XI.—*On the Geology of Richmond County, N. Y.*

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Read April 4th, 1881.

Richmond County, or Staten Island, is the most southeastern portion of the State of New York. It is bounded on the north by Newark Bay and the Kill von Kull; on the east by the Upper and Lower Bays of New York, and the Narrows; on the south by Raritan Bay, and on the west by Arthur Kill. The area thus enclosed by these bodies of water forms an irregular triangle, and according to the best authorities contains about fifty-nine square miles. Its population, as given by the census of 1880, is 38,994, or 661 per square mile. Its length is thirteen and one-half miles, and its breadth about seven miles.

Topography.—The surface of the county is decidedly rough. A range of hills, having an average height of over two hundred feet, extends from the northeastern extremity at New Brighton, through the central part of the island to the county-seat, Richmond. These hills are six miles long, vary from one and one-half to two and one-quarter miles wide, and are capped with magnesian rocks.

Another well-marked series of hills begins at the Narrows, and ranges westwardly until it meets the first mentioned ridge near Garretson's Station. It follows the course of this ridge as far as New Dorp, and there diverging from it runs in a southerly direction to Prince's Bay. Here these hills bend to the westward for a short distance, but again take a southerly course and end on the shore of Arthur Kill opposite Perth Amboy. This second series of hills is about one mile and a half wide, near the Narrows, and rises to a height of one hundred and fifteen feet in places, while between the Great-Kills and Prince's-Bay their width is as great as three miles, but they are seldom over seventy-five feet high. These elevations are composed of rounded bould

ers and pebbles, gravel, clay and sand,—with little or no order of arrangement,—which materials have been brought from the north and northwest by the great glacier which, in post-tertiary times, overspread North America south to about the fortieth parallel, and had its southern extension along the Atlantic coast on Staten Island. East of the Narrows, these hills form the backbone of Long Island; and west of Perth Amboy, they have been traced entirely across the State of New Jersey, and indeed all the way to Missouri and Kansas. They are what is known as the terminal moraine of the North American glacier.

East of the ridge of magnesian rock, and south of the moraine, we have some nearly level plains; these are well shown near New Dorp and Garretson's Stations, and again at the extreme southern end of the island. The surface is also quite level from New Springville to Mariners' Harbor.

Extensive areas of salt meadow occur along the Lower Bay near New Creek and the Great Kills, along Arthur Kill from Rossville to Port Richmond, and small patches near Tottenville.

There are no streams of very considerable size on Staten Island, but brooks and ponds are abundant. The largest of the latter is known as Silver Lake, and is situated high up on the magnesian hills, one mile and a half west of Stapleton.

According to the observations of Mr. Charles Ktgen, the total rainfall in inches for the last ten years, at Stapleton, has been as follows:—

1870 : 38.38	1873 : 53.09	1876 : 46.09	1879 : 47.16
1871 : 53.45	1874 : 49.68	1877 : 42.90	1880 : 37.34
1872 : 45.00	1875 : 45.00	1878 : 58.62	

Literature of the Subject.—The subject of the Geology of Richmond County has been considered principally by the following writers:—

W. B. Mather, in the "Geology of the First District of New York," refers to Staten Island in a number of different places. Mather considered the clays and sands of the southern part of the island to be of Tertiary age, and the magnesian rocks to be of igneous origin; both of which conclusions are now replaced by others, probably nearer the truth.

Issachar Cozzens, Jr.: "A Geological History of Manhattan or New York Island," N. Y., 1843. This book gives a section across Staten Island, and a description of the different formations found thereon.

Prof. Geo. H. Cook, in the "Geology of New Jersey," 1868, and in "Report on Clays," 1878, refers to the serpentine, trap-rock, sandstone and clays of Staten Island, and to the terminal glacial moraine crossing it.

Geology.—We have within the limits of our territory strata of Archæan, of Triassic, of Cretaceous, of Quaternary, and of Modern Eras; these will be considered in the order of their ages, beginning with the oldest.

ARCHÆAN STRATA.

Granitic Rocks.—True granite occurs on the shore of the Upper New York Bay, about four hundred feet southwest of the Tompkinsville steamboat landing, and directly in front of the old building known as Nautilus Hall. The surface of rock exposed at low tide is about eighty feet wide by fifty feet long; at high-water mark the rock disappears beneath a hill of drift some fifteen feet in thickness. A little more of the same rock is exposed at a point about two hundred feet south of the main outcrop; but everywhere else on Staten Island the granite is covered by newer formations. There is reason to believe, however, that it underlies the magnesian rocks, and extends in a belt of undetermined width all around the eastern edge of them, covered by the glacial drift and Cretaceous strata to an unknown depth; and that the same belt continues in a southwestwardly direction to Arthur Kill, and thence across the State of New Jersey to Trenton, where it again comes to the surface. The approximate position of this belt of metamorphic rocks is shown on the accompanying map (Plate XV).

At the exposure at Tompkinsville this granite is very coarsely crystalline in structure, and for that reason could never be satisfactorily employed for building purposes, even were it accessible in quantity. The feldspar is orthoclase, occurs in large masses, and is greatly in excess of the other two constituents; the quartz varies in color from dark brown to nearly white; what mica

there is, appears to be muscovite. In places, the last named mineral is absent, the rock being then a kind of pegmatite or graphic granite. No stratification is observable, but the surface of the rock outcrop dips about fifteen degrees to the east. Mather calls this granite primary, and to the best of our present knowledge it belongs to the oldest geological formation in North America.

Steatitic Rocks.—As before mentioned, magnesian rocks, serpentines, form the tops, at least, of the main series of hills on Staten Island. It is probable that this rock originally was of very considerable thickness, for a large amount must have been removed by erosion; but yet no granite nor gneiss, which are assumed to underlie it, has been seen in place within the serpentine area, which is estimated at about 13.5 square miles. The present thickness it is impossible to estimate accurately, but judging from the exposures, I should place it over one hundred feet.

The most eastern exposed boundary of the serpentine is clearly and unmistakably marked by a series of very sharp slopes, which are nearly continuous from Tompkinsville to Richmond, and in some places are as straight and regular as they could be constructed. This regularity of the slope seems to be quite characteristic of these hills, and is not the least element of their beauty. How far east of the foot of these hills the serpentine extends is not known, but it is probably not a great distance, as the granite at Tompkinsville occurs within a few hundred feet of it. The southern end of the ridge descends rather gradually, and near Richmond is lost under the Freshkill marshes. The western boundary of the formation, or more properly the eastern limit of the Triassic sandstone which rests upon it, cannot be accurately located, as there are no outcrops, and the line as drawn on the map must be considered as only approximately correct.

The magnesian rock varies in color from light green to nearly black, and in texture from compact to quite earthy—much of it being fibrous. Its specific gravity is about 2.55, and in chemical composition it is all a hydrated magnesian silicate. The best exposures are at several places around the base of Pavilion Hill at Tompkinsville; in cuttings for streets in the village of New

Brighton; near the school-house at Garretson's Station; on Meissner Avenue near Richmond, and near Egbertville. The highest point of the ridge is nearly opposite Garretson's Station, and about half-way across the hills, where the elevation, as measured by an aneroid barometer, is four hundred and twenty feet.

There are a number of interesting minerals associated with the serpentine rocks; the following species and varieties have been collected at Pavilion Hill, and in New Brighton:—Compact Serpentine, Fibrous Serpentine ("Amianthus," "Chrysotile"), Marmolito, Silvery Talc, Apple-green Talc, Gurhofite, Dolomite, Calcite, and Chromite. Pink Talc and Deweylito are reported by Prof. D. S. Martin, and Magnesite by Prof. Dana (*Mineralogy*, 1868, p. 774), as found on Staten Island. It is stated by Mather that magnesic hydrate (Brucite) occurs there, but none has been found recently. The fibrous variety of the serpentine has been very generally known as asbestos; this mineral, however, is properly a fibrous amphibole, and does not occur on Staten Island. These minerals must be regarded as products of metamorphism, and were formed during the period when this action was in progress.

The metamorphic rocks of Staten Island are apparently a southern continuation of those of Hoboken, N. J., and New York island; the facts from which this conclusion is drawn are as follows:

First.—The strike of the rocks is nearly the same at both places, and the direction of the Staten Island ridge would, if prolonged, meet the Hoboken exposure of serpentine at Castle Point.

Second.—The serpentine lies west of the granitic rocks at both places.

Third.—Although the texture of the serpentine at Hoboken and that of Staten Island is slightly different, yet their chemical composition and associated mineral species are very similar.

Fourth.—It is highly probable, though not proven, that the

serpentine at Tompkinsville overlies the granitic rocks as it does at Jersey City. This can only be definitely ascertained by borings, as the contact of the two rocks cannot be observed. We have the negative evidence, however, that were the serpentine *older* than the granite, the latter would probably be found in greater quantity, and in more localities than it really is. Hence the probability is that the two rocks have the same relative vertical position on Staten Island that they have at Jersey City; and they are so indicated on the accompanying maps and sections (Plates XV and XVI).

Fifth.—Ellis and Bedloe's Islands, in the Upper Bay, are directly between the two outcrops on the line of strike, and are said to be underlain by gneiss; but no very definite information is obtainable on this point.

As to the origin of the serpentine rocks, I have no new theory to advance, and consider the one which regards them as metamorphosed highly magnesian limestones to be more in accordance than any other with the facts as observed. The reasons for this opinion are as follows:—

First.—It is highly improbable that they were igneous in origin, because they contain about fourteen per cent. of water, are associated with gneissic rocks which we know are metamorphic, and are stratified,—although the stratification can only be distinguished at a few places, and there not very plainly, on account of the cleavage planes which cut the rock in all directions.

Second.—They are certainly not unchanged sediments, because there are no magnesian silicates known to be formed as sediments on such a large scale as these strata present; therefore they must be either metamorphosed sediments or metamorphosed metamorphic rocks.

Third.—These rocks could not have been sandstones or shales, because they would have become quartzites or feldspathic rocks by metamorphism; and while serpentine certainly is the result of the decomposition of hornblende in some cases, the extent of the formation on Staten Island would render this method of

formation very improbable; hence, by this method of reasoning, we have nothing but limestone to refer the original condition of these strata to.

Fourth.—In addition to these negative considerations, we have the direct positive evidence that strata of magnesian limestone gradually passing into serpentine have been observed (see Jukes' *Manual of Geology*, page 167), and that the presence of lime-minerals in the rock may be regarded as indicative of the former presence of greater quantities of calcic carbonate, which has been removed by the dissolving action of the metamorphosing waters, which doubtless held carbonic acid and silica in solution.

We may then outline the probable origin of these rocks in the following manner:—The strata now consisting of serpentine were deposited as highly magnesian limestones; by metamorphic agencies this material has been brought in contact with highly heated carbonic acid and silica-bearing solutions, which, by removing the greater part of the calcic carbonate, and altering the magnesian carbonate to a silicate, have left the rocks in the condition of hydrated magnesian silicates. During or at the close of this period of metamorphism, the eastern edges of the strata were tilted up, forming an anticlinal axis, while the extension of the formation to the westward was subsequently covered by the shale and sandstone deposited from the Triassic sea.

The true geological age of this belt of metamorphic rocks, which runs through Staten and New York Islands, extends far northward through the New England States, where it has a wide expansion, and has been traced southward as far as North Carolina, is not definitely known. There have been three principal theories advanced in regard to their antiquity; these are—

First.—That these rocks are of the same age as the Highlands of New Jersey and the Adirondack Mountains, or of Lower Laurentian age.

Second.—That they belong to the so-called Montalban system, one of the several divisions of the Upper Laurentian distinguished by Dr. T. S. Hunt and others.

Third.—The theory recently advanced by Prof. J. D. Dana (*Am. Jour. Sci.*, [III] Vol. XX, pp. 21, 194, 359, 450), in which he claims that they are of Lower Silurian age. My own opinion is, that they will ultimately be found to be Laurentian, and only another fold of the strata forming the New Jersey Highlands; but the object of this thesis is not to discuss this much-disputed point in American geology.

TRIASSIC FORMATION.

Strata of Triassic age extend over the parts of the county bounded by the assumed western edge of the serpentine rocks, the submerged gneissic belt, Arthur Kill and Newark Bay. This area contains about 14.5 square miles. The rocks consist of red ferruginous shales and sandstones, which dip to the northwest, and are broken through by a dike of diabase or trap-rock. They are in part the eastern extension of the Triassic strata which cover such a large portion of New Jersey.

Shales and Sandstones.—These rocks are exposed at but two places, to my knowledge, and there in but very small quantities. These are on Shooter's Island, at the mouth of Newark Bay, and on the adjacent shore, and were recorded by Mather. Here the strata consist of shaly red micaceous sandstone, differing in no essential particular from that so abundantly exposed in Eastern New Jersey.

No fossils have hitherto been found in these rocks on Staten Island, and the surfaces exposed are not sufficient to warrant any great expenditure of time or labor in search for them.

Diabase,—Trap-rock.—The diabase ridge that disappears beneath the Kill von Kull at Bergen Point, N. J., cuts through the red sandstone of Staten Island from Port Richmond to the Freshkill marshes, and appears as a long, low, round-backed hill, having a general strike of S. 40° W., thus being nearly parallel with the serpentine. Towards its southern end, its elevation is so little more than that of the sandstone that the position it occupies cannot well be distinguished. The length of this diabase outcrop is about five and three-quarter miles, and

its width, measuring from its assumed furthest eastern extension to where the sandstone covers it, averages less than one half mile. Both the eastern and western boundaries of this rock, however, are so obscured by drift that their exact positions cannot be determined, and the outcrop may be wider or narrower at any point than is indicated on the map.

The only places at which the diabase is exposed so as to be easily studied, are at and near the so-called "granite" quarries at Graniteville, and near Port Richmond. The rock is not a granite, but a coarsely crystalline diabase, mainly composed of augite and a triclinic feldspar, which is probably labradorite. It has been found in well-diggings within the area indicated on the map, in the water near the junction of the Fresh Kills and Arthur Kill at Linoleumville, and outcrops near Chelsea, on the road to Springville. It will be noticed that Linoleumville is just at the northern edge of the submerged Archæan belt, and near the junction of the Triassic and Cretaceous formations. The same relative position of the rocks may be seen where this trap-sheet again comes to the surface, as it does about six miles southwest of the city of New Brunswick, N. J. In fact the trap-dykes seem to shun the exposed Archæan rocks and cling closely to the Triassic, none being found outside of the red sandstone area.

The explanation of this curious fact is, as has long since been pointed out, that the strata composing the filling of the Triassic basin are weaker than a like amount of the metamorphic rocks surrounding it, and hence offer less resistance to the intrusion of trap-dykes, which consequently passed through the sedimentary rock rather than through the harder, stronger gneisses and granites which border it. Now, between the New Jersey Trias and that of the Connecticut Valley, we have a fold of these metamorphic gneisses and granites, but not a single trap outburst. This would seem to indicate that this fold existed before the deposition of the sandstone and the subsequent intrusion of the diabase, only very much higher than it is now; and hence it is improbable that these Triassic rocks ever covered the Archæan folded strata, forming a Triassic arch from New Jersey to Connecticut, as has been supposed by some geologists; for, we should expect, if the Archæan rocks had been folded *after*

the deposition of the sandstone upon them, and the latter rock subsequently removed by erosion, to find the intervening space between New Jersey and Connecticut cut by trap-dykes, while in fact none have yet been observed.*

CRETACEOUS FORMATION.

The Cretaceous formation, more or less covered by glacial and modified drift and salt meadows, extends through all parts of the county lying east and southeast of the Archæan rocks. The area underlain by it is therefore about 28.5 square miles.

The strata consist of beds of variously colored clays and sands, dipping slightly to the southeast, and having a general strike of about S. 45° W. They are a direct continuation of the "Plastic Clay" division of the Cretaceous, so named by the New Jersey geologists, and lie at the base of the formation in eastern North America.

South of the terminal glacial moraine, the strata are generally covered by a deposit of grayish-yellow sand and gravel of variable thickness, which is known as the Yellow Drift; this is only seen on Staten Island, in the vicinity of Tottenville, for the area southeast of the moraine near New Dorp and Garretson's is covered with modified drift, imperfectly stratified.

These Cretaceous strata of clay and sand in all probability extend eastward from Richmond County on to Long Island, and perhaps underlie the latter throughout nearly its entire extent. The clays are white, yellow, brown or black; they appear on the surface at a number of places, and the purer varieties have been extensively used in the manufacture of fire-brick, drain-pipe, gas-retorts, and other refractory ware.

White clays outcrop on the road just north of Rossville, at various places south of Rossville and near Kreischerville, along a stream near Prince's Bay; they have been noticed near Gifford's, and are said to occur at the bottom of a well near New Dorp. They will probably be found at other places.

* For a full discussion of this "Triassic Arch" question, see I. C. Russell, in *Annals of this Academy*, Vol. I, 1878, p. 220, and Vol. II, p. 27, 1880.

The white fire-clay is sometimes associated with the so-called "kaolin." This material, which is very incorrectly named, consists of a mixture of white quartz sand with small amounts of white mica and clay, and sometimes grains of feldspar; it is known as "kaolin" throughout the clay district of New Jersey, but of course is not a kaolin, as this term is only properly applied to clays formed by the decomposition of feldspathic rocks in place. An analysis of this substance taken from the pits of C. A. Campbell & Co., near Rossville, made in the laboratory of the Geological Survey of New Jersey, and published in their Report on Clays, 1878, is as follows:—

SiO ₂	92.70 per cent.
Al ₂ O ₃	5.70
H ₂ O	0.70
K ₂ O	0.35
	<hr/> 99.45 per cent.

From this association of "kaolin" and fire-clay, it is supposed that the pits hitherto opened on Staten Island belong to the South Amboy fire-clay bed. These excavations are all south of Rossville, and quite close together. Assuming that these clays do belong to this bed, then those which outcrop north of that village may indicate the position of the Woodbridge fire-clay bed, which lies north of the first-mentioned one in Middlesex Co., N. J. From its position, the clay near Prince's Bay will then belong to the South Amboy bed, and that at Gifford's to the Woodbridge bed. But these are merely suppositions. So far as is known, the strata immediately underlying Tottenville and the extreme southern end of the island consist of sands only, no clay having yet been dug in that vicinity.

The extension of this formation to the east is indicated by an outcrop of buff-colored clay on the shore of the Lower Bay, about one half-mile south of the Elm-Tree Lighthouse. It will be noticed that all the pits from which clay has been taken are in the region between Rossville and Kreischerville. This does not prove by any means that clay occurs only in that neighborhood; on the contrary, the probability is that the beds extend interruptedly across the county, but are deeply covered by the

drift-hills of the moraine, which cover all the territory assumed to be underlaid by the clays, except that portion where pits have been excavated, which is northwest of the moraine, the ice-sheet having flowed over, or perhaps partly around it.

Interstratified with, and overlying the clays and sands, there are found thin beds of Limonite iron ore of limited extent; this substance frequently cements the sand and gravel, and forms a conglomerate of variable coarseness. Hitherto this iron ore has not often been discovered in sufficient quantities or of sufficient purity to warrant its use in the manufacture of iron. Lignite and pyrites are frequently found in the clay excavations.

The former substance may also be seen on the shore of Arthur Kill near Rossville, and in a ravine a little northeast of the village, after slides of the banks occur: it is generally impregnated with the pyrites, and with copperas after exposure to the air. As the lignite dries, it cracks up into little pieces, thus destroying the texture of the fossil wood composing it, and making it very difficult to retain good specimens. No fossil leaves or shells have been taken from the clays of Staten Island, but it is not improbable that they will be found at some future time, when the excavations are more advanced than at present. They are more likely to be found in buff or dark colored clays than in fire-clay. The leaves are of great interest, as they represent the first appearance of angiospermous plants on the earth. Large quantities of them have been collected at South Amboy and other places in the clay district of New Jersey.

Origin of these Deposits.—As these beds are composed of fragments of quartz, mica and clay, or decomposed feldspar, it is evident that they are the products of the disintegration of gneissic or granitic rocks. That they have not been formed in place, but have been deposited from suspension in water, is proved by their stratification and by the assorted state of the materials composing them. That the waters which deposited the clays were fresh, is indicated by the absence of fossil marine organisms, and the presence of shells apparently allied to the modern fresh-water genera, in the clays of New Jersey.

There has been considerable discussion in regard to the position of the gneissic rocks; it would seem probable that the

metamorphic rocks already described as lying just northeast of the clays, have furnished some if not all of the material for their formation. These rocks lie immediately between the Triassic and Cretaceous, and were probably very much higher in those epochs than they are now, for they formed in part the southeastern boundary of the Triassic sea.

The decomposition of the gneiss would produce the materials composing the strata of sand and clay which were deposited in basins along the coast, the strata lying nearest to the rocks being first deposited.

Where the Cretaceous formation is not covered by glacial drift, there is now living on it a peculiarly southern vegetation. I have called attention to this fact in the Bulletin of the Torrey Botanical Club, VII, 81, by showing how the characteristically southern flora of the New Jersey pine-barrens extends into Richmond and Suffolk Counties, N. Y., but only on the sands of the Yellow Drift.

QUATERNARY EPOCH.

Glacial Drift.—Deposits of material brought from the north by the ice of the glacial epoch, are found over the greater part of Staten Island, but do not entirely overspread it.

The most southern terminal glacial moraine crosses Staten Island from the Narrows to Tottenville, and is distinctly marked by a continuous line of hills, the size and appearance of which have been already described. These hills mark the farthest southern extension of the ice-sheet, and the line along which the glacier deposited most of its burden of boulders, pebbles, sand and clay, which it had torn from the rocks in its southward journey. In many places these hills have the peculiar lenticular form which they assume on Long Island and in the Eastern States. The dotted line on the map extending westwardly from Clifton and ending at Tottenville, represents the most southern and eastern position of the boulder-drift on Staten Island, and has been quite accurately determined. The moraine has been partially removed by the wash of the waves from Prince's Bay northward to near the Great Kills, leaving a bluff of variable height.

The glacier moved across Staten Island in a south-southeasterly direction; this is proved by the markings on the trap-rock near Port Richmond, which have about that bearing; the surface of this rock is also smoothed like portions of the Palisades and Newark Mountains. There are no such markings on the serpentine rocks, because they are too soft to retain them; the ice extended over their whole extent, however, with the exception of a small area on Todt Hill, which is east of the moraine.

North and west of the morainal hills, the drift is not so abundant, rarely forming hills of any considerable size; but boulders are to be found over all this area, except where it is covered by newer formations, and the soil is often very clayey.

Diabase of various degrees of coarseness is the most abundant rock in the drift; this has been carried from the Palisades and the Newark Mountains, and probably in part from the trap-dyke on Staten Island itself, and is found over the whole drift area.

Gneiss of various kinds, largely syenitic, is perhaps the next most abundant rock, and occurs often in very large masses. One of these large boulders rests directly on the top of Fort Hill, New Brighton; another along a roadside near Pleasant Plains, and a third worthy of notice, in a field near Huguenot.

Moderately large boulders both of trap and gneiss abound on the moraine between the Narrows and Garretson's; the gneiss has come either from the New Jersey Highlands or from much farther northward, and perhaps in part from New York Island. Triassic red sandstone, carried from New Jersey or the north-western parts of the county, is often met with; a specimen impregnated with copper salts was obtained from the bluff at Prince's Bay. This locality has yielded many other interesting specimens illustrating the material brought by the glacier. Among these may be mentioned Potsdam sandstone, containing the borings of the worm *Scolithus linearis*; a number of rocks of Helderberg limestone, containing *Strophomena rhomboidalis*, *Strophodonta Beckii*, *Spirifer macropleura*, and other brachiopods, with quantities of crinoid stems; a specimen of granite containing graphite; a cherty rock which may belong to the Corniferous, and a conglomerate of uncertain age, but perhaps of the Oneida epoch.

A boulder of Hamilton limestone, containing *Spirifer mucronatus*, occurs near Richmond, and a rock containing *galena* was found in some excavations near New Brighton.

The ice-sheet passed entirely over the clay-beds of the Cretaceous formation in the vicinity of Rossville, apparently without deteriorating them to any great extent. At first sight, it would appear that these soft unconsolidated strata would have been greatly eroded and almost entirely removed down to the bed-rock, by such an immense mass of ice moving over them; but although some was undoubtedly carried away, the ice seems to have swept across the clays without cutting into them very much.

South and east of the dotted line on the map, already alluded to, boulders are almost entirely absent, being chiefly found in the beds of brooks, where they have been carried by water since glacial times, and are never very large.

Modified Drift, or material derived from the glacier, but more or less sorted and stratified by water, may be seen on the plains lying east of the moraine from near Gifford's to Clifton. The soil over this area is seen in well-diggings to be imperfectly stratified, and to consist of loam and sand, with few pebbles and fewer boulders.

On Todd Hill, near the moraine, there is quite an extensive deposit of gravel, colored yellow by oxide of iron, which may perhaps be referred to this formation; and deposits of sand, without clay, gravel or boulders, may be seen in a few places within the morainal area.

Occasionally some stratification may be seen in the morainal hills themselves, but these are generally very heterogeneous in composition. Modified drift also occurs in small quantities along the edge of the moraine near Tottenville. The true glacial drift is not thick in this vicinity, generally forming a mere mantle over the Cretaceous strata, and was probably deposited by a local projection of ice in advance of the main glacier.

Limonite Iron Ore.—The era of the formation of these deposits is only provisionally referred to the Quaternary. It is impossible to say how early their deposition began, but it was

probably long before the glacial epoch; we are only sure that they are more modern than the magnesian rocks which they rest upon, and older than the glacial drift, which overlies them in some places.

These beds of iron ore are found resting directly upon the serpentine or talcose rocks at a number of places; and where mining has been carried on, the localities are indicated on the map. All the deposits have the same general characteristics,—they are superficial, although sometimes covered by glacial drift to a variable depth. The ore consists of the hydrated sesquioxide of iron, Limonite, and is either compact or quite earthy in texture. All that I have examined gave a yellowish-brown streak; it is possible that there is some Hematite occurring with it, but I have never seen any ore from Staten Island which would give a red streak. The Limonite is associated with colorless, green, and red quartz; it has been extensively mined near Four Corners, at several places on Todt Hill and Richmond Terrace, and along the Clove Road, and is known to occur at other places on the serpentine hills.

The following analyses have been kindly furnished me by Mr. D. J. Tysen, Jr., who is interested in the mining industry.

(1) Ore from Todt Hill—

Fe, O,	67.50 per cent.
Mg O	1.90
Ca O	1.46
Al, O,	5.82
P	0.046
Mn	1.619
Si O,	10.80
H, O	7.73
Cr	3.00
Metallic iron.	- - 47.25 per cent.

The amount of Chromium is probably too high.

(2) Ore from near Four Corners—

(A) Fe, O,	79.27	(B) 76.72
Al, O,	1.20	0.96
Cr, O,	1.15	1.60
Mn, O,	0.32	0.64
Si O,	5.70	5.52
Ca O	tr.	tr.
Mg O	tr.	tr.
H, O	12.39	14.76
P	tr.	tr.
S	tr.	—
	<hr/>	<hr/>
	100.03	100.20

Metallic iron in (A), 55.49 pr. ct.

.. .. (B), 53.70 ..

These superficial deposits have probably had their origin in the deposition of the material composing them from the waters of thermal springs, which have come to the surface through crevices in the serpentine; the iron in the solutions was probably in the form of the carbonate, which on reaching the surface became oxidized by contact with the atmosphere, and was thrown out of solution and deposited as the hydrated sesquioxide, as we now find it. Magnetic iron sand occurs with the Limonite in one of the deposits on Todt Hill; this was probably washed in mechanically while the hydrated oxide was being deposited from solution.

The deposits vary from a few inches up to twelve feet, or even more, in thickness; their lateral extent is limited to a few hundred feet in any direction. The Todt Hill mines are the only ones wholly uncovered by glacial drift, being east of the moraine.

Æolian or Blown Sand.—Extensive deposits of light-colored sand, similar in character to those found so abundantly on Bergen Neck, N. J., occur along the edges of the salt meadows on the western side of the Island; from Mariners' Harbor to near Chelsea Landing, sometimes extending to a distance of one-half

or three-quarters of a mile on the upland, and thus occupying a position between the trap-dyke and the salt meadows. The material is a fine, yellowish, loamy sand, containing no gravel or pebbles, but rests on the glacial drift, and is hence of post-glacial age. This sand was once the western beach of the extensive body of salt water which formerly occupied the basin now filled with the salt-marsh deposits, and which extended over all the Newark and Hackensack Meadows, but has now been reduced to the area of Newark Bay. The sands of this old beach were blown inland, and formed into dunes by the generally prevailing westerly winds; on a windy day the manner of the formation of these dunes may still be plainly seen. A number of pine-barren plants have found lodging in this sandy soil, on both Staten Island and Bergen Neck, and it is probable that others will be found there on further exploration.

MODERN EPOCH.

Under this heading are included deposits whose formation began at a comparatively recent period, and whose growth still continues.

Marine Alluvium or Salt Meadows.—These deposits extend over an area of about nine and one-half square miles on Staten Island. The material composing them consists for the most part of partially decomposed vegetable matter, mixed with a little clay and sand. These salt-meadow areas have formerly been shallow bays, which have gradually been filled up, first by the deposit of silt from their waters and the growth of marine plants, and ultimately by the growth and decay of grasses and rushes. This latter process is yet in operation, and thus the salt meadows keep at about the level of the highest tides; their most abundant grass is the *Spartina juncea*, Willd.; while the rush is *Juncus Gerardi*, Lam., commonly known as "black grass." A number of other plants contribute small amounts to the vegetable growth, making the salt-meadow flora quite a varied one.

The most extensive areas covered by these deposits are along New Creek and the Great Kills, on the eastern shore, and from

Rossville northward along Arthur Kill. The thickness of the marshes is exceedingly variable, probably as much as thirty feet in some places, and but a few inches in others. The dried material consists of decaying fibres, mixed with a little clay, sand, and oxide of iron; the latter substance produces the iridescent film commonly seen in the marshes, and popularly supposed to be oil.

Sand Beaches and Points.—Sand beaches occur along all the shores that are directly exposed to the waves; the greatest accumulation of sand is on the shore of the Lower Bay from Clifton southward to the so-called Point of the Beach, near Gifford's, at Seguin's Point, near Prince's Bay, and at Ward's Point, Tottenville. The point near Gifford's is slowly lengthening and curving in toward the shore; a similar point is in process of formation at the mouth of New Creek; and the accumulation of sand at Ward's Point is quite great. These points are produced by the combined action of the currents of the Lower Bay and the streams flowing into it, which carry the sand along the coast until finally it is driven up on the beaches by the waves.

Sands composed of magnetic iron ore occur with the quartz sand, and are generally found in layers of a fraction of an inch in thickness; but an accumulation of this material to a depth of four inches has recently been found at low water on the beach near the Elm Tree Lighthouse, and has excited some attention as a possible iron ore, but it contains titanium, and is not likely to have any economic importance. All the sands have originally resulted from the disintegration of rocks, and have been carried by water down the rivers emptying into the bays, and also resulted in part from the direct disintegration of the coasts.

Peat Swamps.—True peat occurs in but few places on Staten Island. Some is found in the Clove Lake Swamps, in several swamps near Richmond and Gifford's, and towards Tottenville. In one locality near Richmond, the peat deposit is at least ten feet thick. The salt-marsh deposits may be regarded as a kind of peat, but their vegetable matter comes principally from

grasses and rushes, while true peat results from the growth and decomposition of mosses.

Encroachment of the Lower Bay.—The entire southeastern shore of Staten Island is gradually being washed away, and hence receding to the westward. In some places the loss is very apparent. At the foot of New Dorp Lane, near where the Elm Tree Lighthouse is now situated, a large American elm was standing not longer ago than the year 1840. The place where this tree grew is now beyond the end of a dock which extends some four hundred feet from the shore. This indicates a loss of four hundred feet in forty years, or an average of ten feet per year. At Cedar Grove, half a mile south of this point, there has been a loss of about three hundred and thirty feet since 1850, or about the same average. At Prince's Bay, the Government has been obliged to build a heavy sea-wall in front of the bluff on which the lighthouse is placed,—and a like precaution has been taken at the forts on the Narrows.

Now there are two causes operating to effect these results; they are (1) the constant abrading action of the waves and currents, and (2) the gradual depression of the coasts. From the course of the currents in the Lower Bay, the eroded material, together with part of that brought down by the rivers, is carried southwardly along this coast, the sands deposited as beaches, bars and points, while the finer muddy part is carried farther, and finally deposited in the deeper waters of the Bay or in the ocean.

It has been the custom to save property from this very serious loss by building bulkheads filled with stone, some hundreds of feet outward from the shore at the southern end of the land to be protected. These bulkheads act to break the force of the sand-bearing current flowing along the shore; and this check to the motion of the water, causes it to deposit its burden on the north side of the dock. The waves soon drive the sand up on shore, and land is actually made in this manner. It is probably the cheapest and most effective way of protecting property on this coast.

The second cause which is in operation, and which, although very much slower, is perhaps surer to submerge much valuable

land, is the gradual sinking of the coast. Prof. George H. Cook has estimated the depression of the shores of New Jersey and Long Island at about two feet per century; others have thought it somewhat less, but all are agreed that there is a subsidence going on. It will be seen that if our coast settles down to ten feet below its present level, the greater part of the plains extending south of the moraine from Giffords to Clifton, now the most valuable farming land in the county, will be covered with salt meadows within a few hundred years; provided that they are not all washed away before by the action of the currents. For a full discussion of this subject see *Geology of New Jersey*, 1868, pp. 343-374.

ECONOMIC GEOLOGY.

(1) *Iron Ore*.—The Limonite ore of Todt Hill, Four Corners, and other places, has been used in blast furnaces in connection with other more refractory ores, or has been screened, ground and washed, to produce red ochre paint. The total amount hitherto mined may be as great as 250,000 tons, and the present production is about 20,000 tons per year.

(2) *Fire Clay*.—The character of the deposits of this substance has already been described. Messrs. Kreischer and Sons have a large factory at Kreischerville, and produce refractory ware valued at over \$50,000 annually. Their supply of clay is partially drawn from Woodbridge, N. J.

(3) *Brick Clay*.—Clays of glacial drift origin are used in the manufacture of common brick near Richmond and Linoleumville. The number of bricks annually produced has not been definitely ascertained, but it probably amounts to several millions.

(4) *Trap Rock*.—Quarries of this rock have been worked at Graniteville and near Port Richmond for many years. The rock is either cut into blocks and shipped to New York to be used for street pavements, or crushed into small pieces and employed in MacAdam or Telford pavements on Staten Island. Some edifices have been constructed of this rock, but it is not well suited for building purposes.

(5) *Serpentine Rock*.—The compact variety has not yet been used for any economic purpose; it is too soft and weak to be used for building; it might be employed in the manufacture of magnesian salts, or for some purposes where refractory materials are required.

The fibrous serpentine, erroneously called asbestos, has been mined near Tompkinsville Landing to the extent of 25 or 30 tons, and used for the purposes for which asbestos is employed.

(6) *Beach Sands*.—Thousands of tons of this material are annually taken from the southeastern coast, and used in New York and Brooklyn for building. In some places so much sand has been removed that property along the shore has been seriously damaged, by exposing roads and meadows to the action of the waves.

(7) *Peat* has never been used as a fuel to any extent on Staten Island, and has little economic value.

(8) *Gravel* occurs extensively along the beaches, and at the locality already noted on Todt Hill. It is valuable as a road-making material, where only light traffic is employed.

ARCHÆOLOGY.

Implements used by the aborigines have been found abundantly on the sands of the Cretaceous near Tottenville, in association with scattered oyster-shells. These Indians are supposed to have belonged to the Delaware nation; they visited the sea-coast at certain seasons, and oysters appear to have been a prominent article of food with them. These shell-heaps are found much more extensively on the sand-hills between South Amboy and Keyport, New Jersey, and hence most of the Indians are supposed to have remained there, while a few crossed to Staten Island. The stone implements have also been found at other places in the county, but nowhere so abundantly as at Tottenville. Mr. W. S. Page, of that place, has a collection of 4 stone hammers, 2 pestles, 5 spear-heads, 15 arrow-heads and 12 flint chips,—nearly all picked up in his garden. Others have found similar implements in the same neighborhood. Mr. Arthur Hollick, of Port Richmond, has two stone hammers, three spear-heads, and seven arrow-heads, found in various parts of the county.

GEOLOGICAL SECTIONS ACROSS STATEN ISLAND.

BY N. L. BRITTON.