of the land can be determined.

It is interesting to compare briefly the results obtained from the study of the warped shore lines of Lake Passaic with those derived from the seashore and from other glacial lakes. Baron De Geer,* in his studies on post-glacial warping, chiefly along the New England and St. Lawrence coasts, found a gradient varying from 2.70 to 1.07 feet per mile. The differential elevation of the Iroquois beach around the eastern end of Lake Ontario is five feet and more per mile.† The highest of the many beaches observed around the glacial Lake Agassiz has now a northward ascent of about 35 feet in the first 75 miles, 60 feet in the second 75 miles and about 84 feet in the third distance of 74 miles, a total of 175 feet in 224 miles. These gradients vary from slightly less than one-half foot to more than one foot per mile. The gradient, which has been shown to exist within the Lake Passaic basin, lies about midway between the maximum and minimum quoted above.

ECONOMIC CONSIDERATIONS.

Gravel deposits.—As has already been shown, the shores of Lake Passaic are marked by beds of gravel. In the extra-morainic basin the gravel is usually trap, occasionally red shale, more rarely gneiss or quartzite. The value of these deposits as sources of supply for road material has to a limited extent been recognized, and pits have been opened in a number of them. The trap gravel, by reason of its abundance, its durability and its angular character, is by far the best of the gravels for road purposes. The pebbles or fragments, although distinctly water-worn, are not much rounded, and pack firmly, making a hard, substantial road-bed. Although this gravel does not make such fine roads as the assorted sizes of crushed trap rock shipped from the various stone crushers located along the trap ridges, yet be-

* Proceedings of the Boston Society of Natural History, Vol. XXV., pages 454-477.
† Upham, Bulletin of the Geological Society of America, Vol. II., page 260.

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cause of its cheapness and wide distribution it is more available for use on the adjacent country roads. To secure the best results the gravel should be assorted, since in the beds cobbles four to eight inches in diameter are mixed with the finer constituents. The former are serviceable at the bottom of road-beds, but should be covered by the finer. For the best results, a small amount of crushed rock should be used with the gravel, or the finest of the gravel should be reserved for the surface.

The amount of available trap gravel on the shores of Lake Passaic is very considerable. Near Union Village there are deposits upon the property of Joseph Frazer (a 1), John Schwalb (a 2), and the Old Home Life Insurance Company (a 3). South and southeast of Liberty Corner are considerable deposits on the property of J. H. Moore (a 7), James Dougherty (a 8), and Thomas Maddock (a 9). The gravel at the first two places is at least twenty and thirty feet thick, respectively. South of Moggy Hollow is a small deposit on the property of B. Anthony (a 10).

On Long Hill there are deposits, the extent of which is not known. In the sags west of New Providence (c 4) and north of Berkeley Heights (c 6), near Millington (c 10 and 11), there are extensive deposits whose depth is certainly twenty-five feet and is said to be forty feet. Much of this, however, is unavailable for road material, as it is on improved residence property. Other deposits, which have been considerably utilized, are south and southwest of Lyons station, on property belonging to Benjamin Runyon (c 12), Mr. Zieglow and Dominie Bowers (c 13). North of Liberty Corner, also, is a pit owned and worked by Bernards township (c 14), and there are extensive deposits on the adjoining property of Chas. Greulock. Just north of Lyons station, also (c 15), and east and northeast of Bernardsville (a 12, a 13), there are deposits of considerable extent. Extensive deposits are found south of Morristown on the Spring Brook farm (d 6) and on the property of G. E. Taintor (d 5).

Besides these well-defined beds, concerning whose area and depth something is known, surface indications of gravel have been observed along the shore line at many places, particularly in the timber. It is quite probable that much more gravel exists than has been accurately located. The places where it is to be sought are along the old shore line, as shown on the accompanying map. It is entirely within bounds to assert that there is enough trap gravel around the extra-morainic

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shores of Lake Passaic, to macadamize all the roads within that part of the basin.

The red shale gravel, which is used upon the roads to some extent, is not nearly so valuable as the trap. It packs readily, but the shale pebbles are easily crushed and ground to a fine dust, which, in wet weather, makes a sticky red mud. The principal beds of this gravel are the Durie spit west of New Providence (c 3), the gravel beds near Basking Ridge (c 16, c 17, c 18, c 19), and Bernardsville (a 12), and those both west and east of New Vernon (d 1, d 2, d 3).

South of Morristown (d 7) is an extensive deposit of gravel, chiefly quartzite, formed from the weathered Triassic conglomerate. It has been very extensively used by the city of Morristown, and makes excellent roads.

Along the moraine, and within most of the lake basin north of the moraine, glacial gravel is very abundant, and is used more or less upon the roads. It is, however, far inferior to trap gravel for several reasons. It very often contains a large percentage of sand, which makes the road heavy and sandy in dry weather, and prevents the material packing into a hard road-bed. The percentage of red shale pebbles is often large, and these are easily ground up, causing dusty roads in dry weather and muddy roads in wet weather. Since the gravel is generally quite well rounded, it does not pack so firmly as the sharply-angular fragments of crushed trap or the poorly-rounded trap pebbles.

Lacustrine clays.—The clays within the lake basin are used to some extent in the manufacture of brick, rough pottery and tiling. The most extensive brickyards are those south of Morristown, those northwest of this place and those between Little Falls and Mountain View. The supply of clay within the lake basin, particularly in the Great swamp area, is practically inexhaustible. It is not all equally good, but there is much which is of as good quality as that used in the brickyards near Morristown. Unfortunately, it is not all so available. Within the intra-morainic lake basin, too, there are good lacustrine and post-lacustrine clays. These are worked to some extent in the vicinity of Whippany.

The swamp areas.—If the land were to be restored to the altitude possessed during the lake period, the restoration would involve a depression of fifty feet at Little Falls, and about the same at Boonton. Under these conditions the swamp areas of the lake basins would be greatly

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changed. The submerged or partially-submerged lands north of the moraine, along the Whippany and Passaic rivers, would at once be drained and transformed from swamps to rich alluvial bottom lands. The Great swamp area would be differently influenced, since its drainage is held at its present level by the obstruction (trap rock) in the river at Millington. If the land were restored to its glacial altitude this would not be lowered, but, on the contrary, would be raised relatively to the swamp. Such a northward depression might convert the lower parts of the Great swamp area into a shallow lake.

The swamps and meadows along the Passaic river north of the moraine, are conclusive proof either that the Passaic river does not now flow in its pre-glacial channel across the trap ridge at Little Falls, or that the post-lacustrine elevation so tilted the land, that the river has not yet had time to cut down its trap bed at Little Falls to the extent of the differential rise at this point. Until this is done the swampy land will not be drained. No data are at hand concerning a pre-glacial channel at Little Falls other than the present course of the stream. The facts, so far as known, make it improbable that such a buried pre-glacial channel, even if it exists, is as deep as the buried Short Hills gap. The loss of arable land either through the blocking of the pre-glacial channel across the trap, or through the warping of the lake basin, or through their combined action, amounts to many thousand acres. A part of this, however, will soon be reclaimed on the completion of the work of blasting away the rock barriers at Little Falls, a work which has been going on for several years.

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PART II.

Cretaceous and Tertiary Geology.

REPORT OF PROGRESS.

BY

WILLIAM BULLOCK CLARK.

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LETTER OF TRANSMITTAL.

Professor J. C. Smock, State Geologist, Trenton, N. J.:

SIR—I present herewith the report of my investigations the past year upon the Cretaceous and Tertiary formations of New Jersey. Considerable progress was made in deciphering the stratigraphy of the "marl belt" during the field season, which was necessarily short, on account of the small allotment for the work. The services of Messrs. H. S. Gane and R. M. Bagg were had for a portion of the time as assistants. They aided very materially in the investigations conducted, and I desire to cordially acknowledge my obligations to them at this time.

The lines of work pursued may be classed under two heads, viz., areal mapping and section study.

The first was a continuation to the southward of the areal mapping commenced the previous year and which resulted in the completion of the United States Geological Survey Atlas Sheets of Sandy Hook and New Brunswick. During the present season, largely with the aid of Mr. Bagg, the atlas sheet of Cassville was completed, adding 235 square miles to that already done.

Under the second head, five type sections were studied and compared. Two were in the area already mapped, and a third comprised portions of the region under investigation the past season. The other two were without the areas hitherto studied, but were selected at crucial points in order to determine the relations existing between the various formations throughout the area of their outcrop. The five section lines selected run from New Brunswick to Long Branch, Monmouth Junction to Shark River, Trenton to New Egypt, Philadelphia to Vincentown, and Bridgeport to Glassboro.

By means of the auger, the use of which was explained in the last annual report, it has been possible to penetrate the surface deposits so that the stratigraphy may be deciphered in areas where the under-

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lying beds do not outcrop. This method will be pursued throughout the region to be investigated, with the hope of important results.

In my first report the fewest possible alterations were made in the accepted names of the formations, and the results of the work made to conform, so far as it was possible, with those of the State Survey hitherto. It was deemed advisable to act with great deliberation before suggesting changes in a classification proposed by so competent a geologist as the late Professor George H. Cook, for so many years the head of the Survey. As the work has progressed, the necessity of modifying the classification hitherto adopted has become apparent, and such changes are presented at this time.

Very respectfully,

WILLIAM B. CLARK.

Johns Hopkins University, January 1st, 1894.

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CRETACEOUS AND TERTIARY GEOLOGY—REPORT OF PROGRESS.

1893.

BY WILLIAM BULLOCK CLARK.

SECTION I.

GENERAL DISCUSSION AND CLASSIFICATION OF THE FORMATIONS.*

INTRODUCTION.

In the last annual report will be found an historical sketch of the investigations hitherto conducted upon the Cretaceous and Tertiary deposits of New Jersey, together with a description of the several formations represented. On that account it is considered unnecessary to enter into a full consideration of the subject at the present time, although in proposing the important changes in classification found upon the succeeding pages it is important to compare the nomenclature of others, and discuss the grounds for the use of the terms employed. In that connection a brief description of each formation is introduced.

The use of lithologic terms for the formations in the earlier nomenclature will be in the future discarded for place names, the older terms being retained to designate their economic equivalents. Local terms have been adopted, care being taken to select such as would characteristically represent the formations. The names of rivers, hills and towns in the vicinity of which typical sections are found have been

* Portions of this chapter were read before the Geological Society of America, at Boston, December 29th, 1893, and printed in The Journal of Geology, Vol. 2, pages 161–177.

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generally employed. In this manner the results of the work in New Jersey are brought into conformity with methods generally adopted at the present time in other areas.

GENERAL STRATIGRAPHICAL FEATURES.

The geological formations of the coastal area of New Jersey represent a nearly complete sequence from the Cretaceous to the Pleistocene. They form a series of thin sheets which are inclined slightly to the southeastward, so that successively later formations are encountered in passing from the northwestern portion of the district toward the coast.

Oscillation in the position of the shore line and later denudation have occasioned in many instances a marked divergence from these normal conditions, so that detached areas are frequently found far removed from the body of the main outcrop.

The formations of the New Jersey coastal area and their economic equivalents are given in the following table:

Age.	*Formation.*	*Economic Equivalent.*	
Pleistocene	Columbia Formation.		
Neocene	Lafayette Formation.		
	Chesapeake Formation.		
Eocene	Shark River Formation	Upper Marl Bed.	Greensand Series.
Cretaceous	Manasquan Formation		
	Rancocas Formation	Middle Marl Bed.	
	Redbank Formation	Red Sand.	
	Navesink Formation	Lower Marl Bed.	
	Matawan Formation	Clay Marls.	
	Raritan Formation	Plastic Clay.	

The greensands characterize all the deposits from the Matawan formation to and including the Shark River formation. The glauconite appears in varying amounts and under different conditions in these several formations, so that the lithologic features are often sufficiently distinctive and persistent to be of the greatest service in the determination of the horizons. The presence of greensand as an original accumulation has not been observed in the Raritan formation, which underlies, nor in the Chesapeake formation, which overlies, this series of glauconitic deposits.

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DESCRIPTION OF THE FORMATIONS.

Raritan Formation (Plastic Clay).—The term Raritan was introduced for this formation in the last annual report, the name having been long in use by Cook, Newberry, Smock and others for a greater or less portion of the series in question. The most characteristic development of the formation is found along the Raritan river and bay, so that the term is in every way applicable.

The strata consist of alternating beds of sand and clay, many of them of great economic value. Many of the beds, particularly the sandy layers, change in thickness and texture so rapidly that no section is typical except within very narrow limits. Clays, however, preponderate in the lower, and sands in the upper half of the series. No unconformity is found at any point beyond the base of the series which rests upon the Newark formation, although the individual beds of sand often meet along sinuous lines and exhibit frequent instances of cross-bedding. It is difficult to assign a limit to the upper portion of the series, since no physical unconformity occurs, and similar deposits are found in the overlying Matawan formation.

The fossils described from the Raritan formation are chiefly of plant origin, and consist both of leaf impressions and lignite, but indicate a considerably earlier period than do the fossils of the overlying deposits. The invertebrate fossils are very rare and consist altogether of brackish-water types.

The thickness of the formation in the vicinity of the Raritan bay has been estimated at 347 feet, but to the southward it evidently reaches a somewhat greater thickness, as shown by recent borings, although satisfactory data for comparative purposes are not attainable.

Matawan Formation (Clay Marls).—On account of the extensive and typical development of the Clay Marls on the shore of the Raritan bay, in the vicinity of Matawan creek, and along the banks of the latter stream, the name Matawan formation is proposed for the deposits of this horizon.

The greensand is a less pronounced feature than in the overlying formations. The deposits consist, for the most part, of dark-colored clays with inter-bedded layers of sand, the latter becoming very pronounced in the upper portion of the formation. At some points beds of greensand appear, but they are generally thin and of very narrow geographical extent. The deposits are largely fragmental, with here

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and there an admixture of carbonate of lime, derived from the shells of organisms.

The most extensive section is afforded by the bluffs on the shores of the Raritan bay, between the mouth of Chesquake creek and the Navesink Highlands. From this point the formation extends southwestward across the State, the best exposures being found along the stream channels entering the Delaware river from the east. Both along Crosswicks and Pensauken creeks the strata are highly fossiliferous, at the latter locality over a hundred species having been identified. In the main, the forms are the same as those in the overlying Navesink formation, although some are distinctive.

From its surface outcrops the Matawan formation has been estimated to have a thickness of 275 feet.

The most striking differences, both in the character of the materials and the thickness of the beds, are shown by well borings along the line of dip. A recent boring at Asbury Park penetrated the Navesink formation (Lower Marl Bed) at 400 feet, beyond which, for a distance of over 400 feet, typical Clay Marls were encountered. From 750 to 780 feet glauconitic layers were found, while the deposits in general are finer and more regularly stratified than in the surface outcrops to the westward.

Navesink Formation (Lower Marl Bed).—The Lower Marl Bed has an extensive development throughout the region of the Navesink Highlands, in the vicinity of the village of Navesink and along the north bank of the Navesink river, so that the name of Navesink formation may be with propriety employed.

Greensand forms the distinguishing feature of the deposits. The lower portion is frequently quite sandy, in this respect showing the change from the sandy layers of the upper portion of the Matawan formation upon which it lies conformably, to the typical greensands of the Navesink formation. The upper portion again shows the presence of much land-derived material; it is highly argillaceous and just at the top frequently arenaceous. The greensands along the thinned-out western edge of the Navesink formation have been oxidized to so great an extent that their separation from the red sands of the Redbank formation is often a difficult matter.

On account of the great economic importance of the greensand beds of the Navesink formation, frequent pits have been dug into it all

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along its line of outcrop from the northern to the southern end of the district. As a result, the strata may be studied to great advantage.

A magnificent exposure is found in the great bluffs of the Navesink Highlands facing the Raritan bay, while excellent sections are to be found along many of the streams that cut through the formation. The beds are highly fossiliferous, and the most varied fauna in the New Jersey Cretaceous is found at this horizon. Between 300 and 400 species have been described.

The Navesink formation has a pretty constant thickness of forty feet, although locally ranging from thirty to sixty feet. The deposits have been found to be remarkably persistent in character both along the strike and dip, so far as they have been examined.

Redbank Formation (Red Sand).—The bright red sands of this formation afford one of the most striking features of the country throughout the marl district. They are extensively developed in the vicinity of Red Bank, so that the name Redbank formation is proposed for the deposits of this horizon.

The strata are glauconitic throughout, although the great preponderance of coarse arenaceous sediments has facilitated the oxidation of the greensand, changing the green color of the beds to red or brown. The lower portion of the Redbank formation is often composed of black sand or sandy clay, while at the top of the formation there is an indurated clayey layer generally of a distinctly greenish color. This hardened stratum has had an important influence in the development of the topography of the marl district, and especially in the extreme north the higher hills are largely due to its presence. The fossils are, in the main, the same as in the preceding formations, but on account of their poor preservation have not up to the present time been very fully studied. The indurated layers have afforded the greater number. The formation has a pretty constant thickness of 100 feet.

Rancocas Formation (Middle Marl Bed).—The Middle Marl Bed is not as prominent a feature in Monmouth county, where the type localities for the other formations are found, as farther southward. The Rancocas creek, in Burlington county, cuts through the Middle Marl Bed, exposing a full sequence of the deposits of that formation, while in the neighboring area extensive exposures of the strata are found.

The formation is largely a greensand, although much more highly

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glauconitic in the lower than the upper half. Although the lower half is largely a pure greensand, it becomes in some portions of the State very argillaceous toward the base, forming the so-called "chocolate marl," while toward the top it becomes crowded with shells, the upper two feet characterized by the presence of *Terebratula Harlani*, the most persistent fossiliferous zone in the State. The upper half of the formation is highly calcareous, frequently appearing as limestone ledges, known as "yellow limestone," and often containing as much as 80 per cent. of carbonate of lime. It is highly fossiliferous, and has afforded many beautifully-preserved specimens of Bryozoa, Echinodermata and Foraminifera. The fossils are, in the main, different from those in the underlying formations.

The strata reach a thickness of about forty-five feet.

Manasquan Formation (Lower portion of the Upper Marl Bed).—The name Manasquan Marl was, in an earlier publication, made to include the Yellow Sand, together with the "greensand" and "ash marl" of the Upper Marl Bed of Professor Cook. For that horizon the name of Manasquan formation is retained. It is typically developed in the valley of the Manasquan river and its tributaries.

Like the preceding formation, it is essentially a greensand throughout, although distinctly quartzose in the lower part, and, at times, argillaceous in the upper layers. The fossils, so far as observed, are confined exclusively to the more highly greensand member, but the number of species is not large. The large percentage of phosphates in the Manasquan marl has long given it a high reputation as a fertilizer.

The thickness of the strata has been estimated at sixty-five feet.

Shark River Formation (upper portion of the Upper Marl Bed).—The term Shark River Marl was earlier employed by the writer to embrace the "blue marl" of the Upper Marl Bed, which has been generally referred, in recent years, to the Eocene, although the beds are conformable with the underlying strata, concerning whose Cretaceous age there is apparent unanimity of opinion.

The Shark River formation is a characteristic greensand with a slight admixture of argillaceous materials, while a hardened and stony layer is found directly at the top. The fossils are numerous, but cannot be readily compared with those from the Eocene areas to the southward. The strata of the Shark River formation have not been found at any point to exceed twelve feet in thickness.

The Shark River formation closes the series of greensand deposits.

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It is unconformably overlain by strata of a very different character, which show evidence of marked mechanical disturbances and rapid deposition.

Throughout the entire sequence of deposits just described the presence of greensand has been the most distinguishing feature. Its origin is, therefore, a matter of great importance to the understanding of the several formations, and will be found fully discussed in the last annual report.

Chesapeake Formation (Miocene marls, sands and clays).—The name Chesapeake has been employed by Darton for the Miocene deposits of Virginia, Maryland and Delaware. Although the New Jersey strata are evidently in part older than the Miocene of the Chesapeake area, they are a direct continuation of those deposits northward, and the same name may be temporarily, at least, adopted.

The deposits consist of marls, sands and clays, the coarser sediments prevailing, so that few localities exist where fossils are found in any numbers. In this respect they differ greatly from the more southern representatives of the Miocene, where the strata are often largely composed of beds of shells. The sands are highly characteristic, coarse, angular grains of quartz being everywhere interspersed in the deposits, which are commonly snuff-colored and loosely stratified.

Very little is as yet known of the areal distribution of the deposits, but it is probable that they cover an extensive region in eastern and southern New Jersey, and form a series of deposits several hundred feet in thickness. Recent deep well borings at Atlantic City have thrown much light on this subject, while extensive surface outcrops have been found by the writer in Monmouth and Ocean counties, reaching to the summit of the Highland range.

Lafayette Formation (Yellow gravel in part, sands and clays).—An extensive superficial formation, covering levels above the Pleistocene (Columbia) deposits, has been considered to represent the late Neocene or Lafayette of the middle Atlantic slope. Along the landward border of the formation the deposits consist of gravels and coarse sands, and often attain considerable thickness. Portions of the so-called "yellow gravel" are here included under the Lafayette. A satisfactory discrimination of the deposits is not yet possible in all instances. Upon further study of the formation it may seem wise to designate it by a local term.

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GENESIS OF THE DEPOSITS.

The opening of the Cretaceous period along the Atlantic border, as shown in the Raritan formation, witnessed the deposition of large amounts of irregularly-stratified sands and clays, together with beds of gravel in the vicinity of the coast. It was a period of great mechanical disturbance over the area of deposition, and both the physical and faunal characters of the strata point to the close proximity of land, while inclosed basins doubtless existed for a portion of the time.

With the opening of the epoch of greensand deposition as represented in the Matawan formation, much the same conditions at first prevailed. Alternating beds of sand and clay were laid down, but gradually the coarser elements disappeared, deposition became less rapid and greensand was locally developed. The conditions for greensand production were not widely extended nor long existent, for successive periods of rapid and slow accumulation of materials continued to the close of Matawan deposition.

With the advent of the Navesink epoch, land-derived materials became greatly reduced in volume, and shortly ceased almost altogether, so that throughout the area of deposition there was formed at this horizon some forty feet of highly glauconitic greensand. Toward the close of this period terrigenous deposits became more pronounced, but the production of glauconite did not altogether cease.

With the opening of the next epoch represented by the Redbank formation, dark sands, in which the proportion of glauconite was very small, were at first deposited. Throughout the whole series of beds glauconite is found distributed in greater or less amounts, but at no time did its production reach the prominence that it had during the previous epoch. The marked admixture of coarse elements throughout most of the deposits later rendered them subject to the ready percolation of water, by which the complete oxidation of the glauconite was accomplished. Toward the close of the Redbank epoch finer sediments prevailed, and there is every evidence that land-derived materials found ingress to the area of deposition in gradually lessening amounts.

The succeeding Rancocas epoch was a time of slow accumulation of continental materials, so that the production of glauconite went on unhindered. During the latter portion of the epoch, however,

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there must have been a great profusion of animal life, for the deposits show a marked admixture of carbonate of lime, while, in many instances, the shells are still in an excellent state of preservation. The formation of glauconite was not interrupted, although its relative proportion is at times much diminished by the great amount of carbonate of lime, which may, in some instances, reach eighty per cent. of the whole.

The Manasquan epoch was characterized throughout by constant formation of greensand beds, although land-derived materials in considerable amounts reached the area of deposition during the early portion of the period.

No very marked changes apparently affected the region near or at the close of the Cretaceous, but the same conditions persisted on into the Eocene, as shown in the Shark River formation, during which similar deposits with very different types of animal remains were accumulated. At the close of the Shark River epoch the conditions favorable for the formation of greensand ceased, not to be again revived during the period of formation of the coastal deposits in New Jersey.

The succeeding epochs gave proof of much shallower waters, while the ancient Cretaceous-Eocene sea-floor frequently stood above sea-level, and along its landward portions constantly lost as the result of erosion. As the land rose higher and higher in late geological history, during the Lafayette and Columbia epochs, further inroads were made, until the deeper portions of the ancient sea bottom were exposed by the forces of denudation and the present topography produced.

SOURCE OF THE MATERIALS.

The source of the materials which constitute the several formations of the coastal region of New Jersey has not been altogether satisfactorily explained, although the deposits indicate that they were largely derived from crystalline rocks.

That the red sandstones and shales of the Jura-Trias (Newark formation) which adjoin the coastal series upon the landward side have not been the chief source of the materials is a striking fact, and one which has been largely commented on in the past. By some it has been supposed that an area of crystallines must have existed to the eastward to afford the materials for the deposits. A study of the

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drainage of the Jura-Trias belt which separates the coastal formations from the area of crystalline rocks beyond is of interest, however, in showing the probable extension of the coastal deposits quite over the red sandstones and shales of the Jura-Trias to the border of the crystalline region, and, at the same time, affords a sufficient explanation for the absence in the main of sediments derived from the Jura-Trias itself.* The evidence for this has been recently presented by Davis † in the National Geographic Magazine, and the reader is referred to the article for a fuller explanation of the subject.

Accepting the explanation of Davis as highly probable, we may look for the source of the land derived materials out of which the deposits are formed in northwestern New Jersey, eastern Pennsylvania and southeastern New York, a portion of that tract of crystalline rocks which stretches along the eastern side of the continent. A separation of the mineral constituents of the deposits shows a préponderance of both the constituent and accessory minerals which characterize those rocks. It seems pretty conclusive, therefore, that the area mentioned was the source of the materials for the formations of eastern New Jersey.

TAXONOMY.

The geological formations of New Jersey early attracted the attention of geologists, and Professor Peter Kalm,‡ of Sweden who was

* Professor J. D. Dana has called the attention of the writer to the fact that the red sandstones of the Jura-Trias, formed, as they are, chiefly of quartz and feldspar, would be better adapted for the production of the clays of the Raritan formation than crystalline rocks, since the sandstones would be much more porous and disintegration could the more readily take place. Moreover, he finds that thick-bedded and light-colored clays are generally formed in inclosed fresh-water basins or marshy tracts, such as no doubt adjoined the coasts during the earlier portions of the Raritan epoch. The writer is inclined to accept this interpretation of the origin of the light-colored and thick-bedded clays of the lower Raritan, since during the gradual depression of the coast line in Cretaceous time successively more inland tracts must have been submerged, and until this submergence was fully completed the exposed Jura-Trias sandstones would have been an important source of the Cretaceous sediments. The later Cretaceous formations, however, were doubtless derived directly from the crystalline rocks.

† Nat. Geog. Mag., Vol. II., No. 2, pages 1-30, 1890.

‡ En Resa til Norra America, 8vo, 3 vols., 1753-61, Stockholm. Translations in English by J. R. Forster, 1st Ed. 1770-71, 2d Ed. 1772; another edition in J. Pinkerton's Voyages, Vol. 13, 1812; in German, by J. H. Murray, 1754-64; in French, by L. W. Marchand, 1859.

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sent out in 1749 under the auspices of the Royal Academy of Sciences to make a study of the various branches of natural history in America, presents many interesting observations concerning the deposits in question. He spent much of his time in New Jersey.

In 1777, Dr. Johann David Schöpf,* of Germany, visited America in order to study the geological features of the eastern portion of the continent. His observations and comparisons of the coastal plain formations, especially of New Jersey, mark considerable advance over those of Kalm. The importance of his investigations have not been very generally recognized by later writers, but he showed a remarkably keen insight into the geology of eastern America, which was lacking on the part of some of his successors.

The first attempt at a correlation of the deposits of New Jersey with the geological column then established in Europe was made by William Maclure,† in 1809, in his "Observations upon the Geology of the United States." In this publication the coastal deposits of New Jersey are collectively referred to the "Alluvial formation," the fourth of the main divisions of geological strata proposed by Werner. The work was subsequently revised and enlarged, appearing in book form in 1817.‡

Professor John Finch was the first to propose a division in the coastal plain deposits of New Jersey. In his "Geological Essay on the Tertiary Formations in America" he states that what has been called the "Alluvial formation" by earlier writers "is identical and contemporaneous with the newer Secondary and Tertiary formations" of other portions of the globe.

A few years subsequent to this, Professor Lardner Vanuxem,§ through his friend, Dr. S. G. Morton, presents the criteria for a more complete and definite recognition of the several members of the coastal series, in which both the Cretaceous and Tertiary are described in some detail.

With the establishment of the official Geological Survey of New

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* Beiträge zur mineralogischen Kentniss des östlichen Theils von Nord Amerika und seiner Gebürge, 8vo., 1787, 194 pages. Erlangen.

†Amer. Phil. Soc. Trans, vol. 6, 1809, pages 411-428. Translation in Journal de Physique, Vol. 69, 1809, pages 204-213, and Vol. 72, 1811, pages 137-165.

‡ Philadelphia, 8vo., 130 pages. Also in Amer. Phil. Soc. Trans., new series, Vol. 1, 1817, pages 1-92, and Leonhard's Zeitschrift, Band 1, 1826, pages 124-138.

§Amer. Jour Sci, Vol. 7, 1824, pages 31-43.

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Jersey, under the direction of Professor H. D. Rogers,* the first attempt was made at a detailed differentiation of the local deposits. The formations, beginning at the bottom, are designated as follows: *Clays and Sands, Greensand, Limestone, Ferruginous Sand and Brown Sandstone.* Although the various members are not clearly defined, and widely different materials are included under the same division, yet the easterly dip of the strata was observed, and the broader distinctions in the stratigraphy of the area were recognized.

Dr. T. A. Conrad,† in 1848, first suggested that the upper portion of the greensand series was of later age than the Cretaceous, a conclusion which he more fully elaborated at a later date.

The second Geological Survey of New Jersey, organized in 1854, under the direction of Wm. Kitchell, had as Assistant Geologist, George H. Cook, who a few years later became himself State Geologist, a position he held for over twenty-five years, until his death in 1889. He devoted from the first much attention to the greensands, and his classification of the strata has met with wide acceptance. It is elaborated in much detail in the Geology of New Jersey, published in 1868. The series of formations as recognized by Professor Cook is as follows, beginning with the oldest: *Plastic Clay, Clay Marls, Lower Marl Bed, Red Sand, Middle Marl Bed, Yellow Sand* and *Upper Marl Bed.* Subsequently, Professor Cook ‡ considered that an unconformity existed between the Eocene and Cretaceous members of the Upper Marl Bed. The later formations were discussed in these reports, but no satisfactory classification was proposed. The fossiliferous Miocene deposits of Shiloh and Jericho were recognized, and a dark micaceous clay farther to the northward was also referred to that horizon, but the stratigraphical relations of these and later strata were not comprehended.

There is no area in this country where the several formations have been studied more with reference to their own characteristics, and less with reference to the supposed similarity of faunas and deposits with other and particularly European horizons.

The difficulties in the way of extended correlation are so great that for purposes of study it is often necessary to apply local names to the

* Philadelphia Acad. Nat. Sci. Jour., Vol. 6, 1828, pages 59-71.

† Philadelphia Acad. Nat. Sci. Jour., new ser., Vol. 1, 1848, page 129. Philadelphia Acad. Nat. Sci. Proc., Vol. 17, 1865, pages 71, 72.

‡ Annual Report of the State Geologist for 1883, pages 13-19.

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several formations of a particular district. There are, beyond a doubt, objections to the multiplication of names of geological horizons, and already accepted terms should be employed as far as possible, but very frequently they prove to be inadequate for stratigraphical requirements. Such is the case in the New Jersey area.

Outside of the major divisions of the geological column it is impossible to employ the terms of European authors. All such attempts have, upon critical examination, failed to stand the test. The lithological and faunal characteristics show such wide variations that definite correlations of minor horizons are impossible. The geological formations of America must be studied first upon their own merits, and only after a complete understanding of them has been gained, can satisfactory comparisons be made with foreign areas. A detailed correlation of the New Jersey formations with European will therefore not be attempted.

Again, the conditions under which the strata of the different portions of this country were deposited are so varied that the same terms are not applicable over wide areas. The formations of the Interior are, in a marked degree, dissimilar from those of the Atlantic border, and even throughout the Coastal Plain very considerable differences are found in its various portions. Correlations of more satisfactory character can be made here than with foreign areas, but many obstacles debar the geologist from the full consummation of his task. It is possible to show, in a general way, the equivalency of the deposits upon the Atlantic border with those in the Gulf, the Interior or on the Pacific coast, although in the case of individual formations such comparisons are of doubtful character.

The three essays recently published by the United States Geological Survey upon the Cretaceous,* Eocene † and Neocene,‡ contain discussions of the evidence for the correlations of the New Jersey strata. The results there recorded, together with more recent work upon the Cretaceous, indicate a marked time-break between the Raritan and the later formations, although there is no physical unconformity. The recent investigations of Professor L. F. Ward show a much closer relationship between the Raritan formation and the Potomac formation of the Middle Atlantic slope, than has been hitherto supposed to

* C. A. White. Bull. U. S. Geol. Surv., 82, 1891, 273 pages.

† W. B. Clark. Bull. U. S. Geol. Surv., 83, 1891, 173 pages.

‡ W. H. Dall and G. D. Harris. Bull. U. S. Geol. Surv., 84, 1891, 349 pages.

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exist, although it seems probable that the Raritan in its upper beds may be of younger age.

Dr. White * discusses very critically the evidence for the correlation of the New Jersey greensands, but does not attempt to separate the individual members of the series beyond the reference of the upper member to the Eocene, as was also done by the writer † in his report upon the Eocene.

Concerning the other formations of the greensand series, there seems to be little doubt of their reference to the Upper Cretaceous, although they probably do not include its earliest portions. Many of the same species have been found in the Cretaceous areas of the South Atlantic and Gulf States. Stanton ‡ has recognized thirty-five species as identical in Alabama, eighty-six in Mississippi, and fifty-four in Texas. Some of the species which are very much restricted in the New Jersey area appear to have a much greater vertical range in the gulf region. It is, therefore, very difficult to delimit equivalent horizons. It is not unlikely that a fuller knowledge of the formations may render it possible to make more detailed correlations, but at present it is impossible.

It is impossible, likewise, to satisfactorily correlate the upper member of the greensand series with the Eocene elsewhere. It is not known how much of that horizon is included in it, although it has been generally thought to represent the Lower Eocene of other regions.

The later Tertiary deposits as hitherto described are supposed to represent in part, at least, the Chesapeake and Lafayette formations of the Middle Atlantic slope, and these terms have been employed to temporarily designate them.

It will, therefore, be seen that, with one or two exceptions, an independent classification of the New Jersey formations has been rendered necessary. The objections to the use of lithologic terms have been already given, as well as the grounds for employing the place names adopted.

* Bull. U. S. Geol. Surv., 82, 1891, pages 78-84, 92-100.

† Bull. U. S. Geol. Surv., 83, 1891, pages 40-43, 80, 85, 86.

‡ Bull. U. S. Geol. Surv., 82, 1891, page 84.

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SECTION II.

TYPICAL SECTION-LINES ACROSS THE CRETACEOUS AND TERTIARY FORMATIONS.

INTRODUCTION.

Throughout so extensive a portion of the Coastal Plain as that represented by eastern and southern New Jersey, it would naturally be anticipated that changes in the character of the formations would be found upon a detailed examination of the deposits. In order to determine the change in passing from the northern to the southern end of the Cretaceous-Tertiary belt, five sections have been carefully studied. They were selected at points that were held to be thoroughly characteristic and at the same time most useful for the further mapping of the district.

It is important to note that the formations hitherto established, chiefly from an examination of the deposits in Monmouth county, have been found to be remarkably persistent, the several divisions extending almost the entire distance across the State from the shores of the Raritan to the vicinity of the Delaware bay. Local variations in thickness and texture of the deposits occur, but the strata nowhere lose entirely the lithological features found to be characteristic of them. To the southward the Neocene deposits overlap the later members of the greensand series so completely that the full section is not revealed, although deep borings at several points near the border of the overlap have shown their presence. The section lines selected extend from New Brunswick to Long Branch, Monmouth Junction to Shark river, Trenton to New Egypt, Philadelphia to Vincentown and Bridgeport to Glassboro.

FIRST SECTION—NEW BRUNSWICK TO LONG BRANCH.

The section extending from New Brunswick to Long Branch is the most typical, since it crosses the northern part of Monmouth county, where the formations are most characteristically developed. The pronounced topography of the region admits of extensive outcrops so

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that the relations of the several formations may be readily observed. The Raritan, Matawan, Navesink, Redbank, Rancocas, Chesapeake and Lafayette formations are found represented along this section line.

The Raritan formation overlies unconformably the sandstones and shales of the Jura-Trias. It consists chiefly of sands and clays which show marked lateral variation along the line of strike, the individual beds being persistent for very short distances. The clays are found more largely in the lower half of the formation, while the sands characterize the upper half. No line of separation can be found between the Raritan and the Matawan formations, the beds seeming to grade from the one into the other, although a marked faunal break is evidently present. As several thousand feet of deposits in the Southwest represent the hiatus between the two, continuous deposition could not have occurred, although no physical unconformity is shown in New Jersey. Similar occurrences have been recorded at other horizons of the geological scale.

Extensive exposures are shown at Washington and at other points along the banks of South river. The thickness of the Raritan formation has been estimated at 347 feet in this region, although this is not constant, and borings near its eastern margin will doubtless prove it to be much greater.

The Matawan formation consists of sands and clays with beds and seams of greensand scattered sparsely through the deposits. The lower portion of the formation consists of beds so similar to the Raritan that a separation is made with difficulty. Between Browntown and Morganville the Matawan formation outcrops at the surface, but is not so extensively exposed as a short distance to the northward along the shore of the Raritan bay. The deep ravines of Hop brook and its tributaries expose the Matawan deposits on the south flank of the Mount Pleasant hills, but the area of outcrop is not large. The thickness of the Matawan formation in this region has been estimated at 275 feet.

The Navesink formation is chiefly composed of greensand, although the basal beds are arenaceous, while the upper layers are often distinctly argillaceous. The formation is typically exhibited on the northern slope of the Mount Pleasant hills, while extensive exposures are found above the Matawan formation in the valleys of Hop brook

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and its tributaries. The Navesink formation in this section is about fifty feet in thickness.

The Redbank formation is composed primarily of red quartzose sands, in which greater or less quantities of disintegrated greensand are found disseminated. The lower portion of the formation is commonly dark-colored, while the upper portion is indurated and often greenish in color. The Redbank formation forms the greater portion of the Mount Pleasant hills, as well as the lower country to the eastward as far as and beyond the valley of the Swimming river. The thickness of the deposits reaches about 110 feet.

The Rancocas formation is found capping many of the higher levels of the Mount Pleasant hills, and successively lower heights to the east and south of them. It consists very largely of greensand that has been extensively oxidized. The upper calcareous member of the Rancocas formation has not been detected in this region. The greensand member of the formation reaches from twenty to twenty-five feet in thickness.

The Chesapeake formation has been found as an extensive deposit in the area to the south of Long Branch. It also caps many of the higher points of the Mount Pleasant hills, always overlying the Rancocas formation. The deposits consist almost exclusively of sand, the coarser varieties predominating toward the ancient shore line.

The Lafayette formation consists of gravels and sands, for the most part irregularly stratified, that are found best developed in the area lying between Lawrence brook and the western flank of the Mount Pleasant hills. Portions of the yellow gravel of this region should be here included. The deposits seldom attain much thickness.

SECOND SECTION—MONMOUTH JUNCTION TO SHARK RIVER.

The section extending from Monmouth Junction to Shark river is situated about ten miles to the south of the first section, and follows for much of the distance very near the line of the railroad passing from Monmouth Junction to the coast. The country is less broken than in the northern section, so that the natural exposures are not so extensive. The Neocene deposits are much more widely distributed and cover broad areas of the Cretaceous. The formations represented are the Raritan, Matawan, Navesink, Redbank, Rancocas, Manasquan, Chesapeake and Lafayette.

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The Raritan formation is largely buried in this region by the late Tertiary and Pleistocene accumulations. Wherever it has been penetrated, alternating beds of sands and clays have been found, but, due to the level character of the country between Monmouth Junction and Jamesburg, the relations of the deposits cannot be readily observed. Although no deep borings have been made, it seems probable that the Raritan formation is somewhat thicker than in the northern section.

The Matawan formation, although consisting chiefly of sands and clays, affords more extensive deposits of greensand than the northern section. On the railroad below Lower Jamesburg, glauconitic layers are found in the cuttings, while a short distance to the south of the section line at Bergen Mills, over twenty feet of glauconitic clay was penetrated by boring.

The Navesink formation consists chiefly of greensand, as in the northern section, the highly-arenaceous member being found at the base, and more argillaceous deposits capping the formation. Good surface exposures are found along Wemrock brook. The thickness of the deposits is somewhat less than in northern Monmouth county, being commonly about forty feet.

The Redbank formation consists of a loosely-compacted, reddish-yellow sand in the region to the west of Freehold, the proportion of glauconite being very small. The thickness of the deposits is about 100 feet.

The Rancocas formation covers a wide area to the east of Freehold. Along its western edge it is very much altered, giving a very characteristic reddish color to the surface outcrops. In the deeper valleys the typical greensands appear, and along the eastern margin of the formation the strata become somewhat calcareous, a feature that becomes more prominent in the southern extension of the deposits.

The Manasquan formation, which directly overlies the Rancocas formation, is so covered by later deposits that the line of contact was not observed. The upper members of the formation appear along the banks of Shark river, where extensive pits have been opened. The estimated thickness of the formation in this region is sixty-five feet.

The Shark River formation is here typically developed, appearing near Shark River village. The consolidated glauconitic layers cap the series of greensand deposits, but apparently are of limited geographical extent. The formation is nowhere found exceeding twelve feet in thickness.

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The Chesapeake formation caps the upper members of the greensand series, including the Rancocas, Manasquan and Shark River formations. It attains great thickness and is composed chiefly of light-colored sands, although extensive beds of clay also occur, the latter largely confined to the basal portion of the formation. The Hominy hills are largely composed of the sands, while in the valley of Shark river massive beds of clay appear.

The Lafayette formation, is found extensively developed in the broad plain to the west of the "marl belt," being typically exhibited in the vicinity of Jamesburg.

THIRD SECTION—TRENTON TO NEW EGYPT.

The third section is situated about fifteen miles to the south of the second, and follows in a general way the line of the drainage of Crosswicks creek. Some of the formations are less distinctive than in northern Monmouth county, but the occurrence of none but the Shark River formation is in doubt. Those represented are the Raritan, Matawan, Navesink, Redbank, Rancocas, Manasquan, Chesapeake and Lafayette formations.

The Raritan formation is found to the east of Trenton, but deeply buried by late Tertiary and Pleistocene deposits. On Back creek, a tributary of Crosswicks creek, the characteristic clays of more northern localities appear, but without extensive boring the relations of the various members of the Raritan formation cannot be fully deciphered.

The Matawan formation outcrops widely in the vicinity of the village of Crosswicks, and extensive diggings have been made in the dark-colored clays at that point. The pits have afforded great numbers of characteristic molluscan fossils. At other points along the valley of Crosswicks creek the Matawan deposits appear. The thickness of the formation is not far from 275 feet in this section.

The Navesink formation is less distinctive than in Monmouth county, the greensand beds becoming much mingled with argillaceous and arenaceous deposits. As a result the formation is oftentimes not readily separated from the overlying and underlying deposits. On Crosswicks creek it is highly fossiliferous, and the thickness approximates forty feet.

The Redbank formation consists of marked reddish, sandy deposits, interstratified with beds of greensand. The separation of this

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horizon from those overlying and underlying is oftentimes extremely difficult. The formation has thinned greatly as compared with the preceding section, the thickness of the deposits not exceeding thirty feet.

The Rancocas formation is very fully developed in this section, all the characteristic members being represented. On Crosswicks creek, to the north and west of New Egypt, are excellent exposures of both the greensand and calcareous beds. The thickness of the formation is about forty feet at this point.

The Manasquan formation appears to the south of New Egypt as a characteristic greensand. The whole region, with one or two exceptions, is so deeply buried by later accumulations that the full section is not exposed, while the Shark River formation does not appear at any point.

The Chesapeake formation forms an extensive cover over the region to the east of the greensand deposits, and consists of basal clays and overlying sands, as in eastern Monmouth county. It also occurs capping the higher points in the marl district.

The Lafayette formation consists of gravels and sands in the region to the east of Trenton, the deposits being a direct continuation southward of the Jamesburg beds.

FOURTH SECTION—PHILADELPHIA TO VINCENTOWN.

The fourth section extends from Philadelphia to a point somewhat south of Vincentown, and is about twenty miles to the south of the previous section. The country is very nearly level, only a few broad valleys breaking the general uniformity of the surface. Only in exceptional cases do surface exposures appear, so that the deciphering of the stratigraphy was almost exclusively dependent upon the records of well borings and the smaller openings made by the writer and his assistants. The formations represented are the Raritan, Matawan, Navesink, Redbank, Rancocas, Manasquan, Chesapeake and Lafayette. As the section, for several reasons, was not made at right angles to the strike of the beds, the relative thickness of the deposits is somewhat distorted in the section drawing.

The Raritan formation has been penetrated by numerous well borings in Philadelphia and its vicinity, as well as in the deep borings at Maple Shade and Moorestown. Alternating sands and clays have

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been found, the former at times of extreme coarseness, even passing into gravel beds. The Raritan formation is considerably thicker than in the northern sections, having been penetrated to a depth of over 400 feet.

The Matawan formation is well developed in the valley of Pensauken creek, excellent sections being afforded by the well borings at Maple Shade and Moorestown, and at the diggings near the railroad crossing of the east branch. Alternating beds of sand and clay appear, together with a glauconitic layer, filled with fossils. The formation is between 300 and 400 feet in thickness.

The Navesink formation presents few surface outcrops, but has been found in borings in the vicinity of Friendship, where it reaches a thickness of about forty feet. Little differentiation appears in its various parts, the formation consisting largely of an impure greensand, in which argillaceous elements largely appear.

The Redbank formation is characteristically developed as a red sand, although the proportion of glauconite is small except in the upper layers. In a well boring to the west of Medford the upper portion of the formation was found as a typical greensand filled with characteristic fossils. Its thickness is approximately 100 feet.

The Rancocas formation is well developed in this section, which is but a short distance to the south of its typical locality. The dark argillaceous "chocolate" marl is found at the base of the series overlain by thick-bedded greensands, in the upper portion of which is the *Terebratula Harlani* zone, which extends so persistently across the State. The overlying calcareous bed is here strongly developed, although scattered grains of greensand everywhere abound. The thickness of the formation is about forty-five feet.

The Manasquan formation occurs as a typical greensand. At Vincentown it has been extensively worked for marl. It is about sixty feet in thickness in this region.

The Chesapeake formation is not strongly developed in this section, although found a short distance to the eastward very extensively represented.

The Lafayette formation consists of sands and gravels that have been as yet with difficulty differentiated from similar deposits of later date.

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FIFTH SECTION—BRIDGEPORT TO GLASSBORO.

The fifth section is situated about twenty miles to the south of the fourth, and affords an excellent idea of the relations of the leading divisions of the Cretaceous-Tertiary series in southern New Jersey. The upper members of the greensand series do not outcrop, although probably existing beneath the covering of later formations. It was impossible to obtain data upon this point, since few wells have been bored in this region, and no records were accessible.

The Raritan formation is found on both banks of the Delaware river, although on the New Jersey side the covering of late deposits precludes its outcrop at the surface. It, however, underlies the low areas adjoining the Delaware river and its tributaries.

The Matawan formation is found overlying the Raritan formation, and consists of alternating beds of sand and clay. Numerous borings were made into the clays near Swedesboro, but few outcrops are found except near the upper limits of the formation.

The Navesink formation consists of typical greensands, with a variable admixture of arenaceous and argillaceous materials. The formation rarely reaches forty feet in thickness.

The Redbank formation consists of deep red sands, through which considerable amounts of glauconite are frequently found disseminated. The upper portion of the formation is very green at times and is generally firmly consolidated, this feature being well exhibited at Mullica Hill, where the indurated layer is very rich in fossils. The formation is about 100 feet in thickness.

The Rancocas formation is characteristically developed, the highly-glauconitic sands overlying the indurated layer of the Redbank formation. The contact is clearly shown at Mullica Hill. Farther to the east, on Raccoon creek, the *Terebratula Harlani* zone is well exposed, but the calcareous member is not exhibited.

The Chesapeake formation is found overlying the Rancocas formation along its eastern edge, completely burying the higher members of the greensand series. It consists largely of sand, with thin-bedded clays near the base.

The Lafayette formation has not been very fully differentiated from the overlying sands and gravels of later date, but is not absent from the region.

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SECTION III.

AREAL WORK DURING THE YEAR 1893.

The mapping of the atlas sheets of Sandy Hook and New Brunswick during the year 1892 was followed the past season by the completion of the Cassville sheet, which adjoins the New Brunswick sheet upon the south. The work was largely done by Mr. R. M. Bagg, and a fuller explanation of the results will be given at a later time. The formations found represented in the northern district, and described in detail in the last annual report, were traced to the southward, where certain changes in the thickness and character of the deposits were noted.

The Chesapeake formation is widely extended over the southern portion of the district covering the later members of the greensand series, although as the result of numerous borings made at many points along the stream channels the Manasquan formation was detected, a fact not hitherto recognized in this district.

The Rancocas formation was found widely extended, consisting of the characteristic greensand deposits of more southern localities.

The Redbank formation was traced across the area of the map, forming largely the hills in the northwestern portion of the region. It consists chiefly of the characteristic red sands of northern Monmouth county.

The Navesink formation is not characteristically represented, since the greensands are highly argillaceous and at times with difficulty separated from the Matawan deposits in portions of the area.

The Matawan formation is the oldest member of the Cretaceous series represented, and covers a considerable area in the northern portion of the district.

Much information has been collected in regard to the areal extent of the formations on the adjoining atlas sheets of Asbury Park and Bordentown, and it is purposed to continue the work upon them at the earliest opportunity.

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PART III.

Report on Archean Geology.

BY

J. E. WOLFF.

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THE GEOLOGICAL STRUCTURE IN THE VICINITY OF HIBERNIA, NEW JERSEY, AND ITS RELATION TO THE ORE DEPOSITS.*

BY J. E. WOLFF, ASSISTANT PROFESSOR IN PETROGRAPHY, HARVARD UNIVERSITY.

INTRODUCTION.

In the various publications of the Geological Survey of New Jersey, especially the final report of 1868 and subsequent annual reports, the general mode of occurrence of the iron ores and their associated rocks has been described, with many detailed sections of mines, and with discussions of the origin of the ores and rocks, in which a general belief is expressed in the original sedimentary origin of the iron ores and most of the associated rocks. The acceptance of this theory naturally led to attempts to establish definite levels or horizons in the series, and hence, in the report of 1885, and especially of 1886, Dr. N. S. Britton subdivided the whole series of gneisses of the Highlands into three members: a lower, massive one, a middle, iron-bearing one and an upper, schistose group, which were in general supposed to lie in anticlinals or synclinals, so that the Highlands consisted of a compressed series of folds, overturned to the west, and with therefore a uniform monoclinal dip to the east, in which these members alternately appeared or disappeared. In the reports of 1889 and 1890, however, the problem was attacked in a different way by Mr. F. L. Nason, who first showed that the three subdivisions previously made were based on indeterminate characters, and that they could not be applied in practice. He then

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attempted to establish certain characteristic types of rock in the Highlands, and to trace belts of these characteristic rocks through considerable distances. In the latter connection he describes belts of characteristic coarse biotite-garnet-graphite rock, one of which forms an important feature in the present paper. The possibility that a great part of the rocks of the Highlands are eruptive is also discussed. While Mr. Nason's work was only a beginning and his conclusions tentative, he applied the only methods which can now yield definite results in this region.

When, in the spring of 1891, the United States Geological Survey began work on the Archean Highlands, as part of the geological map of the United States, it was realized by the writer that the only way to make any definite advance over the previous work in this region was by careful detailed mapping, going over the ground step by step, and recording observations and collecting specimens in such a way that the work could have a permanent value aside from any theoretical conclusions; a method necessarily slow and tedious, and with at first little to show in the way of results. The completion of the topographic map made this method now possible, a resource denied to many previous workers in this field. The following system was used: Photographs were obtained of the original sheets of the topographic survey (scale three inches to the mile), and divided into quarters; the corresponding squares were cut out from the published topographic sheets (scale one inch to the mile), ruled in small squares and pasted in the front page of the note-book. Each square received a number and letter, and when an observation was recorded in the body of the note book, or a specimen collected, a little dot within a square having the correct number and letter for that sheet made a permanent record of the locality, so that any one subsequently using the material would have no difficulty in determining the exact location. The observations were at the same time, or subsequently, plotted on the large scale map.

In the following pages the results yielded by the study of one of the important ore districts of the State are presented, with the statement that owing to the partial stoppage of the field work in 1892 and 1893 the results are incomplete, and much remains to be done in the application and extension of the facts so far established.

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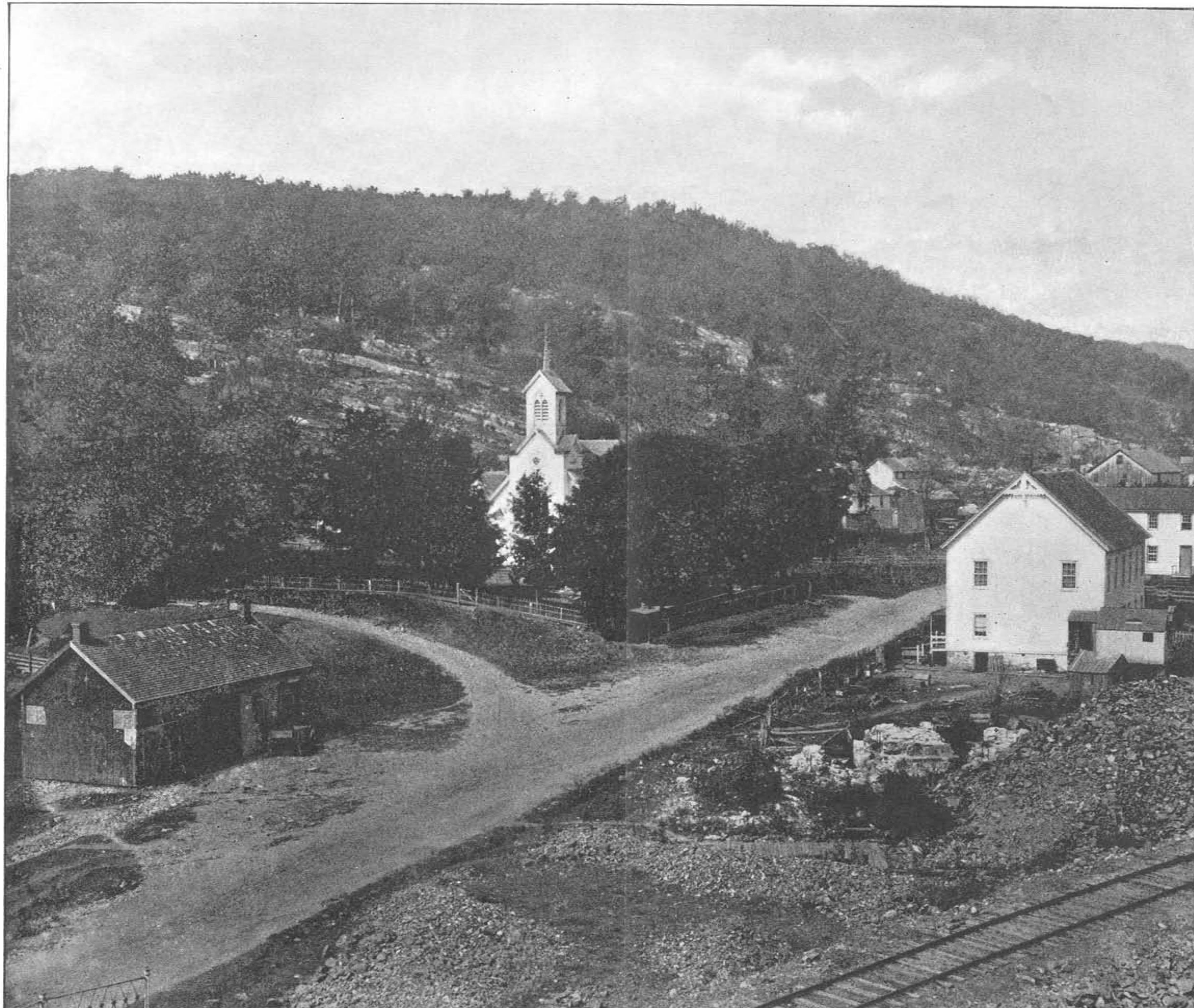

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Plate VII.

View looking northwest from Hibernia, showing "pitch" of rocks.

Plate VIII.

Near view of ledge northwest of Hibernia, showing "pitch."

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GENERAL DESCRIPTION OF THE HIBERNIA REGION.

This lies well in towards the centre of the belt of crystalline rocks forming the New Jersey Highlands, since Hibernia is six miles from the eastern edge of the Archean near Boonton, and twelve miles from the western boundary north of Andover. The fact that it lies north of the glacial boundary and has abundant rock exposures, as well as the presence of some of the largest iron mines in the State, makes it an excellent region for structural investigation.

As will be seen from the accompanying map, the topography between the northeast end of the Hibernia ore bed and Mount Hope is characterized by long parallel ridges trending northeast and southwest, while at the northern end of the Hibernia mines a transverse or northwest-southeast topography begins, both of which are the expression of the rock structure. The termination of the long northeast ridges by a gentle northerly slope and the beginning of others by a steep bluff facing southwest, a feature which is so characteristic of the New Jersey Highlands, and due to the pitch or inclination towards the northeast of the underlying rock masses, is developed here to perfection. Plate VII., from a photograph taken from the trestle at Hibernia looking northwest, shows this feature distinctly on the hillside back of the church, both in the slope of the hill and the structure of the underlying ledges.

DESCRIPTION OF THE ROCKS.

The rocks have a generally uniform structure, consisting of massive or foliated gneiss, of white, grey or light-greenish colors, which grades constantly into darker varieties, whose color is due to the greater abundance of hornblende, biotite or similar minerals. These varieties often form separate beds, which may run as bands of rock for considerable distances, but with one exception none of these varieties have had sufficiently-distinct characters or sufficient continuity to make them of much aid in determining the general structure.

The minerals composing these gneisses are: quartz, feldspar (either orthoclase, plagioclase, microcline or microperthite), brown or green hornblende, a deep-green or colorless augite (sometimes diallage), biotite, sometimes hypersthene, and apatite, magnetite or zircon as constant accessories. The comparative rarity of muscovite is notice-

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able, as well as the frequency of augite—in fact these augite gneisses are widespread elsewhere in the Highlands.

Two constant structures need special mention. In the banded rock there are alternating layers of gneiss of variable thickness, which differ in mineral composition, especially in the relative proportions of hornblende, biotite, &c., and within the individual bands these minerals are arranged in rough parallelism to a plane, which is called the plane of foliation, because the minerals, like the mica, have their flat dimensions, plates or foliæ in this plane. But not merely the mica or hornblende, but the other essential minerals as well, such as the quartz, feldspar, augite, &c., have a flattened shape in reference to this plane, being rather discoid than roundish in outline. As a result of this shape, when we make a thin section parallel to the plane of foliation, the minerals appear in broad, irregular masses, while in transverse sections they appear in narrow, irregular bands. In other cases the rocks of the region are without this plane-parallel structure or show but faint traces of it, yet, while they have a massive appearance on surfaces transverse to the general northeast trend, when we look at the side of such an outcrop we often see a linear structure, due to the fact that the component minerals of the rock are not in roundish grains, but in pencils or elongated, lenticular masses, the long axes of which lie parallel to the strike of the formation, and are generally inclined to the northeast. As described above, Plate VII. shows this structure in the whole hill, the lines inclining northeast about 20°. Plate VIII., taken from a point a little to the right or northeast of the end of the slope in Plate VII., shows this structure near to, while Figures 1 and 2, in Plate IX., are magnified photographs of thin sections of the rock seen in Plate VIII. Figure 1, which is transverse, shows the irregularly-rounded and interlocking shape of the crystals of quartz and feldspar when cut at right angles to their long axis, while Figure 2, which is parallel to the linear structure, shows their irregularly-elongated shape in the latter direction. The well-known occurrence of the magnetic ore bodies of the Highlands in long, pod-shaped masses whose axes incline or "pitch" northeast, needs no further description here, and that the linear structure of the gneisses described above is parallel in direction and angle to the pitch of the adjoining ore bodies was brought out by Dr. Cook and others. That this pitch of the gneisses is connected with compression and folding is well brought out in several places near

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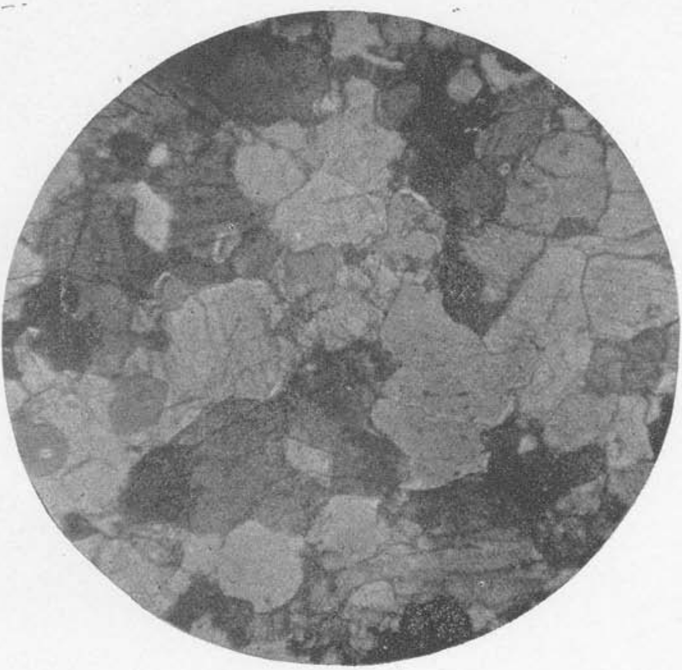

Fig. 1.

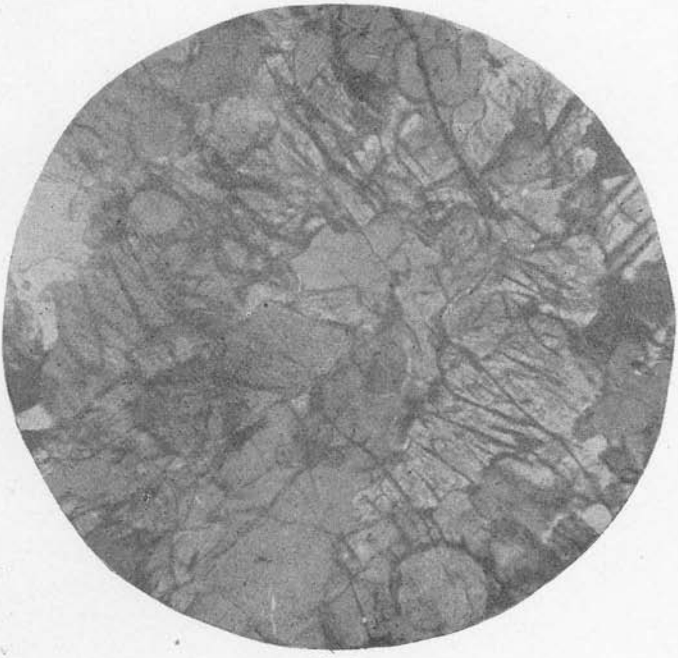

Fig. 2.

Plate IX.

Microphotographs of thin sections of gneiss of plate VIII.
Fig. 1, transverse to pitch. Fig. 2, parallel to pitch.
Polarized light, x 29 diameters.

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Hibernia, where, in beds of massive gneiss with the pitch well developed, there happen to be scattered bands of dark hornblendic rock, which are crumpled in several small folds, the axes of which lie parallel to and incline with the pitch. But another important fact is established from the microscopic study of these massive pitching gneisses, namely, that the elongated shape of the individual minerals which produces the pitch is one impressed on them when they crystallized as we now find them and not by later shearing forces, for the grains of quartz, feldspar, hornblende, &c., are, with rare exceptions, seen to be entirely unaffected by any straining, cracking or granulation, interlocking with all the appearances of primary crystallization, and this is true whatever origin we may assign to them. This pitch is then a marked structural feature in the massive gneisses about Hibernia, often combined with a plane foliation, so that the minerals of the rock have both a flat dimension and a long dimension, the one corresponding to foliation, the other to pitch.

Two special varieties of rock, common throughout the Highlands, occur here. The first is a coarse granite or pegmatite, composed essentially of quartz and feldspar, which is found in narrow bands generally parallel to the structure of the gneisses, but here and there cutting across their foliation at a perceptible angle. This lack of parallelism is especially clear where the gneisses have been much compressed along the strike, and the pegmatite occurs in the space left between the crumpled and faulted layers of the gneiss. Plate X. shows such an occurrence in the hanging wall of the Hibernia ore bed. These facts establish the later age of the pegmatites, whether they be considered as eruptive or segregated masses.

The other variety forms what may be called the dioritic bands of the gneiss. They are dark, basic rocks, composed of plagioclase feldspar, hornblende, augite, hypersthene, biotite and magnetite in varying proportions, with often orthoclase quartz and other accessories, and correspond therefore mineralogically to the eruptive rocks known as diorite, norite, &c., but differ from them in that their minerals have the form and relations described above in the gneisses. They are foliated and pitch like the inclosing gneisses, and have been folded with them, yet they often show, like the pegmatites, a boundary oblique to the layers of the gneiss, as though they were of later origin and intrusive rocks. From our present knowledge, it is hardly safe to assign a common origin to all these occurrences.

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GEOLOGICAL STRUCTURE.

An important feature of the region is the Hibernia ore bed, which outcrops at the surface for about a mile and has been worked down on the dip from 600 to 800 feet in the different mines. The ore has maintained a remarkable continuity from the surface down, so that this deposit is exceptional in the subordination of the pod form, the ore occurring more like a bed of coal or other bedded rock, yet pitch is present both in the ore body and country rock. The strike curves gradually to the east at about the middle of the outcrop, corresponding to the curve in the general strike of the rocks. (See map.) The gneiss forming the hanging and foot walls is well banded near the ore, having a straight, even foliation or bedding, and but rarely sharp twists, such as that shown in Plate X., which interrupt the straight strike of the gneiss layers. The dip averages about 65° southeast, varying from steeper to flatter, and lines of pitch are easily found both in the ore bed and in the country rocks, conforming in angle and direction to the general pitch of the region (21° and greater). At the south end the surface outcrop of the ore disappears under the soil of the valley bottom, while at the north end, in the Willis or Wharton mine, the country rock comes in above the outcrop of the ore as cap-rock, and the ore seems to plunge downward (northeast) and disappear from the surface. The reason for this will appear presently. The straight bedding of the gneiss in proximity to the ore bed extends several hundred yards into both hanging and foot walls, when the gneiss becomes more massive with development of pitch.

This pitch-structure is especially well developed in the long ridge beginning at a point a mile east of Mount Hope (see map) and extending to a point nearly opposite the north end of the Hibernia ore bed. Plate VII. shows the effect of pitch on this ridge where it is cut through by Hibernia brook. The angle of pitch varies from 15° to 20° +, in a direction northeast. The rock of this ridge is a massive hornblende gneiss, with generally little other structure than the pitch, until a point is reached about half a mile northwest of the Willis mine, on the north end of the ore bed, where the structure suddenly becomes a plane-parallel or laminated one, and bands of dark hornblende or biotite gneiss alternate with lighter-colored, more massive rock; in other words, the rock has bedding or foliation

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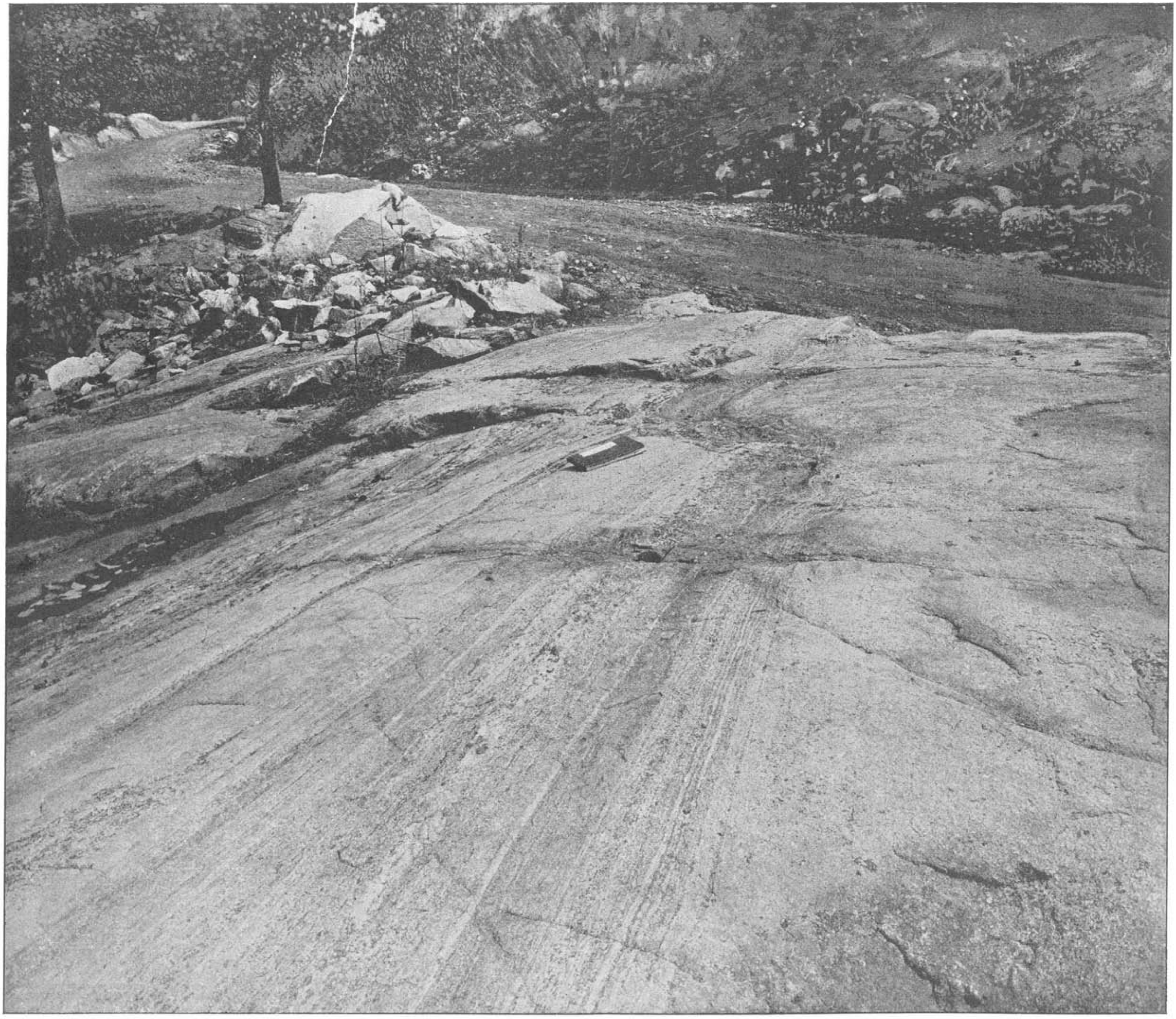

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Plate X.

Banding and contortion of gneiss, hanging wall, Hibernia.

planes which incline in the same direction and at about the same angle as the former pitch, which has been replaced by dip, and continuing in a northeast direction the edges of these northwest-striking and northeast-dipping beds are crossed for a distance of over a mile, representing, therefore, with a dip of 30°, a thickness of rock of at least 3,000 feet. If we go back to the place of change from pitch to dip and follow the northeast-dipping ledges southeast along their strike towards the Hibernia ore bed (see map), they soon curve to the south and then to the southwest, so as to coincide in strike and dip with the ore, and become, in fact, part of the foot wall. If we follow the ledges the other way, or northwest from the starting point, they are found to turn gradually to a west and then a southwest strike, finally losing their dip-foliation and retaining simply pitch.

If we follow the hanging wall of the ore bed along its strike to a point opposite (southeast) the north end of the workings at the Willis (Wharton) mine, we find that it strikes northeast and dips southeast, in conformity with the ore, until this point is reached, when the rocks, like the foot wall, curve gradually to the north and then to the northwest, crossing the line of the ore bed a short distance north of the Wharton mine in a railroad cut and running into the series of northwest-dipping and northeast-striking gneisses previously described.

The structure, therefore, resembles that of a dome-shaped fold in the country rock, the centre of which is about one mile due north of Hibernia, with the ore bed, as far as now explored, lying on the eastern flank at a level several hundred feet above the lowest rocks in the centre of the fold. In this case the strata dipping off from the northern end of the dome should be in normal succession from bottom to top, representing a series at least 3,000 feet thick. But with the possibility in mind that such an anticlinal structure might be simulated in massive rocks either by secondary foliation or the flowing of an igneous mass, it was necessary to find some continuous layer or level of rock which could be traced around the sides of the dome. No marked change in character was observed in the rocks lower down or higher up in this series, and it was only after long search on the side of the dome that this characteristic rock was discovered. It consists in a coarse or fine gneiss, composed of quartz, feldspar (orthoclase and plagioclase), garnet, biotite, magnetite and often graphite, this combination being peculiar and easily recognized, especially as the rock has a deep-red color when weathered. This rock is first found at a

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point about half a mile southeast of the White Meadow mines, and can be traced continuously from there nearly five miles northeast to a point one-quarter of a mile southeast of the Cobb mine, opposite the middle of Split Rock pond. It has in this belt the strike and dip of foliation (southeast) common to the gneisses. Two hundred yards northwest, across the strike from the end of the first belt, near the Cobb mine, a second belt of the same rock begins, which can be traced continuously west and then north, in a crescent, about three miles long, the strike at first southwest, then west, northwest, north and northeast, the corresponding dip being at first northwest, then north, northeast, east and finally southeast (see map), while in the other band the strike is northeast, dip southeast. The presence and structure of this rock, combined with the general structure as shown on the map, seem to establish its character as a continuous band, connecting the east and west flanks of the dome and occurring in its place on the east flank. The same characteristic rock was found in a cliff under hill 939, near the letter A of the profile on the map, consequently in the right place on the west flank of the dome, but there has been no opportunity to trace its connection with the other bands. This garnet-biotite-graphite horizon seems, therefore, to lie above the ore and separated from it by over 2,000 feet thickness of rock. There is a possibility, based on facts observed a few miles west of here, that it represents a limestone horizon. The course of this band, combined with the general structure platted on the map, shows that in the upper layers of the dome the intense compression drew the rocks out into two long, finger-like folds, which were gradually squeezed into parallelism with the general northeast trend.

PROBABLE EXTENSION OF THE ORE BED.

Such being the structure and course of the country rock, both in the hanging and foot walls, it is evident that the ore bed should conform to this, and that consequently its extension should be found in the proper position in the northwest-striking series, as indicated approximately by the dotted line on the map. The plunging downward of the present outcrop of the ore is evidently due to the sharp curve in the rocks, and the resulting nose may continue some distance northeast, carrying the ore with it; but if the ore exists in its proper place in the series, it should be found where indicated. To find the

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ore in the centre of the fold and determine its possible value is, of course, the task of special prospecting and magnetic surveys, which are beyond the scope of the present work.

GENERAL CONSIDERATIONS.

In reviewing our knowledge of the Highland area of New Jersey, Van Hise * writes as follows:

"The weight of opinion in former years has been in favor of the sedimentary origin of this gneissic series. Mather, who gave by far the best early descriptions of the district, and Nason, who has recently been closely studying the limestones of New Jersey, find that the white crystalline limestones which have been regarded as Archean grade into the blue limestones, which are fossiliferous. These writers regard all of the white limestone as parts of a newer series which have been metamorphosed either as a result of extreme folding or by intrusive masses of granite of later date, with which they are frequently associated. If all of these limestones are excluded from the pre-Cambrian, and this is a very doubtful assumption, the evidence in favor of the detrital origin of the Highland area is restricted to the widely-disseminated graphite and to the magnetite beds of iron ore. Magnetite is widely associated with certain belts of the granite gneisses of New Jersey, but this and its concentration in lenticular masses within the gneisses in the form of magnetite can hardly be considered as decisive evidence of their sedimentary character. The magnetites associated with the basal gabbros of the Lake Superior Keweenawan are in purely igneous rocks. The graphite of the graphitic gneiss is a point of more weight. The absence of graphite, as an important constituent over large areas in any definitely-determined igneous granite gneiss, bears in favor of the sedimentary origin of the gneissic series. If this theory proves true, the Highland gneissic series more nearly approaches the characters of a massive eruptive than any other metamorphic sedimentary rock known to the writer. Upon the whole, in the regularity of its lamination, in its lack of extreme contortion and foliation, and in the presence of graphite, the Highland gneiss is not like the fundamental complex, the genuine Archean of Canada and the West. However, there are no certain criteria upon which it can be referred either to the Algonkian or Archean. It must be simply classified, so far as present knowledge goes, as pre-Cambrian.

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* Correlation Papers—Archean and Algonkian. Bulletin of the U. S. Geologica Survey, No. 86, 1892, pages 414, 415.

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"If it cannot yet be decided whether the Highland gneisses are sedimentary, the supposed structural divisions of Britton and Nason can be regarded as only lithological. Britton's arrangement of a massive group in the cores and schistose groups on the outer parts of the ranges can be as well explained, as has been repeatedly seen, by the eruptive theory of the origin of the series as by the sedimentary. From Nason's work it appears that certain varieties of rock have a continuous, widespread distribution, but the descriptions show that his various types grade into each other instead of being sharply differentiated, as supposed. Magnetite is the distinguishing characteristic of one type, and yet, in order to make out the continuity of this belt, rocks have to be classed with this type, in which hornblende and biotite are the chief basic constituents. The same thing is true of the second type, in which the hornblende, the distinguishing characteristic, is locally almost wholly replaced by magnetite or biotite."

With this impartial statement of the difficulties of the problem, what aid does the present work give towards a solution?

It appears to the writer that the following conclusions are justified, so far as this area is concerned:

(*a*) The whole series has a top and bottom, the rocks near the centre of the dome having originally been below those at the periphery, so that as we go outward from the centre we pass to higher levels, and, moreover, the different layers of the series must have been once horizontal, or nearly so, and forced into their present position by folding, unless the common facts of stratigraphy can be set aside.

(*b*) At least one characteristic horizon or layer of rock, the garnet-biotite-graphite gneiss, must, from the stratigraphy, have once existed over a large part of the present area, have been folded and eroded to its present form, and the same would be true of the lower horizon of the iron ore could it be traced completely around the dome.

(*c*) That the foliation, in part at least, is parallel to the bounding planes of the different layers of rock (bedding), and that the pitch and foliation are closely connected, since one takes the place of the other or both occur together; also, the pitch is plainly connected with lateral compression, since it is parallel in direction and angle to the axes of crumples in the gneiss.

(*d*) That the essential crystallization of the rocks as we now find it took place either *during* or *after* the action of the compressing forces which folded the rocks and produced pitch, but not before,

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since the pitch-structure is inherent in the shape of the minerals as they crystallized; and that hence, if we consider the rocks to have been formed by a series of eruptive flows or segregations, one above the other, they must have been able, while in the fused state, to act as solid masses in order to form the folds which have been described —a difficult assumption.

These considerations seem to the writer to favor an origin for the series from a previous bedded series by metamorphism and re-crystallization which took place contemporaneously with the folding and without fusion, a familiar fact in regional metamorphism. The difficulty in understanding how such mineral composition and structure can be produced without fusion is not so extreme, when one studies the characters of the Cambrian gneisses of the Green mountains, which can be traced into sediments. It is perhaps not possible to state definitely at present whether this original bedded series was water-deposited or clastic in the ordinary sense, or of a different nature. Facts already obtained near the Hibernia region point to the transition of a similar garnet rock into limestone. Should this be established, it will go far towards establishing the sedimentary origin of this series, and its consequent classification as Algonkian.

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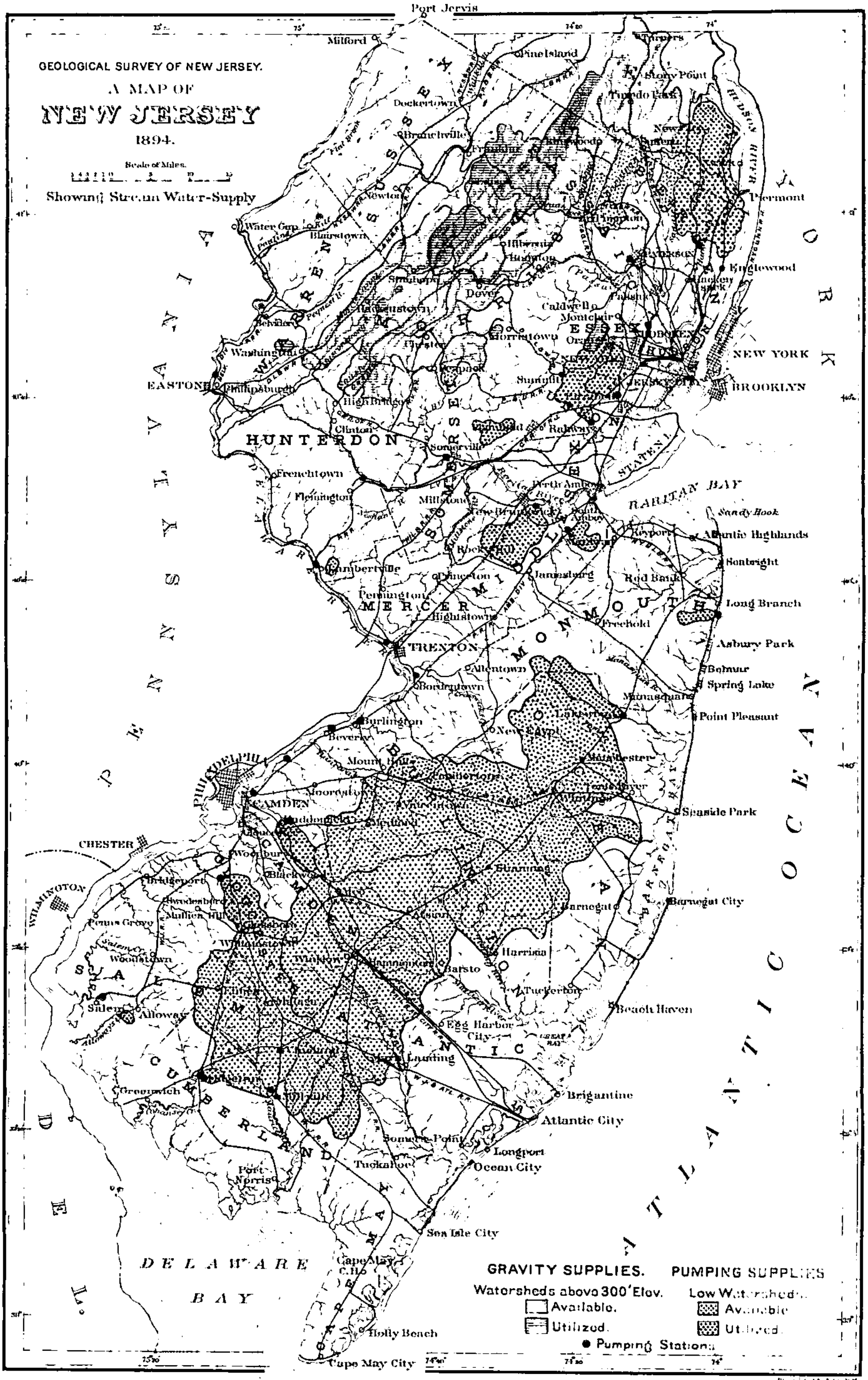
PART IV.

Water-Supply and Water-Power.

BY

C. C. VERMEULE.

NEW JERSEY GEOLOGICAL SURVEY



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WATER-SUPPLY AND WATER-POWER.

BY C. C. VERMEULE.

The collection of data for the forthcoming report upon the water-supply and water-power of the State has been completed. Much interesting and important matter continues to come to hand, but it has been necessary to confine the studies to material already collected in order to close the report. It has been conclusively ascertained that our streams obey definite laws of evaporation and flow, and the report will make possible as close estimates of flow by months, seasons and years as will be necessary for a basis of hydraulic works of all kinds. Some new light has been shed upon the subject, and it is hoped that the report now in press will contribute materially to accuracy in computation of stream-yield and the available water-supply of our State.

We shall confine this present progress report to a consideration of a few points relating to water-supply, which are now prominently before the public.

STREAM POLLUTION.

It appears evident to all that certain streams have become almost indispensable as outlets for the sewage of our populous districts and large cities. They will continue to be more or less defiled in the future, even should systems of chemical treatment or other clarification of sewage be forced upon our cities. Should the sewage be diverted, much effete organic matter will be washed into these channels from their populous water-sheds with every heavy rain. The abandonment of these streams as sources of domestic water-supply is imperative. A prominent example is the Passaic, below Paterson. This stream, including all of its lower branches excepting the head-waters of Saddle river, has become badly polluted. A measure of

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this pollution may be obtained by comparing the volume of actual sewage discharge with the dry-season flow of the stream at various points.

At Dundee the flow for weeks at a time in dry weather does not average more than 150 cubic feet per second. The sewers of Paterson at such times discharge twenty-one cubic feet per second of sewage into Dundee lake, consequently one part in seven of the flow at Dundee is sewage. This is particularly dangerous sewage matter, furthermore, being partly dye-stuffs and refuse from the manufacturing establishments. An average of one part in seven, therefore, of the water passing Dundee dam for weeks together in dry, hot weather is made up of particularly offensive sewage. Nor does this give the worst phase of this pollution at Dundee. There are periods of thirty-six hours over Sunday and of twelve hours over night, a total of ninety-six hours weekly, when absolutely no water passes Dundee dam at all. The raceway gates are closed and all of the flow is held back in the pond. At such times, for thirty-six hours at a time, we have observed an average inflow to Dundee lake of only from fifty-five to eighteen cubic feet per second, the river being held back in ponds above Paterson. This inflow, therefore, held back of Dundee dam, is at such times from forty to ninety per cent. sewage, running into a still pond of water, where it is exposed to the sun with no chance for aëration or oxidization. Below Dundee we have added to the inflow Saddle river, which is reasonably free from pollution, and the dry-season flow of which is about eight cubic feet per second. The city of Passaic, however, immediately adds about two and one-half cubic feet per second of sewage, and the mills a large additional quantity of dye-stuffs and refuse. The other branches, Third and Second rivers, are notoriously impure, and it is plain that at no point below Dundee are the conditions even as good as we find them here. The idea that a stream which flows with a smooth, gliding current, like that of the Passaic below Paterson, can purify itself, is fallacious, and a dangerous one to obtain currency. Streams which leap over cataracts and rapids, or even ripple over stony beds, become purified by aëration and oxidization because a large proportion of their waters are brought in direct contact with the atmosphere. No such contact is obtainable with streams flowing in deep channels with smooth, unbroken surfaces. The figures here presented, bad as they appear, do not take into account all the pollution which

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reaches the stream. An examination of the course of the Passaic from Newark to Paterson will convince any person of intelligence that we have in nowise overdrawn the picture. We call attention to the matter here because it does not merely demand the immediate abandonment of this portion of the Passaic as a source of domestic water-supply, but suggests that unless some effective remedy is applied the stream may become a menace to the population along its banks. The diversion of the headwaters of the stream already begun will lessen the flow through this channel, while the steady and rapid increase of population will increase the amount of sewage.

Three remedies suggest themselves. The building of an intercepting sewer along each bank to the bay is one, the compulsory treatment and clarification of sewage is another. Even should one of these be adopted, the third remedy might be found a desirable one to apply. Briefly, this is the storage of the waters of such of the branches of the Passaic as the Upper Passaic and Lower Whippany, which are unfit for use as sources of water-supply, and their utilization to increase the dry-season flow of the Lower Passaic, thereby preserving and increasing the water-powers of Little Falls, Paterson and Dundee, and at the same time raising the flow to a point where it will be effective to flush and produce reasonably wholesome conditions in this channel. From an engineering standpoint this is a perfectly practical suggestion, and from a sanitary point of view it will probably become a necessity in the future.

While pollution is not yet serious upon the Lower Raritan, population and threatened contamination have reached a stage which makes it necessary to withdraw all of that stream below the town of Raritan, but not including the Millstone, from our stock of potable waters.

The Delaware, at Trenton, during dry seasons, falls below 1,730 cubic feet per second. At such times the sewers of Trenton may be expected to discharge ten cubic feet per second, so that the proportion of sewage is one in 173 for the river below. We may for the present consider that the sewage received at various points above is disposed of by aëration during the rather turbulent course of the river over the rapids. Below Trenton, to Philadelphia, is a long tidal pool, with no chance for aëration. During very dry seasons the total inflow to this pool, down to and including the Schuylkill river, does not exceed 2,500 cubic feet per second. The total amount of sewage

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discharged into this channel at points below where aëration is possible, from the various towns and cities, amounts to 211 cubic feet per second, or one part in twelve of the total inflow. We have at the upper end, therefore, one part in 173 of sewage discharge, and at the lower end, at the mouth of the Schuylkill, one part in twelve. It ought to be evident that tidal action can do little to improve the condition of this water. The upflow will usually be worse than the ebb, and tidal action produces very slight aëration. While we are not prepared to say that the Delaware, considerably above Philadelphia, is at present polluted to an unsafe degree, these figures certainly teach us that it cannot safely be adopted as a future source of supply by our cities, and will probably have to be abandoned in the near future by those cities which are now using it.

We do not wish to be understood as taking the ground that sewage can ever be rendered safe in drinking-water by any reasonable degree of dilution. Its presence in very small proportions may be dangerous, but the figures which we have given furnish an approximate measure of the extent of pollution. For instance, the average pollution of the Passaic at Dundee, in dry weather, amounts to seven gallons, or nearly two pailfuls, of sewage in a barrel of water, and of the Delaware at Philadelphia to four gallons, or one pailful per barrel, and this condition of things is rapidly growing worse.

There are a few other streams of the State similarly polluted, but they are comparatively unimportant, and their use as sources of water-supply would never be thought of, consequently we omit them from our consideration.

Apart from these streams which must be abandoned to drainage purposes, there are some others which may be in danger from pollution which are among those most valued for purity and general adaptability to be a supply for our cities. On the Ramapo, the Tuxedo, New York, sewer is already emptying an objectionable amount of filth into the stream, and the growing villages of Hilburn and Suffern, in New York, threaten further pollution. On the Rockaway, Dover is considering sewers; Rockaway and Boonton are likely to follow suit. The Whippany affords practically the only natural outlet for Morristown. If unrestrained, all of these growing communities may be found sewering into the streams in the next few years. The Rahway is endangered similarly, although Cranford and Roselle contemplate a sewer to tide-water.

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Plainfield, lacking a stream of sufficient size for an outlet, is about to adopt intermittent filtration of its sewage. East Orange has had sewage-disposal works in operation for several years. Similar methods should be adopted by all towns upon small streams, for the use of such small, shallow streams as the Ramapo or Rockaway as sewage outlets not only destroys the beautiful gathering-grounds of the State water-supply, but it endangers the general health along their courses. There is no subject more vital to the conservation of the gathering-grounds needed to supply the large urban population of the State than this of stream pollution. Those water-sheds which are suitable for gathering potable waters must be in some way guarded from sewage contamination, or the demand for good water will very shortly exceed the supply. Many of the communities mentioned appreciate these considerations, and would readily acquiesce in measures taken to protect these streams if they knew it to be the settled policy of the State.

The Delaware above Trenton receives the sewage of several towns and villages scattered over the water-shed, the aggregate amount of which is about ten cubic feet per second, but this is discharged here and there in small volume, and, as we have already remarked, the water is so thoroughly aërated that evidence of serious pollution is not found at present above Trenton, although the evil is increasing. Above Easton the stream is almost entirely free from sewage.

The volumes of sewage used in this discussion are based upon official returns of water supplied to the several towns. The dry-season stream-flows were measured by the Survey. It has been thought best to present the matter in this definite way because of the fact that much has been published that is indefinite and misleading upon this subject, intending either to exaggerate or depreciate the real conditions.

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Classification of Public Water-Supply Systems by Sources.

NORTHERN STREAMS BY GRAVITY.

Town.	Stream.	Population of Town, 1890.	Daily Consumption, 1893. Gallons.	Treatment of Water.	Remarks.
Newark	Pequannock	181,830	15,600,000	None.	
Orange	Rahway	18,844	1,500,000	Filtered.	
Morristown	Springs	8,156	350,000	Strained.	
Dover	"	4,000	60,000	None.	
Lambertville	Swan's creek	4,142	200,000	None.	
Washington	Brass Castle creek	2,834	100,000	None.	
Newton	Morris pond	(3,003)			Proposed.
Hackettstown	Springs	2,417	100,000	None.	
Bound Brook	Middle brook	1,462	100,000	None.	
Pennington	Springs	700	15,000		
Little York	"	100	5,000		
Total gravity supply		224,485	18,030,000		

NORTHERN STREAMS BY PUMPING.

Town.	Stream.	Population of Town, 1890.	Daily Consumption, 1893. Gallons.	Treatment of Water.	Remarks.
Hoboken	Hackensack	43,648			Combined supply by Hackensack Water Co., reorganized.
West Hoboken	"	11,665			
Uniontown	"	10,643			
Hackensack	"	6,004			
Englewood	"	4,785			
North Bergen	"	5,716			
Guttenberg	"	1,947			
Weehawken	"	1,943			
Ridgefield	"	5,477			
		91,827	6,900,000	Aërated.	
Jersey City	Passaic	163,003			
Bayonne	"	19,033			
Harrison	"	8,338			
Kearny	"	7,064			
		197,438	20,000,000 (?)	None.	Unsatisfactory.
Paterson	"	78,347	13,000,000	None.	
Passaic	"	13,028	1,400,000	None.	
Elizabeth	Elizabeth	37,764	3,500,000	Filtered.	Also wells.
Rahway	Rahway	7,105	1,000,000	Filtered.	
Somerville	Raritan	3,861 }	800,000	Filtered.	
Raritan	"	2,556 }			
East Orange	Springs	13,282 }	1,500,000	None.	
Bloomfield	"	7,708 }			
Flemington	Raritan		100,000	None.	
Short Hills	"	500	40,000		
Blairstown	Blair's creek	500	10,000	None.	
Total pumped from northern streams		453,918	48,250,000		

DELAWARE RIVER BY PUMPING.

Town.	Stream.	Population of Town, 1890.	Daily Consumption, 1893. Gallons.	Treatment of Water.	Remarks.
Camden	Delaware	58,313	10,000,000	None.	Unsatisfactory.
Trenton	"	57,458	5,610,464	None.	
Phillipsburg	"	8,644	300,000	Filtered.	Infiltrat'n well.
Burlington	"	7,264	400,000	None.	
Bordentown	"	4,232	250,000	Filtered.	Unsatisfactory.
Belvidere	"	1,768	200,000	None.	
Beverly	"	1,957	100,000		
Riverton & Palmyra	"	3,000	150,000	Filtered.	Largely from infiltration well.
Total from Delaware		142,636	17,010,464		

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Classification of Public Water-Supply Systems by Sources—Continued.

SOUTHERN STREAMS BY PUMPING.

TOWN.	STREAM.	Population of Town, 1890.	Daily Consumption, 1893. Gallons.	Treatment of Water.	Remarks.
New Brunswick	Lawrence's brook	18,603	1,521,097	None.	
Perth Amboy	Tennent's brook	9,512	1,100,000	None.	
Bridgeton	East lake	11,424	500,000	None.	
Millville	Maurice river	10,002	500,000	None.	
Long Branch	Whale Pond brook	7,231	1,000,000	Filtered.	
Gloucester	Newton creek	6,564	75,000	None.	Also wells.
Salem	Laurel creek	5,516	300,000	None.	
Mount Holly	Rancocas	5,376	225,000	None.	
Woodbury	Mantua creek	3,911	225,500	None.	
Moorestown	Pensauken	2,500	135,000	None.	Unsatisfactory.
Haddonfield	Cooper's creek	2,502	75,000	None.	
Lakewood	Metedeconk	2,000	280,000	Filtered.	
Merchantville	Springs	1,225	150,000	None.	
State Reform School	"	500	40,000	None.	
Wenonah	"	500	25,000	None.	
Total from southern streams		86,416	6,151,597		

FROM OPEN WELLS.

Atlantic City		13,055	1,000,000		Also has tube wells.
Cape May City		2,136	500,000		
Montclair		8,656	200,000		
Red Bank		4,145	150,000		
Summit		3,502	75,000 (?)		
Madison			50,000 (?)		
Princeton		3,422	75,000		
Lawrenceville Sch.			15,000		
Total from open wells		34,916	2,065,000		

FROM TUBE WELLS.

Plainfield, &c.		11,267	1,850,000 (?)		Wells at Netherwood.
Asbury Park		5,000	1,000,000 (?)		
Ocean Grove		2,754	500,000		Twenty-four wells.
Seabright			100,000		
Atlantic City			500,000		Also open wells.
Vineland		3,822	200,000		
Freehold		2,932	125,000 (?)		
Keyport		3,411	150,000		New works.
Total from tube wells		29,186	4,425,000		

Summary.

	Population.	Daily Consumption.
Northern streams by gravity	224,485	18,030,000
Northern streams by pumping	453,918	48,250,000
Delaware by pumping	142,636	17,010,464
Southern streams by pumping	86,416	6,151,597
From open wells	34,916	2,065,000
From tube wells	29,186	4,425,000
Total public supply	971,557	96,932,061

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DAILY CONSUMPTION BY WATER-SHEDS.

Hackensack water-shed	6,900,000
Passaic water-shed, above Paterson	30,410,000
Passaic water-shed, below Paterson	20,000,000
Delaware, above Trenton	6,110,464
Delaware, below Trenton	10,900,000

PER CAPITA CONSUMPTION.

Jersey City	102	gallons	daily.
Newark	86	"	"
Paterson	167	"	"
Camden	171	"	"
Trenton	98	"	"
Hoboken, &c	75	"	"
Elizabeth	93	"	"
East Orange and Bloomfield	71	"	"
Orange	80	"	"
New Brunswick	82	"	"
All towns of less than 15,000 inhabitants, excluding summer and winter resorts	75	"	"
Average of whole State	99	"	"

The above table is from the latest data obtainable. Inquiries were addressed to the various companies and city departments, and for the most part brought a prompt response. Some replies have not come to hand at this date, and in such cases estimates have been made. In any cases where these are found erroneous, we shall be pleased to receive a correction from the proper authorities.

The per capita consumption has increased throughout the State, and it is noticeable that it generally exceeds seventy-five gallons daily. The average for the whole State is raised by the large manufacturing and seaport towns, but excluding these it will be seen that eighty gallons is generally reached. We must allow 100 gallons as a basis of future computations, with a prospect that this will be exceeded. The consumption of summer and winter resorts should not be compared with the resident population shown by the census.

THE FUTURE GATHERING-GROUNDS.

It will be observed that the Passaic water-shed furnishes more than one-half of the total public supply of the State. The towns supplied from Passaic falls at Paterson will probably find their source

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satisfactory for some years to come, although the growing population of the main valley will require increasing watchfulness. We have already given our reasons why those drawing from below this point must promptly abandon their present supplies. They will probably go to the headwaters of the same stream, which are the most valuable of the water-supplies of the State. It may be well to again enumerate those sources which, either because of their exceptional excellence or their present occupation by our towns, should be regarded as a part of the future water-supply of the State. They are indicated on the accompanying map.

Hackensack above New Milford.—Elevation at outlet, 4 feet. Supplying capacity, 76,590,000 gallons daily. Used by Hackensack Water Co., Re-organized, to supply Hoboken, Hackensack, &c.

Saddle river above Paramus.—Elevation at outlet, 90 feet. Supplying capacity, 14,000,000 gallons daily. Not utilized. Not available for gravity supply of much magnitude.

Ramapo above Pompton.—Elevation, 202 feet. Supplying capacity, 107,000,000 gallons daily. Not utilized. At an elevation of 275 feet, 90,000,000 gallons daily are available.

Wanaque above Pompton.—Elevation, 200 feet. Supplying capacity, 73,000,000 gallons daily. Of the 109 square miles of water-shed, 28 square miles are tributary to Greenwood lake, a storage reservoir of Morris canal, the waters of which have to flow almost the whole course of the stream. The rights of the canal company on this stream are important.

Pequannock above Pompton.—Elevation of outlet, 220 feet. Supplying capacity, 56,000,000 gallons daily. Utilized by East Jersey Water Company for Newark supply to such an extent as to make the balance of little value.

Rockaway above Boonton.—Elevation, 480 feet. Supplying capacity, 78,000,000 gallons daily. Not utilized. The Morris canal draws its supply from Lake Hopatcong, and has claimed that it diverts no waters from the Rockaway permanently.

The above are the only practicable sources of supply on the eastern slope north of the Raritan water-shed which are sufficient for towns of over 20,000 inhabitants. Of these, only Ramapo, Wanaque and Rockaway rivers are available for new gravity systems of supply of any magnitude. The aggregate supplying capacity of these three streams is 258,000,000 gallons daily. These are the sources to which

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our large cities must go in order to acquire ample, independent supplies.

The importance of a proper development of these sources has frequently been pointed out, and it grows in the eyes of the close observer with every census and with the accumulation of data as to our water-sheds. Not only are these the only sources which are at present accessible enough to be financially within reach of our cities, but they are the most desirable in quality of the streams still unutilized. Those streams which are tributary to the Delaware can generally only be brought to our eastern cities by pumping, or by very costly tunnels.

On the Raritan headwaters we have the following:

North Branch of Raritan.—Above an elevation of 170 feet, the supplying capacity of this stream is 19,300,000 gallons daily, the drainage area being 29 square miles. The intake may be raised to 300 feet elevation with small loss of capacity.

Black river.—At an elevation of about 500 feet we can collect from 32 square miles, the supplying capacity being 22,000,000 gallons daily.

South Branch of Raritan.—At an elevation of intake of 500 feet, we may collect from 55.5 square miles; capacity, 37,000,000 gallons daily.

These Raritan headwaters are not so accessible as those of the Passaic, but are nevertheless a desirable part of the available potable waters of the State.

On the Delaware slope we need only consider those streams which lie mostly upon the gneiss rock. These are the following:

Musconetcong river.—The whole water-shed of this stream comprises 157.6 square miles, and will supply 105,000,000 gallons daily at an elevation of 129 feet. About two-thirds of this, or 70,000,000 gallons daily, is available above 500 feet elevation. Of this, however, 17,000,000 is controlled at Lake Hopatcong, leaving 53,000,000 gallons daily, which ranks next in accessibility and value to the Raritan headwaters.

Pequest river.—This stream drains much flat limestone country, of which eighty-two per cent. is cleared and cultivated. We may expect the waters to be hard and in other respects less desirable than those we have heretofore enumerated. Facilities for storage are also

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lacking, and the stream can scarcely rank as a part of our available water-supply.

Paulins Kill.—Our remarks as to the Pequest apply to this in a slightly modified degree. It is better gathering-ground than the Pequest, and the storage facilities are much better, but it and the other branches of the Delaware northward cannot be considered as good as the Delaware itself, and the latter is more accessible.

Delaware river.—This stream will furnish, without storage, 894,000,000 gallons daily at Trenton, at tide-water. Above Easton, at an elevation of 156 feet, it will supply 631,000,000 gallons daily without storage. Above the Water Gap, from an elevation of 300 feet, 517,000,000 gallons daily without storage, which could be increased to 2,667,000,000 gallons with storage. It will be seen that this last excellent water-shed may at some future time become a valuable resource for supplying the large cities of New Jersey, New York and Pennsylvania. Its water-shed is an admirable gathering-ground. Not being within the control of New Jersey, however, it cannot be regarded as a part of the gathering-grounds of the State.

As we have seen, the Delaware is now supplying nine New Jersey towns with 142,634 population, an aggregate of 17,010,464 gallons daily. In our remarks on pollution we have given reasons why towns below Trenton must eventually seek other sources.

Possibilities of Southern Water-sheds.—We pointed out in our last report some of the possibilities of southern New Jersey streams as a source of supply. In our table of Public Water-Supply Systems, we find fourteen towns, with a population of 86,416 and consumption of 6,151,597, are already using these waters, and they pronounce them satisfactory. This is a better indication of their fitness than any other, but it may be helpful if we give the comparative results of some chemical analyses of a few of these southern streams and some typical northern ones. It will be noted that those of the Croton, Passaic north and Passaic south branches above Two Bridges and the Delaware at Point Pleasant have always been regarded as excellent stream-waters. With these and Professor Leeds' standard we may compare the southern New Jersey stream-waters.

Crosswicks creek water-shed is largely agricultural and partly in the marl region. It is a type of the southern branches of the Delaware.

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Back creek is a type of the purer of these streams, and probably of the headwaters of the Millstone.

Great Egg Harbor and Maurice rivers are types of the Atlantic coast streams.

Some Results of Chemical Analyses of New Jersey Streams.

GRAINS IN ONE U. S. GALLON.

	Total Solids.	Inorganic Matter.	Volatile Organic Matter.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Oxygen Consumed.	Hardness.	Authority.
Croton river, N. Y.	5.22	4.06	1.16	.039	.0012	.0087	.125	....	Mallet, Wormley &
Croton river, N. Y.	7.72	7.05	.67	....	....	....	....	....	Greene, '81.
Passaic above Newark	7.43	4.58	2.85	....	....	....	....	....	Horsford, '51.
Passaic—North branches	5.72	....	....	.29	....	.0065	.127	2.33	Leeds, '83.
Passaic—South branches	3.77	....	....	.174	.0003	.0075	.180	2.09	Leeds, '83.
Passaic—Newark	5.52	....	....	....	....	....	....	2.35	Wilbur, '82-3.
Delaware—Pt. Pleasant	3.54	....	....	.160	.0023	.0099	2.78	1.52	Leeds, '85.
Delaware—Trenton	3.53	2.90	.63	....	....	....	....	....	Wurtz, '56.
Delaware—Frankford	4.08	....	....	.225	.0037	.0090	.178	2.33	Leeds, '85.
Crosswicks—Bordentown	3.31	....	....	.174	.0016	.0029	.151	2.09	Cornwall, '92.
Crosswicks—Groveville	6.06	2.54	3.52	.05	....	....	....	2.39	Chester, '94.
Back creek—Yardville	3.91	1.52	2.39	.10	....	....	....	1.43	Chester, '94.
Maurice—Millville	2.22	1.19	1.03	.03	....	....	....	0.96	Chester, '94.
Great Egg Harbor—Mays Landing	2.51	1.20	1.31	.02	....	....	....	0.72	Chester, '94.
Prof. Leeds' Standard.	20.0	....	....	1.00	.012	.028	0.50	....	See note.

NOTE.—This standard, not to be exceeded, for river-waters in the United States, is given in Prof. Leeds' report to Philadelphia Water Department. See report of 1883, page 243.

It will be observed that Crosswicks creek has less salts or inorganic solids, less chlorine and about the same hardness as the northern streams, but more volatile organic matter. Back creek is lower still in salts and very soft, with very little chlorine. Maurice and Great Egg Harbor rivers are very low in salts and chlorine, with about the same amount of volatile organic matter as the Croton, and are the softest waters of all—as soft as rain-water.

So far as these analyses can show, the southern New Jersey waters are excellent, soft, pure waters. Probably not even such streams as the Crosswicks would show any higher proportion of volatile inorganic matter than the northern streams if they had the same advantages of aëration from roughness of bed. Their smooth, gliding currents give little opportunity for such action, and the natural inference is that such waters would be improved by artificial aëration. All four of these southern streams show a trace of acidity, and this

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might cause slight corrosive action in steam-boilers, although we do not apprehend serious trouble therefrom.

The best of these southern water-sheds, and those which seem worthy to be included in the State gathering-grounds, are the following:

Streams.	Daily Supply, Driest Year.	
Toms river at village	108,000,000	gallons.
Cedar creek at village	37,000,000	"
Wading river at Harrisia	102,000,000	"
Mullica river at Batsto	130,000,000	"
Great Egg Harbor at Mays Landing	144,000,000	"
Maurice river at Millville	146,000,000	"
Rancocas, South branch	112,000,000	"
Rancocas, North branch	96,000,000	"

As these stream-waters are generally much better than the waters obtained from driven wells, they may in future become of value to our southern towns and seaside resorts. They are generally too low to afford a gravity supply, but it would be possible to deliver 170,000,000 gallons daily from the headwaters of Mullica river to the towns along the Delaware or the seashore, at an elevation of from fifty to sixty feet above mean tide. Most of these streams are secure from future contamination. Indeed, as we pointed out in our last report, their waters are subjected to natural filtration on a scale which makes contamination almost impossible, except by direct discharge into the stream.

PROBABLE FUTURE NEEDS.

Our table of Public Water-Supply shows a present consumption of about 97,000,000 gallons. Judging from the growth of the cities of the State this is likely to increase at the rate of forty per cent. in each decade. At this rate our whole available gravity supply is likely to be called into use at the end of a generation. It is quite evident that this most valuable portion of the State supply should be judiciously conserved and developed, and that the public water-supply has a greater importance in this than in other States. The accompanying map shows the utilized and unoccupied gravity sources of supply and the more valuable southern gathering-grounds, as well as the location of pumping-stations of various towns and cities.

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PART V.

Artesian Wells

IN

SOUTHERN NEW JERSEY.

BY

LEWIS WOOLMAN.

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ARTESIAN WELLS AND WATER HORIZONS IN SOUTHERN NEW JERSEY, WITH ECONOMICAL, GEOLOGICAL, AND PALEONTOLOGICAL NOTES.

BY LEWIS WOOLMAN.

The feasibility of obtaining water in southern New Jersey by means of artesian wells may no longer be looked upon in the light of experiment and venture, but may be regarded as a matter of certainty.

The first artesian well in this part of the State was put down about the year 1851, at Winslow. It reached a depth of 335 feet. The water rose above tide-level, but did not overflow, because the surface was too elevated, being 120 feet above tide. Flowing wells not much above tide-level and of no great depth, were put down in the year 1873 at Pleasant Mills, and in 1877 at Weymouth. In 1878 a flowing well was completed at Charleston, S. C., at a depth of 1,970 feet. This well found its supply in Cretaceous strata, while those at Pleasant Mills and Weymouth obtained theirs from Miocene strata.

Doubtless encouraged by these and other facts, Prof. G. H. Cook, in the annual report for 1880, indicated the existence of water-bearing sands in this part of the State and the desirability of reaching them by deep borings. In the report for 1882 he reiterated these views and predicted the depth to the water contained in the red sand below the middle marl bed along a number of northeast and southwest lines drawn across the southern portion of the State map issued that year. The depths named were no doubt fully warranted by the information then in hand. Subsequent developments have, however, shown these depths to be greater than was then stated.

About the year 1883 artesian wells were successfully put down at

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Ocean Grove and Asbury Park. Since that year this method of obtaining water has been gradually growing in favor, and has been largely stimulated by the publication annually in the Survey reports of the details of such wells.

It is probable that in a few years the accumulation of data in the Survey department will render it possible to state the number of water horizons interbedded within the various Miocene, Eocene and Cretaceous strata, and to determine which and how many of these exist beneath any given locality, and to calculate with a close approximation to accuracy the depth to each. For a large part of the area under consideration this can even now be done.

From data collected the past year respecting wells, additional interesting and practical facts have been learned, which may now be briefly stated.

An additional water horizon has been located at Atlantic City, at a depth of 800 feet. This occurs between horizons formerly known at 760 and 950 feet. A well almost simultaneously put down at Ocean City confirms the existence of this horizon. It is a clear, quartzose sand, varying from brownish to greyish in color, about sixty feet in thickness, and must constitute an immense reservoir for water.

This gives us eight horizons from which water has been obtained within Miocene strata. Their position, and depths, at Atlantic City will now be given:

1.	At about	328	feet.	In sands above the diatom bed.
2.	" 406 and	430	"	
3.	" about	525	"	In the middle of the diatom bed.
4.	" "	650	"	
5.	" 700 to	720	"	At the base of the diatom bed.
6.	"	760	"	Below the diatom bed.
7.	"	800	"	
8.	" about	950	"	

All the above have been opened during the progress of drilling the various wells at Atlantic City, except the one at about 650 feet, whose position within the diatom bed has been calculated. This horizon has only been developed in the interior. The first and second horizons have, however, not been utilized at Atlantic City, though the second supplies wells in the interior.

Of the above horizons, those whose extension over a considerable area has been the most thoroughly proven are those at about 525

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feet, and at 700 to 720 feet. The various localities where these horizons have been utilized for water-supply, with their depths at each place, are here given:

	Upper horizon.	Lower horizon.
Waretown	......	280
Great Sedge Island	......	320
Seven Islands	385	535
Beach Haven	425	575
South Beach Haven	535	......
Atlantic City	525	700
Ocean City	......	720

The upper of these was noted at Ocean City at 512 feet, but was not utilized, the parties preferring to go deeper. It will be seen that these two horizons are from 150 to 175 feet apart. Both are, however, stratigraphically higher than the 60 feet of brownish and greyish sands found the past year at the depth of 800 feet, or about 100 feet deeper, both at Ocean City and Atlantic City. This latter horizon probably underlies all the above-named localities

The 525-feet horizon of Atlantic City is in the central part of the 300-feet diatom clay bed. The 700-feet horizon is just below the base of the same bed, while the 800-feet horizon is some considerable distance below. Quite a number of shells occur just above this latter horizon at the two places where it has been reached. The most noticeable of these is a clam shell of the identical form now sold in our markets, though with it are numerous other shells, both bivalves and univalves, that are of decidedly Miocene species.

From wells developed at Woodstown and Quinton, it is learned that the red sand bed, as defined by Prof. G. H. Cook in the Geology of New Jersey for 1868, becomes in the lower part of the State a clear-grey, medium-coarse sand, of about eighty feet in thickness, that yields an abundance of good water. This horizon occurs just below the middle marl bed, from which it is separated by a few feet of impervious strata in the wells at both the above-named places. An interesting geological fact learned at Quinton is that the lime sand overlying the middle marl has a thickness of over 100 feet, or more than four times greater than had been previously known.

Wells successfully developed during the year at Gloucester and Maple Shade emphasize the fact, indicated last year by wells at Pavonia, Stockton and Collingswood, that at the base of the plastic

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clays—or, in other words, at the base of the Cretaceous strata of southern New Jersey—there exists a bed of heavy gravels and cobblestones that yields a large supply of water of better quality than has generally been obtained from the sands within the overlying *clay marls*, the name given to a series of sands and clays about 275 feet in thickness that occur below the lower marl bed and above these plastic clays. This bed of cobbles and heavy gravels is perhaps the equivalent of what has been called by the United States Geologists the Potomac formation, so named because its typical outcrop is found near the Potomac. It probably forms a vast reservoir. This lowermost stratum no doubt rests upon the old crystalline rock floor. It is most likely fed, not only by water percolating from the surface, but also by numerous springs of excellent water in the underlying rocks that in all probability find their way into the aggregation of loose and heavy cobbles and gravels of which it is composed.

If, in the sinking of wells into the laminated sands and clay marls, the water therein be found unsatisfactory, it is most probable that a good quality can be obtained by continuing the boring quite through the underlying white, yellow and red plastic clays till the Potomac gravels are reached.

The sands and gravels in the clay marls may be described as bluish-grey in color, while the sands, gravels and cobbles near and at the base of the plastic clays are by comparison a yellowish-white.

Now that the question of the water-supply of Camden has become an important one, the writer would query whether it might not be wise to incur the small expense needful to sink at least one artesian well at some favorable locality, say to the eastward of the city,* in order to ascertain the thickness of this Potomac bed, the number of water horizons, and the quality and quantity of water that may be obtained.

From the facts as now known this bed may be reasonably expected to yield a large amount of water of good quality, which could always be relied upon to supplement that from any other source should it not be deemed proper to rely altogether upon this horizon for water-supply.

From a set of borings long hidden, but recently brought to light in the office of the Asbury Park Water Commission, the extension of the great Miocene diatomaceous clay bed farther northward than had been heretofore known has been demonstrated. The interval

*The object in going to the eastward would be to avoid reaching too soon the crystalline rock floor that approaches the surface along the Delaware river.

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between fifteen and ninety-three feet at this point passes through the base of this bed as, shown by the diatoms* contained therein. One form, well known to microscopists under the name of Heliopelta,† occurs here. The writer's researches show the occurrence of this form to be mainly, if not entirely, restricted to the base of the bed. It has thus been also found at the following additional localities: Shiloh, N. J.; Clayton, Del.; Claiborne, Eastern Shore, Md.; Nottingham and vicinity, Western Shore, Md., and Bermuda Hundred and Petersburg, Va. This basal portion of the Miocene clay is what has been familiarly called rotten-stone by the artesian-well drillers, and is the same as the astringent clay described by Prof. G. H. Cook.

This fact, *only*, respecting wells at Asbury Park is noted at this time. Further detailed reports are necessarily deferred, pending the completion of deep wells now being developed, both at this point and at Ocean Grove, adjoining on the south.

The extension of Miocene deposits farther westward than heretofore known has also been demonstrated by borings obtained from wells put down at Glassboro and Quinton. Diatoms were not found in the clays at these two points, but instead fossil shells of undoubtedly characteristic Miocene species. These are named in the detailed reports of the wells at these two places. (See pages 407 and 415.

New and novel information respecting underground structure in Cape May county has been learned from a microscopical study of well-borings at Wildwood, on Five Mile or Holly Beach, New Jersey. Between the depths of twenty-nine and forty-six feet occurs a clay bed, the equivalent of one that has several times already been penetrated by wells northward along the beaches as far at least as Beach Haven, at depths varying according to locality from thirty to ninety feet. This bed is marine, as is shown by the presence within it, at all localities from which samples have been received, of the remains of numerous *marine* diatoms. These organisms have a box-like structure formed of two siliceous valves, which are finely marked and highly ornamented. They are now generally regarded as highly-specialized, single-celled plants.

Farther down, however, another clay bed exists that has not been found in any of the borings to the northward. This bed occupies

*These are single-celled microscopic plants. Their siliceous skeletons have been preserved in these beds.

† Formerly called Heliopelta Ehrenbergii, Ralfs., by a recent revision of the genera it becomes Actinoptychus heliopelta, Grunow.

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the interval between 78 and 180 feet, and likewise contains diatoms, in this case both of *marine* and *fresh-water* forms, the latter largely predominating.

A former delta of the Delaware river in past-geological time is perhaps largely responsible for this intermixture of marine and fresh-water forms. This was probably before the formation of the Cape May peninsula.

The assemblage of diatoms in this lower clay is unique, not only in the mixture with marine forms of a surprisingly large number of fresh-water forms, but also in the great variety of species of the latter, and in the occurrence of one form, a triangular one, that has heretofore only been known in New Zealand. It occurs there, living in present waters and fossil at some considerable elevation in the interior. (See last paragraph page 400.)

The various wells of the past year (1893) will now be reported in detail. They naturally fall into three classes that obtain their supply respectively from the Miocene, and the Cretaceous beds and their overlying Quaternary sands and gravels.

Those in the Miocene will be first noted. Included therewith are several wells on or near Delaware bay, but in the State of Delaware. In the absence of necessary information along the bay in New Jersey, these afford valuable data as to the stratigraphical position of our New Jersey water horizons, and should be an encouragement to those interested along the bay shore in this State to search for fresh water beneath the salt marshes. Several failures along the river border have been reported in this State, but generally the records show that, in the light of recent knowledge, the wells were not continued deep enough.

ARTESIANS IN MIOCENE STRATA.

ARTESIAN WELLS, BEACH HAVEN.

Two wells, each with a depth of 425 feet, were noted in the report for 1890 as having been put down for hotel use. During the spring of the present year a third well was put down, this time for the borough, by Uriah White, contractor. In this well the 425-feet water sand of the previous wells was met with and passed, it being pur-

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posed to open the next lower water-yielding sand. This was found between the depth of 543 and 575 feet. This well has a diameter of eight inches and flows over the surface. Its yield is 125 gallons a minute, being considerably more than that of the horizon at 425 feet.

The 425-feet horizon is the equivalent of that at Atlantic City at 525 to 530 feet, while the 543 to 575-feet horizon is the equivalent of that at 700 to 720 feet at Atlantic City. The first is in the middle of the diatomaceous clay; the second is at or below the base of the same clay bed. Wherever these two beds have been tested, the lower one yields much the greatest quantity of water. It is hoped that in the future some well in this immediate region will be sunk deeper and demonstrate the continuance northward of the sixty-feet brown-sand bed horizon developed this year at the depth of 800 feet, both at Atlantic City and Ocean City.

A full set of specimens was furnished by the contractor and his engineer who superintended the work, and by the co-operation of members of the Borough Council. These specimens, and those formerly obtained from the 425-feet wells, have been carefully collated, and the following record compiled therefrom. The first 425 feet is given more in detail than in the previous annual report (1891), but is essentially the same. The present boring adds to our positive knowledge of the diatomaceous clay bed, since examination shows that all the clays from 280 to 543 feet contain diatoms. There appears to be a thickness at this locality of about 250 feet for this bed:

Beach sand	17 feet.	17 feet.	Recent.	Recent—65 feet.
Mud, with roots	1 "	18 "		
Grey sand, with shells and recent marine diatoms	37 "	55 "		
Grey sand	10 "	65 "		
White clay and gravel	25 "	90 "	Fossiliferous gravels.	Quaternary—195 feet.
Fine white clay	5 "	95 "		
White sand, a few fossiliferous pebbles,	20 "	115 "		
Fine white sand	20 "	135 "	White and yellow sands.	
Alternation of sand and clay, both yellow	15 "	150 "		
Coarse grey sand	10 "	160 "		
Black clay	5 "	165 "		
Fine white sand	5 "	170 "		
Fine yellow sand	10 "	180 "		
Medium-fine white sand	20 "	200 "		
Medium-coarse yellow sand	5 "	205 "		
White sand	10 "	215 "		
Yellow sand	35 "	250 "		

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Grey sand	30	"	280	feet.	Diatom clays and interbedded sands.	Miocene—325 feet.
Greenish sand and clay mixed	10	"	290	"		
Greenish marly clay, containing diatoms	75	"	365	"		
Dark marly clay, containing diatoms	45	"	410	"		
Fine sand, with *water*	19	"	429	"		
Coarse sand, with *water*	21	"	450	"		
Tough, diatomaceous clay	26	"	476	"		
Alternation of sandy clays and clayey sands, all diatomaceous	67	"	543	"		
Grey, sharp sand, with *water;* same as at Seven islands, at 510 to 535 ft	32	"	575	"		

Associated with the grey sand and shells at the depth of fifty-five feet were a considerable quantity of marine diatoms. Many of the forms are the same as those in the 250 feet of diatomaceous clay, just noted at 280 to 543 feet. Other forms, however, are quite different, while there are also forms in the lower bed that do not occur in the upper, so that collectively the assembled forms in either distinguish the beds from each other. The existence of these two beds has already been learned from examination of the borings at Atlantic City, Ocean City and Wildwood, and each contains, at all these localities, its same characteristic assemblage of forms.

The equivalent of the upper bed was found at the depths of nine to eighteen feet in the wells bored for the old Atlantic City Water Company, on the mainland at Absecon. What is probably the equivalent of the same bed was exposed at the base of the bluff at Long Branch by the storms, both last year and this. Examinations, made by the writer, of clays from the two localities last named, revealed the same characteristic microscopic forms. This upper bed, which is reached beneath the beaches at depths varying from thirty to ninety feet, represents a deposit much later than Miocene in age, to which the lower bed, the deep artesian diatomaceous clay bed, belongs.

SECOND WELL AT SEVEN ISLANDS, WITH CORRELATION OF RECORD OF THE FIRST WELL.

During the spring of 1893 a four-and-one-half-inch well was bored by Uriah White on Crab island, one of the group known as Seven islands, situated in Great bay, at the mouth of the Mullica river. It reached a depth of 535 feet, and is one-half mile southwest of the first well, which is located upon another of these islands. The first

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well is noted in the annual reports of 1885 and 1886. Its depth was their stated at 408 feet. The superintendent on the ground says the well was bored to a depth of 487 feet, and the writer is further informed that a measurement by sounding was made this season that shows the depth at the present time to be 480 feet. The second well, the one just finished, flows sixty gallons per minute; the water rose, on a test being made, twenty-two feet above high tide. The record furnished by the engineer who did the work is as follows:

Mud and large gravel	58 feet.	58 feet.	Quaternary.
White and yellow sand	75 "	133 "	
Hard crust	2 "	135 "	
Dark bluish-green clay, *hard*	37 "	172 "	
Sand	100 "	272 "	
Marly clay and wood	108 "	380 "	Miocene.
Coarse sand, small flow of *water*	12 "	392 "	
Lighter-colored, bluish clay, *soft*	118 "	510 "	
Coarse sand and gravel, *water* 510 to 535	25 "	535 "	

The water passed at 380 to 392 is the equivalent of that at Atlantic City at 525 and also of that of two wells of 425 feet in depth at Beach Haven. The water utilized by this well, and which comes from between the depths of 510 to 535 feet, belongs to the stratum reached at Atlantic City at 700 feet and at Beach Haven at 543 to 575 feet. The description of material in the central part of this record is not sufficiently minute to enable one to positively indicate the dividing line between the upper or Quaternary portion and the lower or Miocene portion of this well, but from our knowledge of the strata at Beach Haven and Atlantic City it probably occurs at about 272 feet.

ARTESIAN WELL, ATLANTIC CITY.

A well noticed last year as then being put down by P. H. & J. Conlan, for the Knickerbocker Ice Company, has been completed. It reached a depth of 800 feet and entered a brownish sand, shown in the lithographed columnar section in the report for 1889 to have a thickness of about sixty feet. This well opens up an additional water-bearing stratum at this point. As already stated, there are now known to be eight water-yielding horizons in Miocene deposits, including this one. Five of these are now utilized at Atlantic City, viz., at the depths of 525, 700 to 720, 760, 800 and about 950 feet. Two of the others,

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opened in boring, but not used, occur at about 328 and 430 feet, while the remaining one has only been developed in the southern interior. Its position within the great diatomaceous clay bed would place it at the depth here of about 650 feet. This horizon probably does not exist as a water-bearing sand at Atlantic City, since it has not been reported from any of the nine wells already put down there.

This additional or 800-feet horizon has also been opened by a well, put down about the same time, at Ocean City, where it occurs at the same depth. The two localities are nearly upon the same line of strike, hence their agreement in depth. (See next well record.)

ARTESIAN WELL, OCEAN CITY.

In the fall of 1893 a well was bored by Uriah White at Ocean City. This is the second well at this place, a former one, bored to a depth of 720 to 760 feet, but finished with a depth of 720 feet, being noted in the report for 1892.

As was done at Beach Haven, so likewise here it was determined to develop the next lower water-yielding sand. In the process of boring, the water horizon of the first well, that at 720 feet, was found and passed, and this well continued to the depth of 800 feet, when the same brown sand reached by the Knickerbocker Ice Company's well at Atlantic City was met with and at the same depth. The water obtained is excellent. It will rise in the casing fifteen feet above the surface and flows 140 gallons a minute. As noted in the report of the Knickerbocker Company's well, this horizon is probably about sixty feet in thickness. (See preceding record.)

The following record in detail is made up from notes kindly furnished by the engineer in charge for the contractor, and from careful examination of full sets of borings likewise furnished by the same person. To 660 feet the record is a reprint, nearly, of that of the first well, and which was reported last year, since there was no difference shown except the occurrence at 658 feet of 18 inches of rock, probably a local lenticular bed. The water found and noted on the record at 334 and 371 feet is thought, by the engineer who directed the drilling, to be the equivalent of that found at the depth of 350 to 390 feet in a well he put down at Sea Isle City, the record for which was noted in the report for 1890. This correlation is mentioned subject to confirmation in the future:

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RECORD.

Beach sand, recent shells at the base	30 feet.	30 feet.	Recent.
Sand	85 "	115 "	
Sand, with thin clay seams	60 "	175 "	Quaternary.
Sandy clay	10 "	185 "	
Fine gravel and sand, with streaks of clay	93 "	278 "	
Bluish, sandy clay, solid	40 "	318 "	Miocene, not diatomaceous.
Sand, with *water*	16 "	334 "	
Bluish, sandy clay, with small shells	32 "	366 "	
Seam of sand, with *water*	5 "	371 "	
Grey sand, with small shells	29 "	400 "	Miocene, diatomaceous.
Bluish, sandy clay, diatomaceous	112 "	512 "	
Grey sand, with water, 7 gallons a minute	16 "	528 "	
Bluish, sandy clay, diatomaceous	72 "	600 "	
Brownish, sandy clay, hard, with shells and diatoms	55 "	655 "	
Brownish clay, with hard streaks described as crusts, including 18 inches of rock	5 "	660 "	
Grey sand, some diatoms	20 "	680 "	
Clayey sand, diatoms	5 "	685 "	
Sand, with *water*	5 "	690 "	Miocene, not diatomaceous.
Coarse gravel, sand, shell and thin clay seams,	10 "	700 "	
Fine gravel, sand, shell and thin clay seams	16 "	716 "	
Alternation of clay, gravel, sand, shell and thin clay seams; *water* at 720 feet, 25 gallons a minute	20 "	736 "	
Brownish sand, with wood	19 "	755 "	
Coarse brown sand and *water*, 140 gallons a minute	45 "	800 "	

ARTESIAN WELL, WILDWOOD, N. J.

An artesian well was sunk the past year at Wildwood, on Five Mile or Holly Beach, Cape May county. The contractor, J. Shaw, of Bridgeport, Conn., has courteously furnished a very full set of specimens of the borings, together with some notes. The well reached a depth of 215 feet. Water, which did not overflow, was found at 75 and at 215 feet, but was not deemed satisfactory in either case. The drilling of this well has been abandoned. It is, however, intended the coming year to put down a deep well to some one of the excellent water horizons associated with the great diatomaceous clay bed. After an examination of the specimens and a comparison of the notes, the writer presents the following record. The elevation of the surface is about eight feet above high tide:

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Filled-in ground	2 feet.	2 feet.	
Black muck, full of roots of red cedar and holly	1 "	3 "	Quaternary.
Sand, similar to beach sand	26 "	29 "	
Muddy, sandy clay, *marine diatoms*	4 "	33 "	
Bluish, muddy clay, *diatoms*	13 "	46 "	
Sand, similar to beach sand, fine on top, coarse at the bottom, with *water*; rises within 4 feet of the surface	32 "	78 "	
Clay, *marine and fresh-water diatoms*	24 "	102 "	
Sand, salt water	4 "	106 "	
Clay, *marine and fresh-water diatoms*	74 "	180 "	
Sand and *water*	35 "	215 "	

The microscopic examination and identification of the species of diatoms in the seventeen feet of mud at twenty-nine to forty-six feet show this deposit to be the equivalent in age of similar beds met with near the surface at Absecon, and noted in the report for 1892, page 283, and also passed through by the well borings at Atlantic City and at Beach Haven, at depths ranging from thirty to ninety feet. One form, *Triceratium favus*, a beautiful triangular, flat form, has been observed on the slides prepared. This is found in marine deposits now forming along the coast and up the Delaware river as far as Philadelphia. It is never seen in the 300-feet Miocene diatomaceous clay bed throughout its entire known extent, from Asbury Park, N. J., to Richmond and Petersburg, Va.

This Miocene diatom bed, which will be reached at this point by a well to be put down the coming year,* can be equally well recognized by a fine, large, circular, disc form, having three or more central elevations or excavations called processes, that look somewhat like reticulated eyes. This form was shown and can be recognized on the plate opposite page 224, in the report for 1891. It is technically known by the name of *Coscinodiscus excavatus*. It is not now known to be living upon any coast, nor does it occur fossil elsewhere in the world, being confined to the Atlantic Miocene diatom clay bed.

Intermediate, however, between the beds containing, respectively, the before-mentioned *Triteratium* and *Coscinodiscus*, there occurs, at 78 to 180 feet, another clay bed also containing diatoms. In the two beds previously noted the diatoms are almost exclusively marine, but

*At the time of proof-reading, the boring of the deeper well, above alluded to, was being prosecuted and had reached a depth of about 1,000 feet. The clays were diatomaceous between the depth of 370 and 793 feet, and exhibited the characteristic Miocene species.

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while many of them are marine in this bed there is a preponderating number and variety of fresh-water species. A corresponding clay bed does not exist beneath the beaches to the northward, if we may judge by the specimens of borings furnished from the various wells or by the records where no specimens were obtained. It was probably in some way associated with the deposits of the Delaware river delta in a somewhat recently past geological age, and before the present peninsula of Cape May was formed.

A diatomist who has examined this deposit enthusiastically says that it contains almost every known fresh-water species. One of these fresh-water forms is unique. It is named *Triceratium trifoliatum*, and has heretofore been known only from New Zealand, where it occurs, living in present waters and fossil in comparatively recent deposits, but at a considerable elevation in the interior.

Another form has heretofore been reported only from the La Plata, in South America. Taken altogether, this is a remarkably interesting and unique bed.

ARTESIAN WELL, MAHON RIVER, DEL.

In the early summer of 1893 an artesian well of one and one-half inches diameter was put down upon the salt marsh meadows on Delaware bay, at the boat landing just north of Mahon river light and six miles east of Dover, Del. The success of this well demonstrates the entire practicability of obtaining water of good quality at a corresponding depth upon the New Jersey side of the bay. This well is located west-southwest of Fortescue, N. J. W. D. Walls, of Dover, Del., who sunk the well, furnishes the following accurate record, which is inserted verbatim :

Blue marl and mud	35 feet.	35 feet.	
Blue sand and mud	40 "	75 "	Miocene (bracket, 75–206 feet)
Blue sand	35 "	110 "	
Hard blue sand rock	3 "	113 "	
Blue sand and [chalk]	35 "	148 "	
Fine hard white sand	6 "	154 "	
White sand, mixed with a substance resembling [Magnesia]	39 "	193 "	
Very fine white sand, mixed with fine black sand	5 "	198 "	
Coarse white sand, mixed with gravel; an abundance of *cool, fresh water*	8 "	206 "	

The strata described as resembling chalk and magnesia were most probably richly diatomaceous clays and the exact equivalent of clays

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similarly described by the well-drillers at Atlantic City, N. J., and which occur in the middle and lower part of the diatom clay bed there. The water obtained may be regarded as coming from the 700 to 720-feet horizon at Atlantic City, and also as being the equivalent of the upper horizon at Dover, viz, that at 157 feet. This well is nearly on the line of strike with Harrisia, N. J., where many years ago an abundant supply, quite possibly the same, was improperly cased off. The elevation of the well at Harrisia is like this one, but little above tide-water.

ARTESIAN WELL AT KITTS HUMMOCK, DEL.

J. D. Walls, who bored the well already reported at Mahon river, also reports a well sunk seven miles further south, at Kitts Hummock, a picnic resort on Delaware bay. It is 110 feet deep. This well has a diameter of one and one-half inches, and the water rises within two and one-half feet of the surface, The supply comes from a coarse gravel at the bottom.

ARTESIAN WELL, DOVER, DEL.

An artesian well was put down this year at the Dover Water Works by George J. Kennedy, of Philadelphia, who courteously furnished a full set of borings and imparted desirable information. It obtains its supply from a coarse dark sand, some of the grains being as large as peas, that was penetrated between the depths of 167 and 196 feet. The elevation of the surface is about six feet above tide, and the water will rise in the casing six feet higher. The diameter of the well is ten inches, and the natural flow is thirty-five and a half gallons a minute, but it has been pumped 218 gallons per minute, the full capacity of the pump used.

A four-inch well formerly put down in the same inclosure obtained water at a depth of 157 feet. This horizon was found and cased off in this well.

The two water horizons of these wells are probably the equivalent of those at Atlantic City at the depths of 720 and 760 feet. An additional depth at Dover of about fifty to seventy-five feet below the lower horizon would probably find the sixty-feet brown sand bed opened the past season at the depth of 800 feet, both at Atlantic City and Ocean City, N. J. (See pages 397 and 398.)

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The following is the record:

Yellow gravel	7 feet.	7 feet.	Quaternary.
Deep orange-colored sand and clay		at 11 "	
Medium orange-colored sand, coarse		" 26 "	
Slight orange-colored sand, finer		" 42 "	Miocene.
Sandy clay, a few *marine diatoms*		" 54 "	
Sand and marly clay (a few shells were found between 40 and 90 feet)		" 62 "	
Sand		" 71 "	
Brownish clay and sand, with *marine diatoms*,		" 83 "	
Sand and comminuted shell, *marine diatoms and sponge spicules*		" 90 "	
Sand		" 94 "	
Sand and broken shells		" 100 "	
"Marl"		" 109 "	
Micaceous marly sand, some reddish sand grains		" 117 "	
Sand, bad water; *comminuted shells, diatoms, and coccoliths*		" 120 "	
Sandy clay *diatoms*		" 128 "	
Clay, with *diatoms*		" 147 "	
Sand, shell and *diatoms* (*Heliopelta*)		" 150 "	
Clay, a few *diatoms*		" 155 "	
Sand, *good water*		" 157 "	
Clay, thickness, 10 feet; contains pyrite-covered *diatoms*		to 167 "	
Dark sand, some grains large as peas; *good water*	29 "	" 196 "	

This well is furnished with a strainer at the bottom eight inches in diameter and twelve feet long.

The Miocene diatomaceous clay bed of the Atlantic Coastal plain is represented in this well by all the strata below the depth of about fifty feet.

ARTESIAN WELL, LEWES, DEL.

An artesian well was put down as a sanitary precaution and preparation before the possible influx from abroad of epidemic disease early in the summer of 1892, at the United States Quarantine Station at Lewes, Del. It was drilled by P. H. & J. Conlan. The elevation of the surface is about seven feet, the diameter of the well is six inches and the depth 400 feet. The water barely rises over the surface. Information respecting this well was kindly furnished by the health officer, Dr. H. D. Geddings. The water-supply comes from a sand between the depths of 392 and 400 feet. At the bottom, rock was encountered, thought by the driller to be granite. It was, how-

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ever, probably a lenticular bed of cemented sand rock; such beds have several times been met with in sinking wells in southern New Jersey, they generally are but a few inches, or, at most, a few feet, in thickness.

The material passed through was described as follows:

Ordinary beach sand to about......		90 feet.	
Yellowish gravel, medium-coarse..	10 feet.	100 "	
Grey sand and sandy clays.........	200 "	300 "	
A "cedar branch," well preserved, was found at about 200 feet, and a little lower fragments of wood quite friable and changing to brown in color.			
Blue tenacious clay, mixed with about 30 per cent. of pebbles..	30 "	330 "	Almost certainly Miocene, but probably higher than the great artesian diatom clay bed.
Similar blue clay and alternations of sand	62 "	392 "	
Sand and water........................	8 "	400 "	
Stopped on rock.			

There was pumped in one day 22,000 gallons, lowering the water to fifty-five feet, which, however, soon rose when the pumping ceased.

ARTESIANS IN CRETACEOUS STRATA.

DEEP ARTESIAN BORING AT GLOUCESTER, N. J.

A test boring to and into the rock which was met with at 276 feet was made at the water works plant at Gloucester, N. J. This location is upon Newtown creek, directly west of the New Jersey railroad station. The depth this well was prospected into rock has not been learned, but the well has been abandoned. P. H. & J. Conlan, who bored the well, courteously furnished specimens of the various earths passed through to the rock. A group of more shallow wells, to be next noticed, were afterward put down for the company at the same place by another contractor, who also kindly furnished specimens of the borings. After a careful study of both sets of borings, the accompanying record of the soft strata at this point is presented:

Made ground, filled in with yellow gravel from the adjacent higher surface................................	3 feet.	3 feet.	
Meadow muck, accumulation of Newtown creek; contains recent fossil fresh-water diatoms.............	12 "	15 "	Recent.

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	Yellow clay	20 feet.	35 feet.	Clay marls.
	Indigo-blue clay	7 "	42 "	
	Blue-grey sand, wood	12 "	54 "	Sands at the base of the clay marls —bluish-grey gravel water horizon.
A	Coarse blue-white sand and blue-white fine gravel	21 "	75 "	
B	Blue and white gravel, with large pebbles; contains *water*	10 "	85 "	
B	Alternations of sandy clays and *water*-bearing sands	28 "	113 "	Plastic clays, with interbedded yellowish-white gravel water horizons.
	Reddish clay	7 "	120 "	
	White sandy clay	9 "	129 "	
C	Coarse yellow-white sand, some pebbles the size of shellbarks; contains *water*	10 "	139 "	
C	Alternations of white sands and white clays	16 "	155 "	
C	Gravel; *water*	14 "	169 "	
	Red clays	26 "	195 "	
	Clay	31 "	226 "	
	Sand, slightly red	16 "	242 "	
D	Clays and water-bearing sands and gravels; *water at 270 feet*	34 "	276 "	
	Greenish micaceous clay, evidently decomposed rock	14 "	290 "	
	Solid rock.			

The letters upon the left refer to similar letters in the next following record of a group of wells at the same place.

ARTESIAN WELLS AT GLOUCESTER, N. J.—GROUP AT THE WATER WORKS.

A group of eleven four-and-one-half-inch wells were sunk by Leach Brothers at the plant of the Gloucester Water Company, upon Newtown creek, a short distance east of the West Jersey railroad station.

The depths of these wells are as follows:

(A)	Three with depths ranging from	67 to	79	feet.
(B)	Four with depths ranging from	85 "	96	"
(C)	Three with depths ranging from	149 "	162	"
(D)	One with depth of		270	"

The wells of sub-group A draw their supply from the blue-grey gravels at the base of the plastic clays. See sectional record in the report next preceding this. Those of sub-group B draw from transition gravels between the clay marls and the plastic clays, while those from

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sub-groups C and D draw from the yellowish-white gravels interbedded and at the base of the plastic clays.

We are informed that from nine of these wells, connected and pumped at one time, there has been obtained from 700,000 to 1,000,000 gallons per twenty-four hours. The water from these wells will rise about one foot or so above tide. It also pulsates a few inches in the casing with each rise and fall of tide.

GROUP OF WELLS AT THE GLOUCESTER GINGHAM WORKS.

There are six three-inch wells at the works of this manufacturing company. They are near the Delaware river, and were put down by Leach Brothers. They have depths of 65 and 102 feet, two water horizons being utilized. A stratum of blue clay six feet thick was passed near the surface. Below occur the same series of beds noted in the section for the other wells. The gingham works are about one-half mile southwest of the water works plant, or nearly upon the same line of strike. The wells evidently draw from the two horizons designated in the report of the water works wells by the letters A and B. Each well, separately pumped, yielded 100 gallons a minute.

ARTESIAN WELL AT WENONAH, BORED BY ORCUTT BROS.

Elevation, 70 feet; depth, 320 feet.

An artesian well has been finished at this place, which we are informed found water between the depths of 320 and 341 feet. The contractor writes that "the water-bearing stratum is a nice gravel, coarse and fine mixed." Also that "it was pumped forty gallons a minute," and that the water is good. The supply is evidently from the top of the same gravel furnishing the well on the property of F. J. Anspach, at Sewell, reported last year as opening a water horizon at 395 to 420 feet. Making allowance for difference in elevation, Sewell being one and a half miles across the lines of strike from Wenonah, the dip appears to be about thirty-eight feet per mile, which agrees with the observed dips of the marl bed elsewhere. This water horizon is at the base of the clay marls, and above the plastic clays. It is contained within what the writer has designated as the bluish-grey gravels.

From information received from various sources, the writer presents the following as an approximately correct section:

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Loam	32 feet.	32 feet.	Quaternary.
Gravel	20 "	52 "	
Black clay, oyster shell (Exogyra) at 115 feet	193 "	245 "	Clay marls.
Gravel in streaks	35 "	280 "	
Lighter-colored clay	28 "	318 "	
Coarse sand and gravel	23 "	341 "	Top of the bluish-grey gravels.

DEEP ARTESIAN WELL, GLASSBORO, N. J.

An artesian well was drilled for the New Jersey Packing Company at Glassboro, N. J., by Charles H. Leach, of that place. The well is located almost exactly on the 140-feet contour line of the State maps. It reached a depth of 511 feet, but a supply of water deemed entirely satisfactory was not obtained, and the drilling was discontinued. Through the courtesy of the contractor and of J. W. Towles, the company's superintendent, a considerable number of specimens were obtained. The record inserted below is as furnished by the contractor, with the addition, in italics, of the fossils found. In the identification of these, the author had the assistance of C. W. Johnson, of the Wagner Free Institute of Sciences, Philadelphia:

White sand and large white and blue pebbles	8 feet.	8 feet.	Quaternary.
Fine yellow, sticky sand	72 "	80 "	
Black sandy clay and sand and lignite	10 "	90 "	Miocene.
Dark-blue clay, contained *Turritella æquistriata* and *Cardita granulata;* also *coccoliths,* both *discolith* and *cyatolith* varieties; no diatoms seen	55 "	145 "	
Black sand marl (*Ostrea bryani, Foraminifera—large Nodosaria, &c*)	45 "	190 "	Upper marl, including the lime sand (?) or its equivalent.
Blue clay, lighter than above	50 "	240 "	
Conglomerate, ponderous shells*	15 "	255 "	Middle marl.
Light-blue clay (?)	80 "	335 "	Red sand horizon (?).
Green and white sand, mixed (*Belemnitella and ponderous shells**)	45 "	380 "	Lower marl.
Clay, with white quartz and greensand grains, mixed	15 "	395 "	Laminated sands and clay marls.
Yellowish sand	15 "	410 "	
Micaceous, marly, sandy clay	101 "	511 "	

* Obtained in fragments, probably broken by the drill.

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Although this well was not successful as a water-supply, yet the facts learned, being of special geological value at this time, will now be reviewed. Unfortunately specimens were not frequently and regularly saved between 145 and 335 feet at the time of drilling, though some in a mixed condition were afterward obtained from the dump. It is consequently not possible to interpret this portion of the record so accurately in detail as has been done both above and below this interval. The writer has, however, in preparation a vertical section from Camden to Atlantic City upon which numerous wells are plotted. Upon placing this well in its proper position upon the same, it is found that the middle marl bed should occur at 250 feet and the lower marl at 350 feet. Broken and unidentifiable fragments of some ponderous shells, probably a Gryphea, a species of ancient oyster, were furnished, marked 240 to 255 feet. Similar broken fragments, with the addition of Belemnitella, were also received, marked 345 feet. These two horizons may therefore be regarded as accurately defined. The record notes black sand marl at 145 to 190 feet. A considerable number of specimens of a very small oyster, *Ostrea bryani*, were obtained from the dump from marl said to belong to about that depth. This may possibly represent the lower portion of the upper marl bed, since Prof. Whitfield defines this specific form in his Paleontology of New Jersey as occurring in this bed. Among the mixed material procured from the dump are a very noticeable number of Foraminifera, peculiarly characteristic and abundant in the lime sand above the middle marl bed, but no clearly-defined specimen of this lime sand could be obtained. This horizon, very possibly, may be represented here, though being further northeast than the localities where it has heretofore shown a good development, it may be that it occurs only as a thin layer, its character being changed, and the interval where it would otherwise be found being occupied by the "light-blue clay," reported between the depth of 190 and 240 feet. No sample of this blue clay was obtained, for the reason that the well was considerably deeper than this before the fact of the drilling was learned.

In the fifty-five feet of dark-blue clay near the top, occupying the section between 90 and 145 feet, were found a few very small but well-defined shells, readily identifiable and quite characteristic of beds of Miocene age. (See page 407 for species.) As already, in substance, stated in the introduction to this paper, this gives us the first knowl-

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edge of the occurrence of Miocene deposits so far westward in this State.* Peculiarly-small, transparent, oval, calcareous plates, visible only with high powers under the microscope, were also seen in this clay. These are technically called Coccoliths. They are of two forms—named Discoliths and Cyatoliths. Both of these varieties occur here. One of these forms is shaped much like a collar-stud.

ARTESIAN WELL, MAPLE SHADE, N. J.

Elevation, 55 feet; depth, 375 feet.

A well has been put down at Maple Shade, two and three-quarter miles south of west from Moorestown station on the Burlington county railroad. The contractor, Uriah White, furnished a full set of specimens of the earths, &c., penetrated, while Dr. James M. McCrae, of Maple Shade, furnished the following record:

Surface gravel	5 feet.	5 feet.	Quaternary.
Yellow clay	8 "	13 "	Clay marls.
Ferriferous clay and ironstone crust	4 "	17 "	
Fossiliferous black sand (containing *Ammonites, Scaphites, Baculites* and other Molluscs)	3 "	20 "	
Black clay	44 "	64 "	
(A) Fine and coarse gray sands at the top, changing to medium and then to coarse and pebbly gravels at the bottom	33 "	97 "	
Greensand marl	6 "	103 "	
(B) Fine, grey sand and coarse gravel, similar to A	27 "	130 "	

*In the Annual Report for 1891, page 220, the same contractor reports "marl" at seventy-eight feet at Richwood and at ninety-six feet at Pitman Grove. Since Richwood is but two miles northwest and Pitman Grove but two miles north of this well, and as all three localities are upon the same plateau and at about the same elevation, it is most probable that the so-called marl represents at these places a still further westward and northward extension of this same Miocene clay, which is generally bluish-green in color and is often called marl by the well-driller, a name likely to be misleading in New Jersey, at least, where this term is almost universally used to denote the true greensands of the Cretaceous beds. Being unaware of the existence of the Miocene in this region, and supposing the so-described marl was a true greensand, some remarks were made in said report referring these so-called marls at Pitman Grove to the middle marl bed, and at Glassboro and Richwood to the upper marl bed. That these two marl beds are respectively buried beneath these localities, but deeper than then indicated, is, however, most probable.

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White clay	100 feet.	230 feet.	Plastic clay series.
Red clay	10 "	240 "	
Alternations of sand and clay, sometimes reddish	20 "	260 "	
(C) White sand	40 "	300 "	
White sand, fine, with streaks of clay	15 "	315 "	
White sand, coarse	15 "	330 "	
White sand, medium coarse	20 "	350 "	
White gravel, coarse	10 "	360 "	
White gravel, coarser	10 "	370 "	
(D) White gravel, very coarse, with large pebbles and bowlders	5 "	375 "	

The sands and gravels marked A, B, C and D, all furnish water, and may be regarded as water horizons; that marked A being the one reached by wells dug in this neighborhood and which penetrate through the black clay. Strata A and B belong to the blue-grey gravels at the base of the clay marls, while C and D are the yellowish-white gravels within and toward the base of the plastic clays.

This well now supplies water of satisfactory quality to residents of Maple Shade from the bowlder gravel (D) at the base.

The upper portion of the forty-four feet of black clay near the top of this section outcrops at tidewater on the Pensauken one mile to the eastward near Lenola station. It is there dug, together with the nine feet of yellow clay above; the two clays are then mixed and used in making bricks at the factory of Augustus Reeve. In digging there are unearthed large numbers of cretaceous fossil molluscs.

Most of the fossils occur in the bed of black sand about three feet thick, interbedded between the two clay beds, the lower one a thick bed of black clay somewhat micaceous, and the upper one composed of two divisions, as follows: that next the black sand, a ferruginous clay with ironstone crusts, and the one above this, a soft, yellow clay. Over these are the superficial or yellow gravels. A few fossils, however, are found both above and below the black sand but not in the overlying gravels.

The fossils are mainly in the form of casts, and are remarkably well preserved in comparison with similar fossils from other localities in the State.

The most noticeable among them are two species of *Ammonites*, each about twelve inches in diameter, being considerably larger than any of the same species now in the collection of the Academy of Natural Sciences, Philadelphia, from the State of New Jersey, though

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there are in the museum two individuals of one of the forms from the Delaware and Chesapeake canal that measure respectively sixteen and eighteen inches across.

The whole number of forms which the author has seen at this point is seventy-six.

In the identification of the various forms he has had the assistance of Professors A. Heilprin, C. W. Johnson, H. A. Pilsbury and R. P. Whitfield. In nomenclature we have followed Whitfield, to whose work the specialist is referred for synonyms and references to other literature. For convenience the volume, page, plate and figure where each is described and illustrated are noted. The list is as follows:

CRETACEOUS FOSSILS AT LENOLA.

CEPHALOPODA.

Ammonites (*Placentaceras*) *placenta* De Kay.* Vol. II., page 255, Pl. XL., Fig. 1, XLI., Figs. 1 and 2.

Ammonites delawarensis Morton. Vol. II., page 252, Pl. XLII., Figs. 6 to 9.

Scaphites hippocrepis De Kay. Vol. II., page 262, Pl. XLIV., Figs. 8 to 12.

Scaphites nodosus Owen. Vol. II., page 261, Pl. XLIV., Figs. 13 and 14.

Baculites ovatus Say. Vol. II., page 275, Pl. XLVI., Figs. 3 to 9.

GASTEROPODA.

Alaria rostrata Gabb (numerous). Vol. II., page 119, Pl. XIV., Figs. 5 and 6.

Anchura abrupta Conrad. Vol. II., page 113, Pl. XIV., Figs. 1 to 3.

Avellana bullata Morton. Vol. II., page 163, Pl. XX, Figs. 1 to 4.

Cerithium (*Potamides?*) Sp.?

Cithara crosswickensis Whitfield. Vol. II., page 107, Pl. XIII., Figs. 7 and 8.

Dentalium subarcuatum Conrad, internal casts. Vol. II., page 166, Pl. XX., Figs. 19 and 20.

Dentalium subarcuatum Conrad, external impression. Vol. II., page 166, Pl. XX., Figs. 21 to 24.

Endoptygma umbilicata Tuomey. Vol. II., page 136, Pl. XVII., Fig. 30.

Gyrodes obtusivolva Gabb. Vol. II., page 129, Pl. XVI., Figs. 9 to 12.

Gyrodes altispira Gabb. Vol. II., page 128, Pl. XVI., Figs. 7 and 8.

Gyrodes infracarinata Gabb. Vol. II., page 125, Pl. XV., Figs. 13 to 16.

Lunatia halli Gabb. Vol. II., page 130, Pl. XVI., Figs. 13 to 16.

Natica abyssina Morton. Vol. II., page 123, Pl. XV., Fig. 9 to 12.

Margarita abyssina Gabb. Vol. II., page 133, Pl. XVII., Figs. 1 to 5.

Modulus lapidosa Whitfield. Vol. II., page 152, Pl. XVII., Figs. 6 to 8.

Odontofusus slacki Gabb. Vol. II., page 66, Pl. VI., Figs. 8 and 9.

Pyropsis alabamensis Gabb.

Pyropsis naticoides Whitfield. Vol. II., page 43, Pl. II., Figs. 5 to 7.

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*The references, unless otherwise stated, are to Whitfield's Palæontology of New Jersey.

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Rostellites nasutus Gabb. Vol. II., page 86, Pl. XI., Figs. 1 and 2.
Rostellites texturatus Whitfield. Vol. II., page 88, Pl. XI., Figs. 5 and 6.
Rostellites angulatus Whitfield. Vol. II., page 88, Pl. XI., Figs. 3 and 4.
Scalaria thomasi Gabb. Vol. II., page 137, Pl. XVIII., Fig. 1.
Scalaria sillimani Morton. Vol. II., page 138, Pl. XVIII., Fig. 2.
Scalaria ——— Sp?
Turritella encrinoides Morton. Vol. II., page 143, Pl. XVIII, Figs. 19 to 22.
Turritella lippincotti Whitfield. Vol. II., page 145, Pl. XVIII., Figs. 23 and 24.
Turritella pumila Gabb. Vol. II., page 187, Pl. XXIII, Figs. 5 and 6.
Turbinella parva Gabb. Vol. II, page 80, Pl. IX., Figs. 4 to 6.
Turritella vertebroides Morton (?). Vol. II., page 146, Pl. XVIII., Figs. 13 to 18.
Voluta (?) *delawarensis* Gabb. Vol. II., page 84, Pl. X., Figs 5 to 7.
Volutoderma abbotii Gabb. Vol. II., page 173, Pl. XXI., Figs. 4 to 9.
Volutomorpha—Sp.?
Volutomorpha conradi Gabb. Vol. II., page 71, Pl. VI., Fig. 21, and Pl. VII., Figs. 1 to 5.

Included in the total number of molluscan species as above stated, and therefore to be added to this list, are two forms of Gasteropoda pronounced by Prof. R. P. Whitfield to be new to the New Jersey fauna; one of these, in a preliminary note received, he inclined to regard as a *Volutoderma* and the other he stated is probably a *Cerithium* and much resembles *C. conradi* Whitfield, the type of which came from the Cretaceous of Syria. These forms were again referred to him for further detailed description, and were named as follows:

Volutoderma woolmani Whitf. Figured in the Nautilus, September, 1893. Pl. II., Figs. 4, 5.
Described in the Nautilus (August) Vol. VII., p. 38.
Cerithium pilsbryi Whitf. Figured in the Nautilus, September, 1893. Pl. II., Fig. 3.
Described in the Nautilus (August) Vol. VII., p. 38. Drawn from a gutta-percha squeeze of the natural cast.

LAMELLIBRANCHIATA.

Arca quindecimradiata Gabb. Vol. I., p. 208, Pl. XXVII., Figs. 10 to 13.
Anomia tellinoides Morton. Vol. I., page 43, Pl. IV., Figs. 12 and 13.
Axinea mortoni Conrad. Vol. I., page 99, Pl. XI., Figs. 23 to 25.
Aphrodina tippana Conrad. Vol. I., page 154, Pl. XXII, Figs. 6 and 7.
Calliste delawarensis Gabb. Vol. I., page 153, Pl. XXII., Figs. 8 to 10.
Cardium sp.
Cardium (*Criocardium*) *dumosum* Conrad. Vol. I., page 133, Pl. XX., Figs. 9 to 13.
Cardium (*Fragum*) *tenuistriatum* Whitfield (numerous). Vol. I., page 139, Pl. XX., Figs. 15 and 16.
Cyprimeria heilprini Whitfield. Vol. I., page 160, Pl. XXII., Figs. 14 and 15.
Cyprimeria densata Conrad. Vol. I., page 157, Pl. XXII., Figs. 19 to 21.
Camptonectes (*Amusium*) *burlingtonensis* Gabb. Vol. I., page 53, Pl. VIII., Figs. 3 to 9.

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Clavagella armata Morton. Vol. I., page 192, Pl. XXV., Fig. 24.
Crassatella conradi Whitf. Vol. I., p. 209, Pl. XXVIII., Figs. 1 to 5.
Exogyra costata Say. Vol. I., page 39, Pl. VI., Figs 1 and 2.
Gouldia conradi Whitfield. Vol. I., page 125, Pl. XVIII., Figs. 1 to 3.
Idonearca antrosa Morton. Vol. I., page 96, Pl. XIII., Figs. 6 to 11.
Idonearca vulgaris Morton. Vol. I., page 98, Pl. XIII., Figs. 1 to 5.
Inoceramus sagensis Owen. Vol I, p. 76, Pls. XIV., XV., Figs. 15, 1 and 2.
Inoceramus sagensis var. *quadrans* Whitf. Vol. I., p. 79, Pl. XV., Fig. 16.
Linearia metastriata Conrad. Vol. I., page 165, Pl. XXIII., Figs. 6 and 7.
Lucina smockana Whitf. Vol. I, p. 130, Pl. XVIII., Figs. 21 and 22.
Leiopistha protexta Conrad. Vol. I., page 140, Pl. XX., Figs. 1 to 3.
Neithea quinquecostata Sowerby. Vol. I., page 56, Pl. VIII., Figs. 12 to 14.
Mytilus oblivius Whitfield. Vol. I., page 64, Pl. XVII., Fig. 1.
Martesia cretacea Gabb. Vol. I., page 190, Pl. XXV., Figs. 20 to 23.
Modiola (*Lithodomus?*) *inflata* Whitf. Vol. I., p. 197, Pl. XXVI., Figs. 13 and 14.
Panopea decisa Conrad. Vol. I., page 181., Pl. XXIV., Figs. 5 to 8.
Pinna laqueata Conrad. Vol. I., page 81, Pl. XVI, Figs 1 and 2.
Pholadomya occidentalis Morton. Vol. I., page 175, Pl. XXIV., Figs. 1 to 3.
Plicatula urticosa Morton. Vol. I., page 61, Pl. IX., Figs. 1 and 2.
Tenea pinguis Conrad. Vol. I., page 163, Pl. XXII., Figs. 1 to 3.
Trigonia mortoni Whitfield. Vol. I., p. 112, Pl. XIV., Figs. 5 and 6.
Teredo irregularis Gabb. Vol. I., page 191, Pl. XXV., Figs. 18 and 19.
Teredo tibialis Morton. Vol. I., page 201, Pl. XXVI., Figs. 19 to 22.
Veniella conradi Morton. Vol. I., page 144, Pl. XIX., Figs. 8 to 10.
Veniella subovalis Conrad. Vol. I., page 150, Pl. XIX., Fig. 1.

ECHINODERMATA.

Hemiaster parastatus Morton. Morton's Cretaceous Fossils, page 77, Pl. III., Fig. 21.

ARTESIAN BORING AT MOORESTOWN, N. J.

Elevation of surface, about 10 feet; depth, 457 feet.

This well is located upon the west bank of the north branch of Pensauken creek, one and one-quarter miles southwest of Moorestown station. It was bored by Kisner & Bennett for the Moorestown Water Company. Through the co-operation of interested members of the company and of the contractors, a series of the borings was obtained. The following record is presented—it is almost verbatim as furnished by the contractors, with the addition by the writer of notes as to the colors of the sands and gravels and of notes, upon the right, of the geological position of the strata. Water that flowed in considerable quantity above the surface was found at 118, 136, 320 and 338 feet.

1. Bog mud or muck, creek alluvium	6 feet.	6 feet.	} Recent.
2. White quicksand	6 "	12 "	} Clay marls.
3. Blue clay or black mud	81 "	93 "	

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4. Coarse sand, almost gravel, blue-grey in color, *water*	25 feet.	118 feet.	Blue-grey sands at the base of the clay marls.
5. White clay	3 "	121 "	
6. Sand, some water	8 "	129 "	
7. White clay	2 "	131 "	
8. Coarse sand and flinty gravel, blue-grey in color	31 "	162 "	
9. White and red clays	50 "	212 "	Plastic clays and inter-bedded water horizon in yellowish-white gravels.
10. Fine, white sand and large gravel, yellowish-white in color, *water*	38 "	250 "	
11. Sand, coarse gravel and clay mixed	60 "	310 "	
12. White clay	10 "	320 "	
13. Sand and gravel, blue-grey in color, *water*	24 "	344 "	
14. Blue clay	6 "	350 "	
15. White clay	8 "	358 "	
16. Red clay	60 "	418 "	
17. Red clay and quicksand	33 "	451 "	
18. Red clay and cobblestones (no water)	6 "	457 "	

The tubing of this well was finally withdrawn to the 136-feet water horizon, and the well finished with a depth of 150 feet. It flows constantly, but has not been utilized for supply. To the writer, at least, it is a matter of regret that the boring was not, or could not, have been prosecuted further. It was probably not many feet deeper to the heavy gravel and cobble horizon at the base of the Cretaceous, and which has already been defined, page 410, as a good water-bearing horizon. The last line of the record indicates that this stratum was nearly reached. Its upper portion was probably mixed with impervious clay, and hence yielded no water. An open and free water-bearing stratum may possibly exist below.

ARTESIAN WELL AT KEYPORT, N. J.

RECORD FURNISHED BY THE CONTRACTORS, KISNER & BENNETT, OF BELMAR, N. J. WATER WAS FOUND AT 242 FEET.

Common sand and gravel	16 feet.	16 feet.	Recent.
Blue clay	5 "	21 "	Clay marl (?)
Fine sand	6 "	27 "	Plastic clay series.
White clay	17 "	44 "	
Grey quicksand	20 "	64 "	
White clay	22 "	86 "	
Fine sand	15 "	101 "	
Blue and white clays	37 "	138 "	
Fine sand	15 "	153 "	
Red and white clay	37 "	190 "	
Sand and water	52 "	242 "	

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ARTESIAN WELL AT QUINTON N. J.

A six-inch artesian well was bored in the fall of 1892 at Quinton, N. J. It was put down for the Salem Water Company, under the supervision of I. S. Cassin & Son, civil engineers. The drilling was done by Kisner & Bennett. Charles W. Casper, president of the company, and I. S. Cassin, Jr., cordially furnished notes of the strata passed through and also divided with the writer a series of specimens that had been preserved. Further samples were collected from lumps of clay that were still lying about and which had been thrown out from a dug well put down some years previously to the depth of about 35 feet.

After a careful examination of all the specimens and comparison with the notes, the following record has been made:

1. Surface soil............	1 foot.	1 foot.	Recent.	
2. Gravel	3 feet.	4 feet.		
3. Clay, with shells......	26 "	30 "	Astringent clay or rotten-stone.	Miocene.
4. Green and white sandy, clayey marl,	8 "	38 "	Upper marl (?).	Cretaceous.
5. Alternations of lime sand and lime rock,	108 "	146 "	Lime sand.	
6. Clay	2 "	148 "		
7. Greensand marl and shell comminuted by the drill..........	14 "	162 "	Middle marl.	
8. Clay	4 "	166 "		
9. Grey quartzose sand, with *water*...........	82 "	248 "	Red sands.	

The elevation of this well is about ten feet above tide.

That the clay (No. 3) is Miocene, is shown by the following fossil shells found in the lumps obtained from the dug well: *Lucina contracta, Yoldia limatula, Corbula elevata, Astarte undulata, Turritella pleibeia* and numerous fragments of another shell believed to be *Artemis acetabulum.*

Shells were also shown in the borings from the drilled well, but so thoroughly comminuted as to be entirely unidentifiable. Stratum No. 4, in the washed-out borings, appears as a sand, but in the lumps from the bottom of the dug well it is shown to be more compact than sand, and is better described as a sandy, clayey marl. It contains white sand grains and pure greensand grains, with a considerable mixture

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of Foraminifera. This stratum probably represents the lower layer of the upper marl bed.

The alternations of lime sand and lime rock (No. 5), are especially interesting, since they unexpectedly reveal a thickness of 108 feet for this upper member of the middle marl, as against twenty-five feet, the maximum thickness heretofore known from outcrops, and which, therefore, exhibit only the basal portion of this lime stratum. This section consists of an aggregation of Bryozoa, large and small Foraminifera and coral.

Stratum No. 6 is the true marl of the middle marl bed, and shows clustered greensand grains beautifully illustrative of the casts of Globegerina, which they really are. This greensand comes out so pure that it is called, by well-drillers, "powder-grain marl." With it is seen some finely-comminuted shell, probably from the Terrebratula layer that is so generally shown in outcrops of the same marl.

The lowest ten feet of the lime sand and all the underlying strata, Nos. 6, 7, 8 and 9, correspond with beds penetrated by the wells at Woodstown, between the depths of 8 and 134 feet. No. 6, however, shows a difference in composition—here it is a thin clay seam, there it becomes a correspondingly thin cemented shell rock or coquina.

The water, both at Woodstown and Quinton, is obtained from a pure, clean sand, No. 9 in above record, showing at both localities a thickness of eighty feet. This is the equivalent of the so-called red sand bed that occurs below the middle marl. At outcrops its color is frequently reddish, but in these wells it changes to grey.

This water horizon has also been opened by a well one and three-quarter miles southeast of Mullica Hill (see page 417), and is doubtless quite extensive. It is probably identical with the one at Asbury Park below the middle marl or at the depth of 425 feet from the surface. The bed, however, seems to thicken in this more southern region, where it furnishes a large supply of good water. The yield at Quinton is stated at about fifty-five gallons per minute, and at Woodstown at about sixty gallons. The wells at both localities have a diameter of six inches. The elevation of the surface at Quinton is about ten feet, and the water rises to within one foot thereof. This sand bed should be expected to yield a good supply at Glassboro and eastward and southward therefrom.

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ARTESIAN WELL NEAR MULLICA HILL, N. J.

An artesian well was drilled by Charles H. Leach for Thomas Borton one and three-quarter miles due southwest of Mullica Hill, at a point having an elevation of 100 feet.

The middle marl bed has long been worked upon lower ground on the opposite side of the road, where it is exposed at an elevation of about seventy feet. This well is reported to have found marl near the surface, and to have continued in the same till water was reached. No specimens of material penetrated were saved.

The supply was found in a grey sand that was penetrated about ten feet, evidently the equivalent of the red sand bed below the middle marl. This is the same stratum that furnishes the wells at Woodstown, and also the water plant of the Salem Water Company located at Quinton.

ARTESIAN WELL NORTHEAST OF AND NEAR MEDFORD, N. J.

This well is upon the farm of Joshua S. Wills, about one and three-quarter miles northeast of Medford station. A set of borings were exhibited in a drug store at Medford, and were afterward forwarded to the writer through the recommendation of a geological friend who chanced to see them, and who rightly appreciated the value of the specimens to the Survey.

By correspondence with J. S. Wills, the elevation of the surface is learned to be sixty-three feet. After careful examination of the various specimens the following record has been made:

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Specimen.					
No. 1.	Soil	2 feet.	2 feet.		
2.	Clay, yellow sand	3 "	5 "		
3.	Fine grey sand with greensand grain		5 to 15 "		
4.	Coarse grey sand with greensand grain		15 to 23 "		
5.	Olive-colored marl, at		30 "		
6.	Dark-green marl, at		35 "	Bottom of upper marl.	Cretaceous.
7.	Lime sand and Foramanifera, Bryozoa, at		50 "	Lime sand.	
8.	Green marl with shell *Gryphea* and *Terrebraluta*, at		70 "	Middle marl.	
9.	Pure greensand, dark color, at		76 "		
10.	" " light color, at		80 "		
11.	" " dark color, at		91 "		
12.	" " chocolate color, at		104 "		
13.	" " dark green, at		120 "		
14.	Grey sand with greensand grains and shell, &c., *Exogyra* and *Belemdetes*, at		124 "	Red sand bed.	
15.	Grey sand and *water*, at		126 "		

In last year's report, page 302, a record is given for a well bored for Isaac W. Stokes, one and a half miles almost due northwest on ground elevated about 78 feet. The relative position of these two wells is almost directly across the line of strike of the strata. I. W. Stokes' well, as stated last year, was deepened from a water horizon at about 70 feet to one at 175 to 183 feet A comparison of the records and specimens of the two wells shows conclusively that the upper water horizon at 64 to 70 feet in I. W. Stokes' well is the same as that at 126 feet at the bottom of J. S. Wills' well.

ARTESIANS IN THE SUPERFICIAL STRATA.

ARTESIAN WELL AT BRIDGETON, N. J.

A shallow well was bored at the residence of O. Cook, in East Bridgeton, on ground near the forty-feet contour line. It reached a depth of ninety feet and was then abandoned without water having been obtained. The well is reported and the record inserted because it has a value in interpreting the geological structure of the superficial covering of New Jersey that overlies the Miocene beds and which were not probably reached by this boring, though they no doubt exist not much lower down.

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The drilling was started from the bottom of a dug well having a depth of twenty-one feet. The owner kindly saved and presented samples of the materal passed through and furnished the following record:

Depth of old well		21 feet.
Clay	1 foot.	22 "
Light-grey quicksand	40 feet.	62 "
Sandstone, top of clay	1 "	63 "
White clay	1 "	64 "
Sand	2 "	66 "
Quicksand	3 "	69 "
Coarse sand	8 "	77 "
Quicksand	"	79 "
Sand, small amount of water	1 "	80 "
Hard, stiff, yellow clay	2 "	82 "
Sand	2 "	84 "
Reddish clay	1 "	85 "
Sand	4 "	89 "
Dark clay	1 "	90 "

ARTESIAN WELLS AT CLAYTON, N. J.

Three two-inch wells and three three-inch wells were bored at Clayton by Chas. H. Leach for Moore Brothers. These all found water in a coarse gravel at approximately 80 to 105 feet from the surface. The elevation here is about 140 feet—the water rises to within twenty-one feet of the surface. C. H. Leach says each well on being tested pumped 150 gallons a minute, the full capacity of the pump, without lowering the supply. These wells draw from the superficial sands and gravels that, from the record at Glassboro, we now know rest in this vicinity upon the beveled edge of the Miocene clays, which clays cannot be far below the greatest depth reached by either of these wells.

The bottom of these wells is above tide level; the underlying impermeable Miocene clays probably prevent the water contained in these gravels from sinking deeper.

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SHALLOW ARTESIAN WELLS AT GLASSBORO.

Elevation, about 140 feet.

Five wells were bored at this point for the West Jersey Railroad Company. They find their supply in a water-bearing sand at seventy-three to eighty feet, at which depth the wells were finished. A test bore, however, was made to eighty-eight feet, from which the following succession of strata was learned.

Leach Brothers, who bored the wells, furnished the following record:

Clay to	20 feet.	20 feet.	Quaternary.
Sand and gravel	3 "	23 "	
Yellow quicksand	47 "	70 "	
Yellow clay	3 "	73 "	
Sand, with water	7 "	80 "	
Light, fine gravel	6 "	86 "	
Black sand	2 "	88 "	
Green marl, marly clay			Miocene.

This group of wells was noticed last year, but without a detailed record. The green marl at the base is, doubtless, the top of the bed of Miocene clay described in the record of a much deeper well at the same place as having been reached at the depth of eighty to ninety feet and continuing to the depth of 145 feet. (See page 407.)

These Miocene clays, when brought out of the wells, and before becoming dry, are variously described as dark blue, greenish or bluish-green marls by the well-drillers.

RECAPITULATION.

In the preceding pages there have been noticed as follows:

Wells in Miocene strata.

At Beach Haven, Seven islands, Atlantic City and Ocean City, N. J., and at Mahon river, Dover and Lewes, Del. With these has been included one well at Kitts Hummock, Del., that possibly barely

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entered the Miocene, and one at Wildwood that should and would have entered beds of that age had work not been temporarily suspended.

Wells in Cretaceous strata.

In the *red sand bed* wells have been described in detail at Woodstown, Quinton, Mullica Hill and Medford.

In gravel, at the base of the *clay marls*, one well is reported successfully developed at Wenonah, while one at Glassboro, N. J., is noticed as abandoned at the depth of 511 feet.

In the *Potomac gravels*, at the base of the *plastic clay*, or in other words, at and near the base of the Cretaceous as it exists in New Jersey, wells have been noted in detail at Gloucester, Maple Shade and Moorestown.

Wells in Quaternary strata.

In the Quaternary or superficial gravels, wells are reported at Glassboro, Clayton and Bridgeton.

Enumeration of Horizons.

There has been demonstrated the existence of several water-yielding sands interbedded within impervious Miocene clays, of which the most promising are those occurring at Atlantic City at the depths of 525, 700, 760 and 800 feet.

In Cretaceous strata a similar water-producing grey sand bed, the so-called red sand bed, is shown to occur below the middle marl.

Also in Cretaceous strata water horizons are revealed in certain bluish-grey gravels at the base of the clay marls, and again in coarse gravels and bowlder gravels, yellowish-white in color, toward and at the base of the plastic clays.

A few wells in the superficial strata of sand and gravel of later age than any of the preceding have been noticed. These are of local application only.

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PART VI.

Minerals of New Jersey,

WITH

Notes on Mineral Localities.

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MINERALS OF NEW JERSEY AND NOTES OF MINERAL LOCALITIES.

I. Metallic Minerals.

GOLD.

Gold has been reported as occurring in pyritiferous rocks at several localities, and some failures have resulted from attempts to win the metal from these so-called gold-bearing minerals. Many assays have been made of them without finding any gold, excepting traces in a very few assays. The evidence is against its probable existence in workable quantity in the State.

SILVER.

Silver occurs in the galena at the old Andover iron mine in Sussex county, but the occurrence has no practical value. It is present in the copper ores of the red sandstone belt, although not in amount to justify working, as these ores are lean, and the percentage of silver is small. Also in copper pyrites, Howell farm, Jenny Jump mountain.

References: Geology of New Jersey, 1868, p. 682.
Ann. Rep. State Geologist, 1880, pp. 174–177.

COPPER.

Native copper, cuprite (the red oxide of copper), and the carbonates of copper (malachite and azurite), occur in contact deposits in the sandstone near the trap-rock sheets in the Triassic belt of the State. Other copper-bearing minerals also occur associated with these ores. Copper mines have been worked at Fort Lee on the Hudson; at

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Belleville, in Essex county; at New Brunswick, in Middlesex county; near Plainfield, at Chimney Rock, near Somerville, at Martinsville, at Griggstown, and near Pluckamin, in Somerset county; and at Flemington and at Copper Hill, in Hunterdon county. The Schuyler mine, at Belleville, was opened long before the Revolution, and was worked vigorously for English works. These copper mines have attracted a great deal of capital and have not yielded corresponding returns for the outlay, on account of the lean ores.

Chalcopyrite, or copper pyrites, is of common occurrence, and attempts to mine it have been made near Glen Gardner and on Jenny Jump mountain near the Great meadows.

At the Pahaquarry mine, on the Kittatinny mountain, copper ores are found, but apparently in wide distribution in the sandstone.

REFERENCES: Geology of New Jersey, 1868, pp. 218–223, 675–680.
Ann. Rep. State Geologist, 1870, pp. 55–58.
Ann. Rep. State Geologist, 1881, pp. 39, 40.

LEAD.

Galenite occurs in quantity at the Sussex lead mine, near Howellsville, and at the old Andover iron mine, both in Sussex county. At the latter locality cerussite was found with the galenite and chalcopyrite. The Sussex lead mine is the only locality where lead ore has been mined in the State, but it has been idle for many years. The mineral occurred in a coarsely-crystalline limestone and so disseminated through the rock as to make it a lean ore.

The other occurrences of lead-bearing minerals are of mineralogical importance only.

REFERENCES: Geology of New Jersey, 1868, pp. 681, 682.
Final Report of State Geologist, Vol. II., Pt. 1, p. 10.

ZINC.

The zinc ores are limited to Sussex and Warren counties. The famous mines at Stirling Hill, near Ogdensburgh, and at Franklin Furnace, in Sussex county, are worked steadily and yield a large product of high-grade ores. They consist of zincite, willemite, franklin-

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ite, calamine and other associated zinc-bearing minerals. Sphalerite or blende occurs in considerable quantity on the Raub farm, near Oxford, Warren county, and the locality has been opened for zinc, but has not been developed into a productive mine.

REFERENCES: Geology of New Jersey, 1868, pp. 669-674.
Catalogue of Minerals in Final Report State Geologist, Vol. II., Pt. 1, p. 3, *et seq.*
Ann. Rep. State Geologist, 1875, p. 36.
Ann. Rep. State Geologist, 1883, p. 167.
Ann. Rep. State Geologist, 1884, pp. 109, 110.

IRON.

Native Iron.

Iron occurs native, but sparingly disseminated, in the trap-rock of Bergen Hill; also in red sandstone and shale at Martin's dock, on the Raritan river.

REFERENCES: Ann. Rep. State Geologist, 1874, pp. 56, 57.
Ann. Rep. State Geologist, 1883, pp. 162-164.

IRON ORES.

Magnetite, hematite and limonite are the ores of iron which are worked. The magnetic ore is the basis of the iron-mining industry of the northern part of the State. It occurs in large masses, and also as a constituent of the rock in the crystalline schists of the Highlands. At many localities these masses or beds are of workable extent, and there are many mines in Sussex, Warren, Morris, Passaic and Hunterdon counties, besides a few small ones in Bergen and Somerset counties.

Hematite has been mined at Simpson mine, Vernon township, and Andover mine, Sussex county; Cooley's mine, West Milford, in Passaic county; and at Marble mountain, Warren county. The total production of hematite is inconsiderable in comparison with that of the magnetic variety.

Limonite, or brown hematite, is common in the limestone-slate valleys of the northern part of the State. It has been worked ex-

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tensively at several localities. As an ore of iron it is next in importance to the magnetite.

Siderite—carbonate of iron—has been found at bottom of Shields' brown-hematite mine, Beattystown, Warren county. Also sparingly at the Cedar Hill mine, Sussex county. These occurrences have not, however, been proven of extent to be of practical importance.

The lists of iron mines and ore-producing localities, and descriptive notes are to be found in the references as below.

REFERENCES: Geology of New Jersey, 1868, pp. 532-668.
Ann. Rep. State Geologist, 1873, pp. 21–90.
Ann. Rep. State Geologist, 1874, pp. 12–32.
Ann. Rep. State Geologist, 1886, pp. 135–154.
Ann. Rep. State Geologist, 1890, pp. 51–72, 87–127.
Ann. Rep. State Geologist, 1891, pp. 235–253.

IRON MINERALS.

Vivianite—Mullicite.

Vivianite—iron phosphate—occurs in the greensand-marl beds at Shrewsbury, in Monmouth county; also in Gloucester county, at Mullica Hill.

REFERENCE: Geology of New Jersey, 1868, pp. 282, 283.

Bog-Iron Ore.

Bog-iron ore—limonite in part—is abundant, particularly in the southern part of the State.

REFERENCES: Geology of New Jersey, 1868, pp. 664–668.
Ann. Rep. State Geologist, 1880, p. 178.

Ochre.

A bed of yellow ochre near Harmony, Warren county, has been worked to some extent.

In Monmouth county a bed of red ochre was worked near Englishtown, which was a deposit from a chalybeate spring.

Near the Delaware Water Gap there is in the town of Pahaquarry a large bed of ochreous earth deposited from a mountain spring.

REFERENCE: Ann. Rep. State Geologist, 1872, pp. 31, 32.

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Pyrite, Pyrites, Sulphide of Iron.

This mineral is common in all parts of the State, but at a few localities only to workable extent. It is found associated with magnetite at the Green or Copperas mine, Vernon; Silver mine, near Waterloo; Old Copperas, or Green Pond mine, Morris county; Jenny Jump mountain, Davis's mine, Warren county; and in smaller percentages at other localities in the iron-ore district. It is abundant in the clay beds, with lignite, near Cliffwood on Raritan bay, and at Bordentown on the Delaware river.

In places it is mixed with marcasite and pyrrhotite, more rarely chalcopyrite.

REFERENCES: Geology of New Jersey, 1868, pp. 711, 712.
Ann. Rep. State Geologist, 1881, pp. 176, 177.
[See also references to Nickel.]

MANGANESE.

Manganese ore has been mined one mile southeast of Clinton, in Hunterdon county. This ore is a mixture of the oxides pyrolusite and braunite, and occurs in the Triassic sandstone.

Manganese is characteristic of the ores, minerals and rocks at the zinc mines in Sussex county. Franklinite, rhodonite and rhodochrosite occur, as also manganiferous calcite or spartaite. The manganese is utilized in the spiegel-eisen product in the working of the ores, but the manganiferous calcite is not used.

REFERENCES: (Clinton) Geology of New Jersey, 1868, pp. 224, 711.
Geology of New Jersey, 1868, pp. 670, 673.

NICKEL.

Nickel has been found in traces in pyritiferous crystalline schists at several localities in the Highlands. It occurs in pyrrhotite and in arsenopyrite and, probably, in pyrite also.

LOCALITIES: Jenny Jump mountain, Warren county.
Washington, Warren county.
Pottersville and Chester, Morris county.

REFERENCES: Ann. Rep. State Geologist, 1871, p. 34.
Ann. Rep. State Geologist, 1876, p. 55.
Ann. Rep. State Geologist, 1879, p. 152.

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ARSENIC.

Arsenopyrite, containing 29.8 per cent. arsenic, occurs on Jenny Jump mountain, near the Great meadows.

REFERENCE: Ann. Rep. State Geologist, 1871, p. 34.

MOLYBDENUM.

Molybdenite or sulphide of molybdenum and the oxide or molybdite, occur associated with magnetite in the Hude iron mine and at the Ogden mine, in Sussex county.

REFERENCES: Geology of New Jersey, 1868, pp. 623, 711.
Ann. Rep. State Geologist, 1889, pp. 58, 59.
Ann. Rep. State Geologist, 1890, pp. 56, 57.

II. NON-METALLIC MINERALS.

GRAPHITE—PLUMBAGO—BLACK LEAD.

Common in the crystalline rocks of the Highlands, disseminated sparingly in gneisses and white limestone.

Mine localities: Englemann's, near Peapack, in Morris county; Bloomingdale, Morris county; High Bridge, Hunterdon county; Pottersville, Morris county.

Other localities: Mendham, Chester, Morris county; Conover farm, near High Bridge, Hunterdon county.

REFERENCES: Geology of New Jersey, 1868, pp. 710, 711.
Ann. Rep. State Geologist, 1873, pp. 112, 113.
Ann. Rep. State Geologist, 1879, pp. 153–156.
Ann. Rep. State Geologist, 1880, p. 178.
Ann. Rep. State Geologist, 1883, pp. 167, 168.
Ann. Rep. State Geologist, 1885, pp. 107, 108.
Ann. Rep. State Geologist, 1889, pp. 64, 65.

COAL.

Coal has not been found in workable quantity in the State.

Thin seams of bituminous coal are known in the Triassic formation at Old Boonton, Morris county; Martinsville, Somerset county; near Pompton, Passaic county; and near Trenton.

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Shafts in search of coal have been put down at localities of dark-colored shales in the Kittatinny valley, as well as in the red sandstone district.

REFERENCES: Geology of New Jersey, 1868, pp. 174, 509, 511, 696.
Ann. Rep. State Geologist, 1888, pp. 27, 28.

LIGNITE—BROWN COAL.

Lignite is common in the Raritan formation, in Middlesex, Monmouth and Burlington counties. A bed was opened and worked near Jacksonville, Middlesex county, about thirty years ago. Pyrites occur generally with the lignite in these clay beds.

REFERENCE: Geology of New Jersey, 1868, pp. 696–698.

PEAT.

Extensive beds of peat are found in the northern part of the State. They are underlain in some places by calcareous or shell marl.

The peaty earth of the cedar swamps in the southern part of the State is properly classed under this head.

Attempts at the utilization of peat have been made at Allendale, Bergen county, and near Mountain View, in Morris county.

REFERENCE: Geology of New Jersey, 1868, pp. 236, 481–484, 698–700.

QUARTZ.

[See Sand, Sandstone, Infusorial Earth.]

GARNET.

Abundant at Franklin Furnace, also at many localities elsewhere in the Highlands, but not to workable extent.

REFERENCE: Final Report, 1889, Vol. II., Pt. 1, p. 11.

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ZIRCON.

Common in the Highlands. A notable locality is near Stockholm, Sussex county.

REFERENCES: Ann. Rep. State Geologist, 1889, pp. 58–61.
Final Report, 1889, Vol. II., Pt. 1, p. 22.

MICA.

Common in the crystalline schists of the Highlands as a mineralogical constituent of the rocks. Mines have been opened in the Scott's mountain range near Broadway, and in Harmony township north of Stewartsville, in Warren county. They are not worked.

REFERENCES: Ann. Rep. State Geologist, 1871, pp. 38–40.
Ann. Rep. State Geologist, 1872, p. 31.

ASBESTOS.

A long, fibrous variety occurs at the Roseville iron mine, Sussex county. Undeveloped.

REFERENCES: Geology of New Jersey, 1868, p. 630.
See also Catalogue of Minerals in Final Report, 1889.

TRIPOLITE—INFUSORIAL EARTH.

Large deposit at Drakeville, Morris county, which has been worked at irregular periods since 1872.

Also near Andover, Sussex county.

REFERENCES: Ann. Rep. State Geologist, 1874, pp. 54–56.
Ann. Rep. State Geologist, 1876, p. 56.

TALC.

Massive steatite or soapstone occurs in Marble mountain, north of Phillipsburg, Warren county. Opened and worked to some extent. Also on Jenny Jump mountain, near Great meadows.

Other localities of mineralogical importance only.

REFERENCE: Geology of New Jersey, 1868, pp. 319, 655.

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SERPENTINE.

In rock masses at Stevens Point, Hoboken. Associated with fibrous variety (chrysotile) at Montville, Morris county, and Wanaque, Passaic county. Mixed with dolomite in *ophiolite*, near Augusta and Branchville, Sussex county.

REFERENCE: Geology of New Jersey, 1868, pp. 128, 325.

KAOLINITE.

[See Clays.]

APATITE.

Hurdtown apatite mine, Morris county.

[See descriptive notes in Geology of New Jersey, 1868, pp. 603–606.]

Canfield phosphatic-iron mine, Ferro Monte, Morris county.

REFERENCES: Ann. Rep. State Geologist, 1871, pp. 34–38.
Catalogue of Minerals in Final Report, Vol. II., Pt. 1.

BARITE—BARYTES.

Barytes has been found in workable extent near Newton, Sussex county; near New Brunswick; and at Hopewell, in Mercer county. The Hopewell mine is the only mine in operation. Other localities are Feltville, Union county; and Lambertville, Hunterdon county.

REFERENCE: Geology of New Jersey, 1868, pp. 129, 224, 709.

CALCITE.

[See Limestones, Marbles and Shell Marls.]

MAGNESITE.

With serpentine, at Hoboken.

SIDERITE.

[See under Iron Ores.]

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III. Materials of Construction—Structural Materials.

GRANITE—GNEISS.

Granitic and gneissic rocks occur in the Highlands. Quarries have been opened near Pompton, at Bloomingdale and at Charlotteburg, in Passaic county; on Pochuck mountain near Franklin, and near the Cranberry reservoir, in Sussex county; at Port Murray and Washington, in Warren county; and in the vicinity of Dover, Morris county. Many other localities afford stone for local use only.

References: Geology of New Jersey, 1868, pp. 502, 503.
Ann. Rep. State Geologist, 1873, pp. 99, 100.
Ann. Rep. State Geologist, 1881, pp. 41, 42.
Ann. Rep. State Geologist, 1889, pp. 56–58.

MARBLE.

The crystalline limestone of the Highlands and Highland valleys affords, in places, a good marble, and there are quarries near Roseville and Andover, in Sussex county; at Upper Harmony, Marble mountain, and the "rose-crystal marble" quarry on Jenny Jump mountain near Danville, in Warren county. The variegated calcite and serpentine at Montville, Morris county, and at Augusta, in Sussex county, are notable localities, but not worked.

References: Geology of New Jersey, 1868, pp. 400–404.
Ann. Rep. State Geologist, 1872, pp. 26–28.
Ann. Rep. State Geologist, 1881, p. 42.

LIMESTONE.

The magnesian limestone of the Kittatinny valley and the valleys in the Highlands is quarried in many localities for local use in building. There are quarries near Deckertown, at Franklin and at Newton, in Sussex county; Washington, Oxford, Belvidere and Phillipsburg and other places in Warren county; Clinton, in Hunterdon county, and others in Morris and Somerset counties. For geographic limits of the limestone, see Geology of New Jersey, 1868, p. 90, *et seq.*, and pp. 513–515.

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The limestones of the upper Delaware valley, from Flatbrookville to Carpenter's Point, have not been used, except to a small extent for local construction.

SANDSTONE—FREESTONE.

The largest and most important sandstone quarries are in the red sandstone (Triassic) belt. Quarries have been opened at many places in Bergen, Passaic, Essex, Somerset, Middlesex, Hunterdon and Mercer counties. The more notable are Paterson, Little Falls, Belleville and Avondale, Newark, Orange, Washington Valley, Martinsville, Princeton, Wilburtha on the Delaware, Stockton and Milford.

REFERENCES: Geology of New Jersey, 1868, pp. 504-512, 515.
Ann. Rep. State Geologist, 1879, pp. 21-25.
Ann. Rep. State Geologist, 1881, pp. 42-60.
Ann. Rep. State Geologist, 1888, pp. 16-23.

CONGLOMERATE AND SANDSTONE.

The older sandstone and conglomerate (siliceous) formations in the Highlands, Kittatinny valley and Kittatinny mountain have not afforded much building stone. The Medina sandstone and Oneida conglomerate in the Kittatinny mountain are hard and difficult to dress, and are, therefore, not used, except for local use. In the Highlands valleys there are small quarries, which are worked occasionally at Franklin, Sussex county; Danville, Oxford Furnace, and near Washington, Warren county; and McCainsville, in Morris county.

The Green Pond mountain conglomerate has been quarried at one place on Kanouse mountain, Passaic county. Bowlders in Morris county have been used effectively in construction in Morristown and Boonton.

REFERENCES: Geology of New Jersey, 1868, pp, 303, 304.
Ann. Rep. State Geologist, 1872, pp. 28, 29.
Ann. Rep. State Geologist, 1881, p. 42.

In the southern part of the State the brown, iron-cemented sandstone is used for local construction. It occurs generally in the hilltops in the greensand marl belt.

REFERENCES: Geology of New Jersey, 1868, pp. 516, 517.
Ann. Rep. State Geologist, 1881, pp. 66-68.

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FLAGGING-STONE.

Quarries: Flagstone hill, Sussex county.
Bearfort mountain, Sussex county.
Milford, Hunterdon county.
Woodsville, Mercer county.

The Flagstone hill quarry is in the Hudson river slate formation. It has been worked extensively. The Milford quarries also have yielded a great deal of good stone. Some of the thin beds of the red sandstone formation at other localities have been used for flagging.

REFERENCES: Geology of New Jersey, 1868, pp. 520–523.
Ann. Rep. State Geologist, 1872, p. 30.
Ann. Rep. State Geologist, 1881, pp. 63–66.

SLATE.

The Hudson slate formation of the Kittatinny valley and of the valleys in the Highlands, has been worked at several localities in Sussex and Warren counties for roofing slate. The important quarries are near Lafayette and near Newton, and at the Delaware Water Gap.

REFERENCES: Geology of New Jersey, 1868, pp. 518, 519.
Ann. Rep. State Geologist, 1872, pp. 29, 30.
Ann. Rep. State Geologist, 1881, p. 66.

HYDRAULIC LIMESTONE—CEMENT ROCK.

The water-lime group is represented by limestones and shales in the Upper Delaware valley, and there are good sections at several places in Sussex county between Flatbrookville and the State line. It is undeveloped.

The calcareous shale, or shaly limestone, at Bonneville, near Phillipsburg, is the basis of a Portland cement works, the only one in the State.

REFERENCE: Geology of New Jersey, 1868, pp. 155, 156, 525–527.

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LIMESTONE FOR LIME.

Lime is made from limestones in the various limestone formations of the State, but almost exclusively in the northern part. There are quarries near Hamburg and McAfee, in Sussex county, which yield stone for lime for masonry purposes. Others do a more local business, while a far greater number afford lime for agricultural uses only.

REFERENCES: Geology of New Jersey, 1868, pp. 387–413.
Ann. Rep. State Geologist, 1872, pp. 38, 39.
Ann. Rep. State Geologist, 1873, pp. 105–109.
Ann. Rep. State Geologist, 1877, pp. 53, 54.
Ann. Rep. State Geologist, 1878, pp. 104, 105.
Ann. Rep. State Geologist, 1879, pp. 175, 176.
Ann. Rep. State Geologist, 1882, pp. 173, 174.

CLAYS.

Brick Clays.

Clays for brick-making are found in all of the counties, and bricks are made in all parts of the State. The plastic clays and clay marls have thick beds of clays and sands, which are adapted to brick-making, and worked extensively at Washington and Sayreville on the Raritan and South rivers, and at Cliffwood, Matawan and Union, in Monmouth county. There are yards at Kinkora and Fish House, on the Delaware river which use the same clays. There are many localities undeveloped.

The more recent geologic formations afford good brick earths at many localities. The most extensive brick works on them are at Hackensack and at Trenton. Other important localities are Newton, Sussex county; Singac and Mountain View, Passaic county; Flemington, Hunterdon county; Winslow, in Camden county; Vineland; Bridgeton, and Mays Landing.

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Clays for Terra Cotta—Tile—Hollow Brick.

These clays are dug at Maurer, near Perth Amboy, and along the Raritan river. They are found in the Raritan formation.

The surface clays found in many localities are available for brick and tile-making, and some of them for terra cotta.

Fire-Clays—Clays for Fire Brick—Refractory Clays.

The clays of the Raritan formation are in large part refractory and superior fire-clays. The Raritan river clay district is famous for its product. Large pits are worked at Woodbridge, Perth Amboy and on the north shore of the Raritan, and south of that river at Sayreville and South Amboy, in Middlesex county; along the Delaware river at Florence; Pensauken creek and Fish House, in Camden county; and Bridgeport and Billingsport, in Gloucester county.

In the northern part of the State, fire-clay has been discovered near Holland, in Hunterdon county.

Pipe clays have been found in the southeastern part of the State at Wheatland, and Union Clay Works, in Ocean county; Conrad, in Camden county.

Clays for Pottery.

The stoneware clay bed of the Raritan formation yields a large amount of clay. It is worked at Ernston and Morgan, in Middlesex county. The Raritan clay district of Middlesex county produces much fine potters' or ware clay. Extensive pits in vicinity of Woodbridge, on north shore of Raritan river, Sayreville, South Amboy.

Other localities of potters' clay are near Ten Mile run, Somerset county; Hamilton Square and Trenton, Florence, Pensauken creek, Fish House, Red Bank and Billingsport, on the Delaware river; Vineland, along Maurice river below Millville, Mays Landing, Egg Harbor City, Union Clay Works, all in central and southern parts of the State; Stewartsville, in Warren county, Bethlehem and Holland, in Hunterdon county, are localities in the crystalline schists in the northern part.

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REFERENCES: Report on Clay Deposits, 1878.
Ann. Rep. State Geologist, 1874, pp. 50–52.
Ann. Rep. State Geologist, 1875, p. 37.
Ann. Rep. State Geologist, 1878, pp. 48–69.
Ann. Rep. State Geologist, 1879, p. 157.
Ann. Rep. State Geologist, 1892, pp. 181–190.

SAND—GLASS SAND, FIRE SAND AND MOULDING SAND.

Glass Sand.

Sand for glass-making is dug extensively along Maurice river below Millville, near Williamstown and south of Bridgeton.

For full list of localities in southern part of the State, see Annual Report State Geologist, 1878, pages 70–80.

In the northern part of the State, sand was formerly obtained at Sand pond, on the Kittatinny mountain; also at Flanders, Morris county.

Fire Sand.

Large pits in the Raritan clay district, Middlesex county. Hylton's, on Pensauken creek, Camden county.

Moulding Sand.

South shore of Raritan river, Whitehead Brothers' pits; Chesquake creek, near Ernston, Middlesex county; Hylton's, Pensauken creek, Camden county.

REFERENCES: (Glass sand)—Geology of New Jersey, 1868, pp. 293, 294, 690–692.
Ann. Rep. State Geologist, 1873, p. 105.
Ann. Rep. State Geologist, 1878, pp. 70–80.
(Fire sand)—Report on Clay Deposits, 1878 (see Fire Sand).
(Moulding sand)—Geology of New Jersey, 1868, pp. 692, 693.

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ROAD MATERIALS—ROAD METAL.

Trap-Rock.

The trap-rocks afford excellent stone for both Telford and Macadam roads. The Palisade mountain and Bergen hill, Snake hill, Watchung mountains, Hook mountain, New Vernon trap hills, Long hill, Ten Mile Run mountain, Rocky hill, Pennington mountain, Bald Pate hill, Belle mountain, Sourland mountain, Round mountain, Cushetunk mountain and New Germantown trap hills afford inexhaustible supplies of trap-rock for the northeastern and north-central parts of the State. There are large quarries in Bergen hill; near Orange; Upper Montclair; near Rocky Hill; at Lambertville; and at Raven Rock, on Delaware river.

The trap rubbish on some of the steeper slopes of these hills affords material already broken. In the Upper Passaic valley the shore line of the old Lake Passaic has rolled trap-rock fragments available for road-building.

Conglomerates and Crystalline Rocks.

The quartzose conglomerate at Delaware Water Gap and the siliceous rocks at Gravel Hill, near Holland, are also notable localities for road material. The crystalline rocks of the Highlands are also adapted to road construction. The limestones and sandstones answer for some localities and for local use.

Yellow Gravel.

The widely-distributed yellow gravels in the southern part of the State are used largely for turnpike-building.

REFERENCES: Ann. Rep. State Geologist, 1871, pp. 40-43.
Ann. Rep. State Geologist, 1872, pp. 39, 40.
Ann. Rep. State Geologist, 1873, pp. 113-115.
(Trap-rock)—Ann. Rep. State Geologist, 1879, pp. 25, 26.
" Ann. Rep. State Geologist, 1881, pp. 60-63.
" Ann. Rep. State Geologist, 1882, pp. 43-66.
" Ann. Rep. State Geologist, 1888, pp. 32-38.

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FERTILIZERS.

Limestones and Limes.

Lime is made for agricultural use at many places in the limestone valleys of the northern part of the State. Generally kilns supply local or neighborhood markets only. The industry is declining. The largest centers of the lime business have been Peapack, in Somerset county; Clinton, in Hunterdon county; Carpenterville, in Warren county; and Hamburg and Stillwater, in Sussex county.

The calcareous member of the middle marl bed, or yellow limestone, has been used in Gloucester and Salem counties as a source of lime.

Along the coast, oyster shells are burned into lime.

REFERENCES: Geology of New Jersey, 1868, pp. 387-413.
Ann. Rep. State Geologist, 1871, pp. 43, 44.
Ann. Rep. State Geologist, 1873, pp. 105-109.
Ann. Rep, State Geologist, 1877, pp. 53, 54.
Ann. Rep. State Geologist, 1878, pp. 104, 105.

Calc Sinter—Travertine—Calc Tufa.

There are notable deposits of earthy and stony calcareous tufa in Sandiston township, Sussex county, at Dingman's Ferry and at Peters Valley. They are undeveloped.

REFERENCE: Geology of New Jersey, 1868, pp. 172, 479.

Greensand Marl—Glauconitic Marls.

Marls are dug in the greensand marl belt which stretches from Raritan bay across Monmouth, Ocean, Burlington, Camden, Gloucester and Salem counties to Delaware river. The use is local, almost exclusively, and there are openings on nearly every farm on the outcrop of the greensand beds.

Farmingdale, Pemberton, Vincentown, Kirkwood, Barnsboro (West Jersey Marl Co.) are localities whence marl is shipped by rail to outside territory.

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REFERENCES: Geology of New Jersey, 1868, pp. 258–282, 414–470.
Ann. Rep. State Geologist, 1873, pp. 109–112.
Ann. Rep. State Geologist, 1878, pp. 108, 109.
Ann. Rep. State Geologist, 1880, pp. 183, 184.
Ann. Rep. State Geologist, 1886, pp. 154–210.

Calcareous Marls—Shell Marls.

Shiloh, Cumberland county, is a locality of calcareous marls of Miocene age. The use is local and small, declining.

Shell marls in the northern part of the State occur under peat beds or on shores of ponds. The use in agriculture is experimental. For Portland cement these marls afford calcareous constituents in a fine, pulverulent condition.

REFERENCES: (Shell marls)—Geology of New Jersey, 1868, pp. 297, 298, 471–473.
Ann. Rep. State Geologist, 1877, pp. 22–30.

Peat—Muck.

[See references above under "Peat."]

As a fertilizer, the use is local and very limited in extent. The beds in the northern part of the State are large, and in some cases lie upon shell marl.

REFERENCES: Geology of New Jersey, 1868, pp. 481–486.
Ann. Rep. State Geologist, 1879, pp. 119, 120.

GEM STONES.

A number of minerals have been cut as curiosities, as willemite, prehnite, quartz, red and blue corundum, orthoclase, amethyst, agate, jasper, tourmaline, rhodonite, isopyre, greenockite, smithsonite, spinel (red and green), opal and pyrite. Willemite and amethyst are perhaps the only real gem stones.

REFERENCE: F. A. Canfield, List of Minerals, Vol. II., Pt. 1, Final Report State Geologist, 1889.

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MINERAL STATISTICS.

IRON ORE.

The statistics of iron ore for the year 1893 are: total output of the mines, as collected by John Birkinbine, of Philadelphia, special agent of the United States Geological Survey, division of Mining Statistics, and the total iron ore carried on the various railroad and canal lines from stations in the State and from New Jersey mines.

The total output of the mines amounted to 356,150 long tons, valued at $909,458. Of this total, 351,453 tons are magnetite, the remainder brown hematite and red hematite.*

The total shipments of iron ore from New Jersey stations, reported by railroad companies to this office, were 328,028 tons.

There is a falling off in the annual production of 109,305 tons, or 23 per cent., from that of 1892, and 169,462 tons, or nearly 48 per cent., from that of 1891, which was the largest yearly output since 1882, and the maximum in the decade 1882–1891. The rank of the State was ninth, having fallen from eighth in the iron-ore producing States in 1892.

The statistics of last year's report are reprinted, with the output for 1893 added to the table:

IRON ORE.

1790	10,000 tons	Morse's estimate.
1830	20,000 tons	Gordon's Gazetteer.
1855	100,000 tons	Dr. Kitchell's estimate.
1860	164,900 tons	U. S. census.
1864	226,000 tons	Annual Report State Geologist.
1867	275,067 tons	" " "
1870	362,636 tons	U. S. census.
1871	450,000 tons	Annual Report State Geologist.
1872	600,000 tons	" " "
1873	665,000 tons	" " "
1874	525,000 tons	" " "
1875	390,000 tons	" " "
1876	285,000 tons†	
1877	315,000 tons†	

* Through the courtesy of John Birkinbine, of Philadelphia.

† From statistics collected later.

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1878	409,674 tons	Annual Report State Geologist.
1879	488,028 tons	" " "
1880	745,000 tons	" " "
1881	737,052 tons	" " "
1882	932,762 tons	" " "
1883	521,416 tons	" " "
1884	393,710 tons	" " "
1885	330,000 tons	" " "
1886	500,501 tons	" " "
1887	547,889 tons	" " "
1888	447,738 tons	" " "
1889	482,169 tons	" " "
1890	552,996 tons	" " "
1891	551,358 tons	" " "
1892	465,455 tons	" " "

ZINC ORES.

The zinc ore mined in the State in 1893 amounted to 55,852 tons, as reported by the companies working the mines at Stirling Hill and at Franklin Furnace, in Sussex county.

The statistics for preceding years are reprinted:

1868	25,000 tons*	Annual Report State Geologist.
1871	22,000 tons	" " "
1873	17,500 tons	" " "
1874	13,500 tons	" " "
1878	14,467 tons	" " "
1879	21,937 tons	" " "
1880	28,311 tons	" " "
1881	49,178 tons	" " "
1882	40,138 tons	" " "
1883	56,085 tons	" " "
1884	40,094 tons	" " "
1885	38,526 tons	" " "
1886	43,877 tons	" " "
1887	50,220 tons	" " "
1888	46,377 tons	" " "
1889	56,154 tons	" " "
1890	49,618 tons	" " "
1891	76,032 tons	" " "
1892	77,298 tons	" " "

*Estimated for 1868 and 1871. Statistics for 1873 to 1890, inclusive, are from reports of the railway companies carrying the ores to market. The reports for 1890, 1891 and 1892 were from the companies working the mines.

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PUBLICATIONS OF THE SURVEY.

DISTRIBUTION OF PUBLICATIONS.

The demand for the publications of the Survey has in nowise diminished during the past year.

There is a steady call for the topographical maps. The sales during the last year amounted to $400.

It is the wish of the Board of Managers to complete, as far as possible, incomplete sets of the publications of the Survey, chiefly files of the Annual Reports, in public libraries, and librarians are urged to correspond with the State Geologist concerning this matter.

By the act of 1864 the Board of Managers of the Survey is a board of publication with power to issue and distribute the publications as they may be authorized. The Annual Reports of the State Geologist are printed by order of the Legislature as a part of the legislative documents. They are distributed largely by members of the two houses. Extra copies are supplied to the Board of Managers of the Geological Survey and the State Geologist, who distribute them to libraries and public institutions, and as far as possible, to any who may be interested in the subjects of which they treat. Several of the reports, notably those of 1868, 1873, 1876, 1879, 1880 and 1881, are out of print and can no longer be supplied by the office. The first volume of the Final Report, published in 1888, was mostly distributed during the following year, and the demand for it has been far beyond the supply. The first and second parts of the second volume have also been distributed to the citizens and schools of the State, and to others interested in the particular subjects of which they treat. The appended list makes brief mention of all the publications of the present Survey since its inception in 1864, with a statement of editions that are now out of print. The publications of the Survey are, as usual, distributed without further expense than that of transportation,

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except in a single instance of the maps, where a fee to cover the cost of paper and printing is charged as stated.

CATALOGUE OF PUBLICATIONS.

GEOLOGY OF NEW JERSEY, Newark, 1868. 8vo., xxiv.+899 pp. Out of print.

PORTFOLIO OF MAPS accompanying the same, as follows:

1. Azoic and paleozoic formations, including the iron-ore and limestone districts; colored. Scale, 2 miles to an inch.

2. Triassic formation, including the red sandstone and trap rocks of Central New Jersey; colored. Scale, 2 miles to an inch.

3. Cretaceous formation, including the greensand-marl beds; colored. Scale, 2 miles to an inch.

4. Tertiary and recent formations of Southern New Jersey; colored. Scale, 2 miles to an inch.

5. Map of a group of iron mines in Morris county; printed in two colors. Scale, 3 inches to 1 mile.

6. Map of the Ringwood iron mines; printed in two colors. Scale, 8 inches to 1 mile.

7. Map of Oxford Furnace iron-ore veins; colored. Scale, 8 inches to 1 mile.

8. Map of the zinc mines, Sussex county; colored. Scale, 8 inches to 1 mile.

A few copies are undistributed.

REPORT ON THE CLAY DEPOSITS of Woodbridge, South Amboy and other places in New Jersey, together with their uses for fire-brick, pottery, &c. Trenton, 1878, 8vo., viii.+381 pp., with map. Out of print.

A PRELIMINARY CATALOGUE of the Flora of New Jersey, compiled by N. L. Britton, Ph.D. New Brunswick, 1881, 8vo., xi.+233 pp. Out of print.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. I. Topography. Magnetism. Climate. Trenton, 1888, 8vo., xi.+439 pp. Very scarce.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. II. Part I. Mineralogy. Botany. Trenton, 1889, 8vo., x.+642 pp.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. II. Part II. Zoology. Trenton, 1890, 8vo., x.+824 pp.

BRACHIOPODA AND LAMELLIBRANCHIATA of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield, Trenton, 1886, quarto, pp. 338, plates XXXV. and map. (Paleontology, Vol. I.)

GASTEROPODA AND CEPHALOPODA of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield, Trenton, 1892, quarto, pp. 402, plates L. (Paleontology, Vol. II.)

ATLAS OF NEW JERSEY. The complete work is made up of twenty sheets, each twenty-seven by thirty-seven inches, including margin, intended to fold once across, making the leaves of the Atlas 18½ by 27 inches. The location and number of each map are given below. Those from 1 to 17 are on the scale of one mile to an inch.

No. 1. Kittatinny Valley and Mountain, from Hope to the State line.
No. 2. Southwestern Highlands, with the southwest part of Kittatinny valley.
No. 3. Central Highlands, including all of Morris county west of Boonton, and Sussex south and east of Newton.
No. 4. Northeastern Highlands, including the country lying between Deckertown, Dover, Paterson and Suffern.
No. 5. Vicinity of Flemington, from Somerville and Princeton westward to the Delaware.
No. 6. The Valley of the Passaic, with the country eastward to Newark and southward to the Raritan river.
No. 7. The Counties of Bergen, Hudson and Essex, with parts of Passaic and Union.
No. 8. Vicinity of Trenton, from New Brunswick to Bordentown.
No. 9. Monmouth Shore, with the interior from Metuchen to Lakewood.
No. 10. Vicinity of Salem, from Swedesboro and Bridgeton westward to the Delaware.
No. 11. Vicinity of Camden, to Burlington, Winslow, Elmer and Swedesboro.

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No. 12. Vicinity of Mount Holly, from Bordentown southward to Winslow and Woodmansie.
No. 13. Vicinity of Barnegat Bay, with the greater part of Ocean county.
No. 14. Vicinity of Bridgeton, from Allowaystown and Vineland southward to the Delaware bay shore.
No. 15. Southern Interior, the country lying between Atco, Millville and Egg Harbor City.
No. 16. Egg Harbor and Vicinity, including the Atlantic shore from Barnegat to Great Egg Harbor.
No. 17. Cape May, with the country westward to Maurice river.
No. 18. New Jersey State Map. Scale, 5 miles to an inch. Geographic.
No. 19. New Jersey Relief Map. Scale, 5 miles to the inch. Hypsometric.
No. 20. New Jersey Geological Map. Scale, 5 miles to the inch.

In order to meet the constantly increasing demand for these sheets, the Board of Managers of the Geological Survey have decided to allow them to be sold at the cost of paper and printing, for the uniform price of 25 cents per sheet, either singly or in lots. This amount covers all expense of postage or expressage, as the case may be. Sets of the sheets, bound in atlas form (half morocco, cloth sides, gilt title, maps mounted on muslin, and guarded), are furnished at $13.50 per copy. Application and payment, invariably in advance, should be made to Mr. Irving S. Upson, New Brunswick, N. J., who will give all orders prompt attention.

REPORT OF PROFESSOR GEORGE H. COOK upon the Geological Survey of New Jersey and its progress during the year 1863. Trenton, 1864, 8vo., 13 pp. Out of print.

THE ANNUAL REPORT of Prof. Geo. H. Cook, State Geologist, to His Excellency Joel Parker, President of the Board of Managers of the Geological Survey of New Jersey, for the year 1864. Trenton, 1865, 8vo., 24 pp. Out of print.

ANNUAL REPORT of Prof. Geo. H. Cook, State Geologist, to His Excellency Joel Parker, President of the Board of Managers of the Geological Survey of New Jersey, for the year 1865. Trenton, 1866, 8vo., 12 pp. Out of print.

ANNUAL REPORT of Prof. Geo. H. Cook, State Geologist, on the Geological Survey for the year 1866. Trenton, 1867, 8vo., 28 pp. Out of print.

REPORT OF THE STATE GEOLOGIST, Prof. Geo. H. Cook, for the year 1867. Trenton, 1868, 8vo., 28 pp. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1869. Trenton, 1870, 8vo., 57 pp., with maps.

ANNUAL REPORT of the State Geologist of New Jersey for 1870. New Brunswick, 1871, 8vo., 75 pp., with maps.

ANNUAL REPORT of the State Geologist of New Jersey for 1871. New Brunswick, 1872, 8vo., 46 pp., with maps.

ANNUAL REPORT of the State Geologist of New Jersey for 1872. Trenton, 1872, 8vo., 44 pp., with map. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1873. Trenton, 1874, 8vo., 128 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1874. Trenton, 1874, 8vo., 115 pp. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1875. Trenton, 1875, 8vo., 41 pp., with map.

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ANNUAL REPORT of the State Geologist of New Jersey for 1876. Trenton, 1876, 8vo., 56 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1877. Trenton, 1877, 8vo., 55 pp. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1878. Trenton, 1878, 8vo., 131 pp., with map. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1879. Trenton, 1879, 8vo., 199 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1880. Trenton, 1880, 8vo., 220 pp., with map. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1881. Trenton, 1881, 8vo., 87+107+xiv. pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1882. Camden, 1882, 8vo., 191 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1883. Camden, 1883, 8vo., 188 pp.

ANNUAL REPORT of the State Geologist of New Jersey for 1884. Trenton, 1884, 8vo., 168 pp., with maps.

ANNUAL REPORT of the State Geologist of New Jersey for 1885. Trenton, 1885, 8vo., 228 pp., with maps.

ANNUAL REPORT of the State Geologist of New Jersey for 1886. Trenton, 1887, 8vo., 254 pp., with maps.

ANNUAL REPORT of the State Geologist of New Jersey for 1887. Trenton, 1887, 8vo., 45 pp., with maps.

ANNUAL REPORT of the State Geologist of New Jersey for 1888. Camden, 1889, 8vo., 87 pp., with map.

ANNUAL REPORT of the State Geologist of New Jersey for 1889. Camden, 1889, 8vo., 112 pp., with cut.

ANNUAL REPORT of the State Geologist of New Jersey for 1890. Trenton, 1891, 8vo., 305 pp., with maps.

ANNUAL REPORT of the State Geologist of New Jersey for 1891. Trenton, 1892, 8vo., xii.+270 pp., with map and cuts.

ANNUAL REPORT of the State Geologist of New Jersey for 1892. Trenton, 1893, 8vo., x.+368 pp., with maps.

ANNUAL REPORT of the State Geologist of New Jersey for 1893. Trenton, 1894, 8vo., x.+452 pp., with maps.

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