GAUSSOIN

MEMOIR ON THE ISLAND OF NAVASSA

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ON

THE ISLAND OF NAVASSA,

(WEST INDIES.)

BY EUGENE GAUSSOIN,

MINING ENGINEER AND METALLURGIST.

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MEMOIR ON THE ISLAND OF NAVASSA.

To the Corporation of the

Navassa Phosphate Company of New York:

WALTER E. LAWTON, ESQ., *Treasurer.*

SIRS:

I beg leave to present you my memoir on the Island of Navassa, property of your Company.

The vast importance of the interests involved in this concern, the scientific questions connected with it, and their bearing on the development of agricultural wealth, will, I hope, be considered as an apology for the length of this paper.

With great respect,

Sirs,

Your most obed't serv't,

EUG. GAUSSOIN.

BALTIMORE, *May,* 1866.

MEMOIR.

I.—Introduction.

On the 8th of November, 1865, with the Vice President of the Navassa Phosphate Company, John C. Grafflin, Esq., I sailed from Baltimore in the Company's Brig Romance, Captain P. Duncan, to visit the Island of Navassa.

The objects of our visit were manifold.

All the different departments of the management of the Island had to be investigated for the introduction of such ameliorations that might be found useful to the general interests of the concern.

To the Vice President, Mr. Grafflin, it belongs to give to the officers of the Company, on the Island, what credit they deserve for their services.

As it was to be expected from the relative short space of time elapsed since the organization of the Company in September, 1864, many improvements were required for a more effective and economical working of the property.

The storage of provisions and culinary arrangements; the distillation of salt water; the erection of convenient buildings for residence and offices of the Superintendent and Medical Officer; for workshops, stores, and railroad sheds; the railroad construction and equipment; the enlarging and building of wharf facilities; the boating by lighters and other points of minor importance have already been the subject of propositions which have been approved and sanctioned by the action of the Company.

The pressing necessity of enlarging the facilities for working and shipping were most evident during the six weeks we spent on the Island. From four to six vessels were constantly and at the same time in the harbor. During that time two ships, three barks, six brigs, and three schooners were loaded and left with full cargoes. This activity has been increasing since we left, requiring a corresponding increase in the number of the laborers, and in all the other branches of the service. To-day the population on the Island consists of 30 white men, officers and mechanics, and 180 black laborers.

After the payment of two semi-annual dividends, out of the earnings of the Company during the first year of its existence, a sum of fifty thousand dollars has been appropriated to carry our propositions into immediate execution.

This large investment of capital will at once, and without injurious delays, allow the Company to follow in the development of its property, the continually rising demand for this most valuable fertilizer, the Phosphatic Guano or Phosphate of Lime found in such vast deposits on the Island of Navassa, situated in the Caribbean Sea, 18° 25′ North latitude, and 75° 5′ longitude West of Greenwich; 33 miles South-west of Hayti, and 72 miles East of Jamaica.

It is an upraised coral Island, with all the cavities in the rock filled with Phosphate of Lime.

All questions connected with the geological character of this formation have such a bearing on the economy of the works, and the real value of the property, that I could not ignore their importance. In recording in the present paper my incomplete observations and the result of my studies, I can but express my deep regret at my want of ability for treating a subject so interesting in its scientific speculations, and so vital to the interests of agriculture.

Fully aware of the importance for the progress of Natural Sciences, of collecting the largest possible number of facts, to elicit more perfect theories, I have endeavored to record in this paper the facts which, at Navassa, came under my observation. They are mostly a confirmation of the conclusions of the eminent geologists, Sir Ch. Lyell, J. D. Dana, Ch. Darwin, R. J. Nelson, and others who have, during the last years, so minutely described, and so satisfactorily explained the wonders of those immense structures in course of building, in the tropical seas, under our eyes by agglomerations of minute coral zoophytes.

I will not entirely have missed my object, if I have succeeded in attracting the scientific attention to this most interesting field of observations presented at the Island of Navassa, or if, from the discussion of the principles established by those great observers, I have deducted some application useful to the development and economy of practical works.

II.—Description of the Island.

Rising abruptly from the depth of the sea, without sand beach, the lower rocky bluff of the Island of Navassa stands conspicuous as a perpendicular wall. Its foot incessantly battered by the waves which have undermined in it a deep cut, several feet high, would necessarily tumble down if it was not protected against further erosion by a fringing reef of living corals, forming a breaker several feet wide, very distinct from the white limestone of the bluff by its dull red color, shining under the emerald green waves.

A man could easily walk around the whole Island, following the foot of the bluff on the flat top of this reef, if the sea did not break constantly over it, and roll at many points into deep recesses, where the air, compressed by the rush of the waves, soon dilates again, and blows off with great violence the water in a fine spray, covering the surface of the sea, for a distance of several yards, with a snowy foam.

Those "air holes" are important records for the history of the elevation of the Island.

On the summit of this first bluff, forming a terrace, varying from a few chains to about half a mile in width, rises a second bluff, less abrupt. The rocks successively rolling down from its sides, have in some places formed a declivity of about 45°, when in other places its summit still stands nearly perpendicular. The top of this second bluff forms the summit of the Island where it is designated as the "Upper Flat," when the first terrace is called the "Lower Flat."

This upper summit is at the highest point 310 feet above the level of the sea, inclining from south-east to northwest. Heavily timbered by gum and palm trees, it is intersected by several reefs forming annular depressions filled by deposits of Phosphate of Lime, which I will describe hereafter.

Those reefs present a very rough surface; rugous, pointed and in many places seem to be long piles of rocks, broken and heaped by the action of the waves; when in other places they are solid, and form continuous undulations, varying much in direction but not in form, which has always a tendency to be ring-like. This annular disposition is the most remarkable at the north-western extremity of the Island, where the vegetation has been destroyed for the digging of the Phosphate; there the edges of the bluff towards the sea, and the reef traversing the summit assume the form of a basin depressed towards its centre, in the shape of ellipse, the great axis being about a mile long, and the small axis not quite half a mile.

The whole summit of the Island itself has a similar shape, the form of an atoll. All around it, the edges of the upper bluff are raised in the shape of an immense brim, followed at variable distance by a second elevation of the same character, inclosing between the two, a depression where the vegetation grows more luxuriantly between the irregular masses of limestone, with all its cavities filled by Phosphate of Lime.

Many caves or holes of different sizes are found on this upper summit of the Island, principally near those reefs that I have just described. The deepest that I visited was 45 feet deep perpendicularly, forming an irregular room of about 30 feet diameter. The bottom was covered by a deep deposit of Phosphate, probably carried down by the flow of the rains, and increasing rapidly. I base my supposition on the rapid increase of the deposits in those caves on the fact that although they present many stalactites, no stalagmites are found except in some crevices where the water drips down above the actual level of the Phosphate. Those crystallizations, although generally made of Carbonate of Lime as usual, sometimes present strips of Phosphate in their layers of successive deposition.

Except at the north point of the Island, where the bluff descends without interruption down to the sea, all this upper structure is encircled by the terrace or shore platform. The height of this terrace, from an elevation of only 15 to 20 feet above the level of the sea at its extremity west of North Point, rises at Lulu Bay, the shipping point of the Island, to 60 feet; at the south-eastern end to 65 feet; and on the north side forms a low rocky beach, in some places sloping down to the level of the sea, till it terminates against the north side of the cliff of North Point.

The lithological character of this shore platform and of the top of the Island are similar. The edges above the sea also present the form of a brim; the surface is intersected by several reefs running with the same irregularity, and all the cavities in the masses of limestone are filled with the Phosphate of Lime.

The limestone is hard, compact, clinks under the hammer, and takes a polish like a secondary white marble.

Nevertheless, in breaking some of those hard masses, I found in the interior, in several instances, small blue specks of Phosphate of Iron, and more commonly nests of Phosphate of Lime. This intermixture of Carbonate and Phosphate of Lime is also found in the corals now built by the Zoophites; and I even found a mass of coral entirely made of Phosphate of Lime, a pseudomorph of the ordinary Carbonate of Lime of the corals. I found again a very interesting specimen of this intermixture of corals made of Carbonate and Phosphate of Lime, in the interior of a small sponge taken from the sea.

Everywhere on the two flats, and on the sides of the Island, are found on the surface of the limestone the forms of corals, mostly of the species astrœas and madreporas. I may say that at every place that I have examined, there is hardly a space of a few yards square where those marks are not found more or less obliterated, showing evidently the organic origin of the limestone. In breaking some pieces of limestone from the reefs, I found cavities filled with branches of coral. It is well to say that those marks of corals are not found on the rocks forming the brim of the upper and lower bluffs. There the limestone is smooth as if polished by the action of the waves.

It is important to remark here that the Island of Navassa having been, as it seems, upraised from the depth of the sea, without beach, no sand or debris of shells have been accumulated by the joint action of the winds and waves, to fill and cement the cavities existing between the branches or masses of coral rock. Those cavities which might be described by every word conveying the meaning of hollowness, run from the top to the bottom of the Island through the different strata, and the openings so left have become the recipients of the deposits of Phosphate of Lime.

In masses of rock, of such confused shapes, the lines of stratification are, of course, very obscure; still they may be traced plainly enough in several places on the perpendicular wall of the shore platform, and of the summit, to show the successive formation of the different strata on the top of each other. The vertical cracks or fissures formed by the contraction of the rocks, under the constant heat of the tropics, are always more irregular in shape, and shorter than the lines of horizontal stratification, and by a careful observer cannot be mistaken.

This horizontal stratification, in places favorable for observation, seems to dip with an angle of a few degrees towards the centre of the Island.

Like all the limestones of coral origin, the Navassa rock is not abundant in fossils. I could only collect two pectens from the upper flat, and a bivalve found in breaking a mass of limestone in the diggings of the lower flat. I have submitted those fossils, and other specimens for determination, to Professor F. V. Hayden, of the University of Pennsylvania, and thankfully quote here his letter on the subject:

DEAR SIR:—I have examined with some care the specimens which you left with me, from the Island of Navassa, W. I., and I find them all of recent origin, geologically speaking. They affirm to my mind what you expressed to me as your own conviction, that Navassa is one of those coral reefs which are still now in process of formation along the Florida Coast, and many portions of the West Indies. The corals and the shells, a chama and pectens, are all identical with species living in those seas at this time. The white limestone is very interesting as throwing light on the manner in which the old limestones of the Palœozoic ages grew to their enormous thickness and extent.

Yours respectfully,

F. V. HAYDEN.

To EUG. GAUSSOIN, ESQ.,
Baltimore, Md.

III.—ELEVATED CORAL ISLANDS.

Having thus described the form of the Island of Navassa, and the character of the rock which constitutes its whole frame, in comparing it with other upraised coral Islands, my object is not only to remove all possible doubt as to its origin, but from identity of forms, general likeness and peculiarities, to arrive to some conclusions of economical importance for its "exploitation."

In his book on coral reefs and Islands, our celebrated geologist, James D. Dana, gives the following description of Metia or Aurora Island, one of the Western Paumotas group in the Pacific Ocean.

"It is a small Island about four miles by two and a half in width, and 250 feet in height, and consists throughout of coral limestone. On approaching it from the north-east, its high vertical cliffs were supposed to be basaltic, and had much resemblance to the palisades of the Hudson. This appearance of a vertical structure was afterwards traced to vertical furrowings by the waters dripping down its front and the consequent formation of stalagmitic incrustations. Deep caverns were also seen.

"The cliff, though vertical in some places, is roughly sloping in others, and on the west side the surface of the Island gradually declines to the sea.

"The rock was found to be a white and solid limestone, seldom presenting any traces of its coral origin.

"In some few layers there were disseminated corals looking like imbedded fossils along with beautiful casts of shells, but for the most part it was as compact as any secondary marble, and as uniform in texture. Occasionally there were disseminated spots of crystallized calc-spar.

"The surface of the Island is singularly rough, owing to the erosion of rains.

"The shores at the first elevation of the Island must have been worn away by the sea, and the cliff and some isolated pinnacles of coral rock still standing on the west are evidence of degradation. But at present there is a wide shore platform of coral reef, 200 to 250 feet wide, resembling that of the low coral Islands, and having growing coral, as usual, about the margin and in the shallow depth beyond."

After this description, showing such a striking resemblance between Aurora and Navassa, amongst several other similar Islands met in the Pacific, it will be sufficient for my object to quote the following:

Mangaia, nearly 300 feet high, has a level summit, and is surrounded by a terrace like plain, at about the height of 100 feet. It is formed of coral rock with some fine ground basalt in the interior. In the central hollow of the upraised reef there are many scattered patches of coral rock.

Rurutu has an elevated coral reef 150 feet in height.

Vavau, the northern of the group of the Tonga Islands, made of coral limestone, 30 to 100 feet in height, has precipitous cliffs with many excavations along the coast.

Savage Island, a little to the east of the Tonga group, resembles Vavau in its constitution and cavernous cliffs, and is elevated 100 feet.

The cliffs of Elizabeth Island are 80 feet high, and from the description of Capt. Beechey, appear to consist of a homogeneous coral rock.

From the above quotations it will be seen that like Navassa, those other elevated coral Islands most generally do not exceed 300 feet in height.

Like at Navassa the cliffs, vertical in some parts, slope roughly in others, and on one side of the Island, gradually decline to the sea.

The rock, a white and solid limestone, seldom presenting any traces of its coral origin, still contains accidentally imbedded corals.

Like at Navassa, the surface of those Islands is singularly rough.

Finally Navassa, like the other elevated coral Islands, presents this most singular peculiarity, the shore platform, rising above the level of the sea as a vertical cliff; at Navassa, from fifteen to sixty feet high, till on the Northern side of the Island it gradually declines to the sea, forming a low rocky beach.

The deep indentation that I have described at the foot of the lower bluff of Navassa, is a fact in confirmation of the theory of J. D. Dana, on the formation of the shore platform of the elevated coral Islands, when he says that the existence of this platform, apparently so peculiar, is due to the simple action of the sea, and is a necessary result of this action. Passing to New Holland from the coral Islands of the tropics, he found there the same structure exemplified along the sandstone cliffs, in most places one hundred or more feet in height. There is a layer of sandstone rock lying like the shore platform of a coral Island near low tide level, and from fifty to one hundred and fifty yards in width. It is continuous with the bottom layer of the cliff, the rocks which once covered it having been removed by the sea.

The erosion of the foot of the shore platform bluff at Navassa, and the enlargement of the fringing reef, cornice like, now building by living corals, would reproduce the same phenomenon, if a new elevation of the Island would take place; but as it is, its incipient form seems to be a very strong argument in favor of Dana's theory of the origin of the shore platform.

The Island of Navassa, as we have demonstrated by its lithoological characters, and resemblance of form with other similar Islands, being an elevated coral Island; with Darwin, we must admit that to rise to its actual height it had to subside and be elevated several times, as it is a fact well known that corals do not build above the level of the sea.

I did not remain at Navassa a sufficient length of time to allow me to make the minute observations that would be necessary to ascertain the different periods of elevation and subsidence, but some old air-holes, found below the summit of the Upper Cliff on the north side of the Island show plainly that the rocks now at an elevation of about 300 feet, were once on a level with the sea, and probably records of the same kind would be found lower down if the rocks, that have tumbled down against the Upper Cliff, were removed.

Also the works now in progress at Navassa, to remove the Phosphate, will probably, in the course of time, show the differences existing between the strata built at different periods; although to-day all the surface rock of the Island seems to be homogeneous by its long exposure to the same atmospheric influences. The regularity and horizontality of the stratification at Navassa also precludes the supposition of any volcanic action in the elevation of the Island, or of any violent convulsion during the earthquakes which have so often desolated the two neighboring Islands of Jamaica and Hayti. The absence of all traces of extraordinary disturbance would lead us to admit periods of gradual subsidence and elevation, which will require for demonstration a more complete study of the geology of the West Indies Islands.

Having arrived to the conclusion that Navassa is an elevated coral Island, I had to examine the question, if in such formation there was hope to find a supply of fresh water for the use of the officers and operatives of the Company. Up to the present time the necessary water had to be imported, or distilled at great cost from the sea water.

The existence on the south side of the Island of a cave containing, after rain, a beautiful sheet of fresh water, and called by the operatives the "spring" cave, gave me the hope to find a place where I would be justified, with some chance of success, to advise the boring of a well. But the horizontality of the stratification, the formation of the limestone full of irregular cavities of all sizes and shapes, and my remark, during an excursion of examination in a row boat around the Island, that there was a stratum very near the surface of the sea, from which the water dropped in many places, leaving dark spots, showing the spongious character of the rock, left me little hope of the existence of an underground water level of sufficient importance for any economical purpose.

After those observations I felt disposed to abandon entirely the idea of boring for fresh water, and merely advised to turn into a cistern, by some masonry work, the spring cave, in view of saving all the rain water falling through this opening to the sea, a quantity sometimes considerable after heavy rains. But with every step that I made towards the conclusion, that Navassa was a coral Island, I felt that I should not give up the hope of finding fresh water, as we may expect to find the same phenomena in identical geological formations.

REMARK.

While reading the proof-sheets of this memoir, I have received a very elaborate paper on the geology of the Key of Sombrero, West Indies, by Alexis A. Julien, Esq., Assistant in the School of Mines, Columbia College, published in the Annals of the Lyceum of Natural History, of New York, Vol. viii, April, 1866, Nos. 8, 9 and 10. The many analogies between the geological formation and deposits of Phosphatic Guano of Navassa and Sombrero are very remarkable. I entertain little doubt that the interesting observations of Mr. J. on the successive periods of subsidence and elevation at Sombrero, will find new and strong arguments in favor of his scientific views when the development of the diggings, or more complete observations than mine, will allow a more complete discrimination between the different strata of Navassa.

IV.—Research for Fresh Water.

J. D. Dana states that in coral islands water is to be found commonly in sufficient quantity for the use of the natives, although the land is so low and flat. They dig wells five to ten feet deep in many points of the dry islets and generally obtain a constant supply. These wells are sometimes fenced around with special care, and the houses of the villagers, as at Fakauto, are often clustered about them. On Aratica (Carlshoff) there is a watering place 50 feet in diameter, from which several hundred gallons may be obtained in a few hours.

The Tarawan Islands are generally provided with a supply sufficient for bathing.

On Taritari there is a long trench or canal several miles long and eight feet deep. These islands have been elevated a little above the sea, but are not over 15 feet above the sea.

Kotzebue states that in the interior of Oldia, one of the Marshall Islands, there is a lake of sweet water, and in Tabual a marshy ground exists. There is no want of fresh water in the largest islands ; it rises in abundance in pits dug for the purpose.

The only source of this water, says Dana, is the rain which percolating through the loose surface settles upon the hardened rock that forms the basis of the island ; as the rock is white or nearly so, it receives the heat but slowly, and there is consequently but little vaporization of the water that is once absorbed.

What may be my deference for the opinions of so eminent an authority as Prof. J. D. Dana, I must say that I cannot accept this explanation for the presence of fresh water on the coral islands, considering the nature of such formation so full of cavities of every size through which the fresh water percolates with all facility to the level of the sea. By far more rational seems to be the explanation of this same phenomenon by R. J. Nelson, who by several years of residence in the West Indies had a full opportunity to observe and study this important fact.

R. J. Nelson in his memoir on the geology of the Bermudas, states that fresh water may be had in nearly all parts of the islands, provided the bottom of the well is not sunk under the level of low tide.

Generally speaking it is deemed prudent to be contented with twelve or eighteen inches of water, rather than incur the risk of rendering the well brackish, since from the porous nature of the rock the salt water always filtrates through it.

At the Naval Wells where large quantities of water are required for shipping, it is only taken between the half flood and half ebb, to avoid the brackish quality of water drawn at improper seasons, for all the wells on the sea coast are affected by the tide, and more or less so those at a distance from it.

Again, Nelson in his memoir on the Bahamas, has recorded his observations relative to the occurrence of fresh water in those islands, and says: It appears that from the universally porous character of the constituent rock, all the rain that falls passes directly down, percolating through it to nearly the sea level. Here it meets with a body of salt water that permeates the lower portions of the rocky structure, and from its lighter specific gravity the fresh water floats upon the sea water, rising and falling with the tide, not contemporaneously at all points, but at a time peculiar to each spot, according to its distance from the sea, and the more or less porous condition of the intervening stone.

In digging wells, therefore, the shaft is not carried lower down after the first appearance of the "spring" than is necessary to give room for the bucket, so that the salt water may not follow the fresh water into the well. Both salt and fresh water may thus be most certainly met with by sinking a pit at any spot or in any variety of the rock; from the dense kind in the large islands to the mere isolated sand bank, such as at the southwest of Memory rock and Little Bahama Bank, where the wells are mere pits in the sand, a few feet deep.

This explanation of Nelson seems the more conclusive, seconded as it is by the repetition of the same fact in so many distant coral islands. It is well known, and some very simple experiments will convince every one, that with proper attention and patience in the absence of all agitation, a liquid of less specific gravity may be deposited on the top of another one of more gravity, and when the first sheet has been successfully deposited, the thickness of the lighter liquid may be increased with less care; the two liquids remaining unmixed for a length of time, a drop of the upper liquid may then easily be sucked through a hollow tube. On a large scale the operation becomes more easy, and we may readily understand how it is successfully enacted in the deep recesses formed by the coral rock, where a lasting tranquillity opposes the mixture of the fresh and salt water, when the rain water percolating in minute drops, gently settles on the top of the sea brine.

Therefore the existence of this porous stratum of lime rock near the level of the sea, that I considered at first as an objection to the existence of a fresh water level, probably has a most important part to play, by being, as it were, an immense filter through which the rain water slowly drips on the top of the sea water, contributing more effectively to this separation of the two liquids, which explains so satisfactorily the presence of fresh water on coral islands.

Consequently the researches for fresh water on the coral islands must be directed by principles entirely different from those in other geological formations, and may be undertaken on the Island of Navassa with justifiable expectations of success.

Besides the general features that I have described at some length on account of their great importance, several local facts point out at Navassa where the first trials ought to be commenced with the most probable success.

The existence of many caves or holes through which the rain water evidently passes to the lower levels, and the existence of the water cave or "spring" to which I have alluded before, are points near which the first diggings ought to be done. This water cave is found on a line of depressions passing through the shore platform and corresponding with other depressions on the summit of the Island. On this course at the foot of the upper cliff, the first well ought to be started.

This experiment, if successful, will be of so much importance to the Island, and the source of so great an economy and comfort; in case of failure would not be without much advantage to the interests involved. Through this well it would be possible to pump the water running and lost to-day through the water cave; besides this boring, if properly conducted, would be most important for the confirmation of my views of the structure of the Island, the character and depth of the deposits of the Phosphate, and consequently for the best system of working the diggings. For these reasons I most earnestly recommend this trial so important as a scientific and more so as an economical question.

V.—Deposits of Phosphates.

All the cavities of the coral rock forming the frame work of the Island of Navassa are filled by deposits of Phosphate of lime.

Those cavities are of every form and size, their opening and depth varying from a few inches to several feet. I cannot convey a better idea of this formation than by saying that it resembles an immense group of coral branches, in which all the interstices have been filled by those deposits.

Their origin explains itself by the presence on the Island of innumerable quantities of sea birds, Boobies and Frigates, and a species of large lizards, the Iguanas, not less numerous.

The dung and bones of those birds and lizards accumulated for centuries have formed those immense deposits.

In my excursions on the Island, I never stopped at any place without finding a quantity of debris of bones of those animals; sometimes collecting from a square yard a handful of pieces of bones. As it should be expected, the last debris generally consists of the hardest parts of the bones of the Iguanas, such as the maxillary, and the large bones of the birds; the small bones having been first decomposed. How from such sources those immense deposits have been formed, may be accounted for by the circumstance that there is on the Island no animal of genera, carnivora or rodentia, few insects, and consequently no cause for the destruction of bones.

Their dissolution progresses under the most favorable conditions, accelerated by the fermentation of the dung, which is rapid in a hot climate, under the alternating influence of the heavy dews of the night and the intense heat of the day.

The putrefaction which takes place causes copious and continuous emanations of carbonic acid, and since it has been ascertained by numerous experiments that the solubility of phosphate of lime depends upon the presence of carbonic acid in water, the conversion of those accumulations of bones and dung into basic and neutral phosphate of lime may readily be accounted for.

It is on a large scale the conversion of bones into apatite, a fact already noticed by Girardin and Preissner, who state that bones buried in the earth under the influence of putrefaction are converted into basic and neutral phosphate of lime, which crystallizes upon the surface and in the interior of the bones in small prisms identical with apatite.

Up to the present time no crystals of the phosphate of lime have been found at Navassa, perhaps because the diggings have not been carried yet at a depth beyond the action of atmospheric influences, which may have disturbed the conditions favorable to crystallization, or it may be because no crystallization has been possible during the rapidity of its formation in such large masses of animal matter in putrefaction.

The same causes may explain why no fossil bones have yet been found in the deposits of phosphates.

During this process, so favorable to the expulsion of the gasifiable matters, the ammonia of the dung has been evaporated or washed away, and the phosphatic parts only of the animal excrements left to increase the deposit.

The stalactites of phosphate of lime found at the Island of Ascension in contact with guano, illustrate this transformation.

This formation still going on under our eyes does not require any supposition to explain the simplicity of its process, and would not be contradicted even if, in deeper diggings, it was found, as on the Sombrero Island, that extinct animals, such as land turtles, have been contributors to this vast mass of organic detritus. The globular forms of the grains of phosphates forming the great bulk of this deposit may also be accounted for by the regularity with which the undisturbed decomposition takes place.

Securely nestled in the large cavities of the coral rock against the action of the winds or other causes of disturbance, the spherical form of the grains is the result of the quietness of those recesses.

The largest part of the deposits consists of those loose spherical grains varying from the size of a mustard seed to a buckshot.

Like in the formation of many sand stones, those grains agglomerate in lumps cemented together by water carrying in solution carbonate of lime, and by the continuous action of the heat of the climate, become mineralized, undergoing a true metamorphism. In places favorably situated the whole mass has become indurated, the oolitic rock thus formed having sometimes the hardness of Feldspar.

This process of cementation was beautifully demonstrated on several heaps of fine phosphate left for some years standing at a place called Brownstone, from where the first shipments were made from the Island. There I found in many places a hard crust one or two inches thick, presenting already all the appearance and nearly the hardness of the phosphatic rock, the analysis showing that carbonate of lime was the cementing substance.

This mode of formation is also exemplified by the fact that the sides of nearly all the cavities, from which the phosphates have been extracted, are coated with a crust of the hardest phosphate, evidently cemented there more rapidly by the water washing the carbonate of lime, and by the heat more intense on this white rock.

In the process of cementation the carbonate of lime dissolved by the rain water containing carbonic acid permeates through the globuliform grains of the phosphate, and by the action of heat, the water being evaporated, leaves the cementing substance to aggregate those grains and run them into rock, subsequently hardened by the action of the constant elevated temperature of the tropics; a double process of mineralization and metamorphism of recent masses of organic substances. The presence of iron and alumina in those deposits as phosphates, and of the oxide of iron as coloring substance, may easily be accounted for.

It is known that in the inorganic structures of marine animals there is some iron. Herberges found, in Spongia Ursa, 6 to 8 per cent. of protoxide, and in the red corals, about one per cent. of peroxide is present. Although made principally of carbonate of lime, the corals contain a small proportion, besides other substances, of alumina and oxide of iron, which must be found also in the limestone rock made by corals.

VI.—Character and Composition of the Phosphate.

The result of this formation is a mineral found principally in loose spherical grains mixed with a large quantity of lumps, the result of the accidental agglomeration of the original grains. Those lumps are generally richer in phosphate of lime than the grains; and the hard rock, resulting from the same cementing process on a still larger scale, is also superior in its contents in phosphates.

Numerous analyses of several cargoes quoted in the appendix to this memoir, give the contents, in bone phosphate of lime, of the phosphates shipped from the Island for commercial purposes. They show the superiority of the Navassa over the phosphatic guanos of other Islands of the West Indies. This purity results probably from the absence of a sand beach and the elevation of the Island, which prevents the sands being carried on the deposits by the winds. Near the surface, the soil now in course of formation by the decay of the vegetation, has sometimes to be removed in digging, and, to a certain point, lowers the value of the phosphate, but in depth the quality always improves, being there more protected against foreign mixtures. Generally the cargoes shipped from Navassa have been found to contain over 60 per cent. of bone phosphate.

In the process of cementation it seems also that foreign substances are carried away, and the following analysis gives the composition of the hard phosphatic rock made by the agglomeration of large globules of phosphate of lime, of a light buff color. This analysis was made by Dr. G. A. Liebig, who, after visiting the Island of Navassa, has been mainly instrumental by his report and chemical labors in bringing to the public notice the true value of the Navassa deposits. It is composed of

Water at 160° C	1.49
Organic Matter	0.43
Silica and Sand	1.38
Oxide of Iron of Alumina	3.94
Lime	50.22
Carbonic Acid	2.21
Phosphoric Acid	39.88
Loss	.45
	100.00

Leaving the oxide of iron as merely accidental, the percentage found corresponds well with the formula.

Carbonate of Lime........................ ....5.02
$CO_2$2.21. CaO2.81.
Phosphate of Lime...... ....87.48
$PO_5$40.07. CaO47.41.

In the absence of any crystal of phosphate of lime of Navassa, my object in giving the result of this analysis of a selected specimen has been to show the composition of this substance in a state of purity about as perfect as found up to the present time.

The importance of the result of this analysis will be understood from the fact that the quantity of this hard rock increases in depth under the double action of the cementing process and of the pressure of the superincumbent matter. Also after the removal of the phosphates from the cavities of the rock, the hard crust of rich phosphate adhering to the limestone by the action of the atmospheric influences crumbles down and fills anew the cavities. In many places where the phosphates have been extracted only a few years ago by the first owner of the Island, the holes are already half filled up by this disintegration, probably increased, to some degree, by stuff carried down from higher places by the flow of rain water.

VII.—Extent of the Deposits.

In my description of the Island I have remarked that no signs could be found of violent disturbances during its periods of subsidence and elevation. On the shore platform or on the summit of the Island the limestone has the same appearance, and its cavities present the same fantastic irregularities. Everywhere where it is possible to observe it, the stratification has the same regular horizontality. In sailing around the Island, the lowest beds above the level of the sea present themselves as a compact rock made of carbonate of lime, with, I would have said, large veins of solid phosphate, if by using the word *vein* I did not fear to convey a wrong idea of this intermixture of the two rocks. The inferior strata of the Island being evidently the oldest, the intermixture of the two varieties of rock—the carbonate and phosphate of lime—shows that the formation of the phosphates has been going on since the Island was first elevated above the level of the sea, or at least that the cavities in the limestone have been filled to the lowest stratum, and probably below the level of the sea, to the depth where the coral zoophytes commenced their structure.

Besides the evidences before our eyes at Navassa, this supposition is justified by analogy with the formation of the Island of Sombrero, where they dig now by blasting under the level of the sea, a phosphate bearing a close resemblance to the Navassa phosphate. The difference with the Island of Sombrero is, that being of less elevation than Navassa, no arenaceous phosphate is found there, as it must have been washed out by the sea. The same thing exists on the low beach at Navassa, where by the washing of the waves, only the hard phosphate is left.

Of the early formation of the phosphate we have also abundant proof in breaking the limestone in the diggings of the shore platform, a relatively ancient part of the Island, where phosphate of lime, and sometimes blue specks of phosphate of iron, are found imbedded in the hard limestone, as I have stated before.

From the homogeneous character of the rock from the top to the bottom of the Island, and the facts to which I have just alluded, we may safely conclude that the depth of the deposits reaches the lowest part of the coral limestone, and the lowest parts being probably the hardest, the richness of the phosphate will increase with the depth.

Up to the present time, the phosphates shipped from Navassa have been dug out only from a few acres on the summit of the Island and on the shore platform, without blasting. The deepest cavities from which the phosphates have been extracted seldom exceed twenty feet, the whole average depth being not more than ten feet. During my presence on the Island, I gave great attention to discover some system or regularity in the disposition of the cavities containing the phosphates, but was every day more convinced of their absolute want of system.

With that conclusion before me, the deposits to be worked out by the actual mode of labor being extensive enough to last a great number of years, I could not advise to resort to blasting as a systematic way of working, but to use blasts only when it would be found useful to increase the size of a cavity to give easier room to the laborer in digging out the phosphate. By doing so, in many places the deposits will be followed to a great depth with more advantage, without much increase of expense, and the field of operations will eventually be enlarged by deeper workings.

From one acre of land, not quite worked out, at an average depth of about ten feet, during the time we spent on the Island, about 4,000 tons of phosphates were shipped. As I have remarked, all the cavities of the coral rock are filled with the deposits, and where the phosphates are not visible at the surface, it is because they are covered up by the piles of stones of the reefs, or the loose rocks that have tumbled down from the cliffs.

These facts and what I have just said of the depth of the deposits, will leave no doubt of the existence at Navassa of an almost inexhaustible deposit of the richest Phosphatic Guano.

VIII.—Concluding Remarks.

In another publication, "the Island of Navassa illustrated" from my sketches, a topographical map and five views complete the description of the general features and appearance of the Island. In this Memoir I have endeavored by a discussion of its topographical, lithological and geological characters to demonstrate its economical importance.

Its formation as an elevated coral island has been first discussed.

The characters of those islands, so interesting to the progress of natural sciences, have but recently been the object of study and publications of eminent geologists, and the record of all facts bearing on this subject is still needed to confirm or perfect the theories of those great observers.

The facts elicited at Navassa will be found valuable, as bearing on the following questions of so great interest to geology:

The formation of hard compact limestone in modern ages, and still going on under our eyes, by the work of zoophites.

Additional proof of the phenomena of subsidence and elevation of lands; the regularity and horizontality of the strata at Navassa, and the absence of traces of all violent disturbances, showing that such elevation may have taken place, as Sir Ch. Lyell and other geologists have demonstrated in other cases, without volcanic action.

The soundings made around the Island by Capt. E. K. Cooper, of Baltimore, (who first discovered the existence there of phosphatic guano, and was the owner of the Island before the organization of the present company,) prove anew that elevations may be formed under the level of the sea by the action of currents and the accumulation of sands to afford a foundation to the construction of the corals, other than submerged volcanic peaks. These soundings establish that all around the Island there are the following depths, commencing at Lulu Bay, on the southwest side of the Island, and found on circumferences:

At a distance of one-half mile	13, 14, 14, 20, 20	fathoms.
" one mile	14, 13, 15	"
" two miles	15, 12, 15, 50, 50	"

Those depths indicate that the rocks of Navassa are built on an elevation, with a gentle declivity, the formation of which does not require for its explanation, volcanic action; but may have been formed, as an island in the bed of a river, by the action of the currents in the channel between the older islands of Hayti and Jamaica.

The description of Navassa shows its uniformity of character with the other islands of the same origin; presenting the same remarkable peculiarities of a shore platform and numerous caves.

As a consequence of those analogies, results the probability of finding fresh water by digging wells, a discovery of so much economical importance for the working of those vast deposits of phosphatic guanos.

The formation of those deposits of phosphates of lime originating from organic matters modified, indurated and mineralized by the protracted action of atmospheric influences, show how mineral masses have been formed by the accumulation of organic matters, as exemplified by the microscopic researches of Ehrenberg and others.

From the mode of formation of Navassa, and the facts that I have mentioned, there is good ground to admit that the deposition of phosphate has been going on since the Island was elevated above the level of the sea, filling all the cavities of the coralline limestone. This leads to the conclusion, in my opinion, that those deposits are of great depth, increasing in value by their freedom of foreign matters as it was announced by Dr. G. A. Liebig, in his report on the Island, and subsequently demonstrated by his numerous analyses and chemical studies of the Navassa guano.

G. Bischof, in his treatise on Chemical Geology, has said:

"There is perhaps no instance in which the influence of organized structure upon minerals is shown to a greater extent than in the circulation of phosphoric acid. Plants are the true collectors of this acid. They increase its quantity in uncultivated soils where the subsoil contains phosphates, or where those salts are supplied by water."

This remarkable action of the plants on the collection of phosphoric acid proves its importance for the life of vegetation, and the consequent necessity to supply it from other sources when exhausted by crops. It explains also the lasting benefit to the amelioration of soils afforded by the appliance of phosphatic fertilizers; all parts of this indispensable substance, the phosphoric acid, being collected by the organism of vegetation.

Many times in passing over the celebrated battle field of Waterloo during the summer months, more than thirty years after the bloody conflict, I had occasion to remark vast clusters of luxuriant wheat, rising high above the common level, showing by its height, its vivid color, the strength of the straw, the length and weight of the heads, the places where large accumulations of human or other bones deeply buried beneath the soil, did supply year after year by their successive decomposition, the soluble phosphoric acid absorbed, and I might say sucked by the plants.

So lasting must be the influence on the crops of the fertilizers manufactured with the Navassa phosphate after the early and powerful action of the soluble phosphoric acid, resulting of the partial conversion of the phosphate into super-phosphate has been exhausted.

This action of the phosphoric acid, aided by the addition of a due and limited proportion of ammoniacal salts, cannot be over estimated for fertilizing purposes, and the economical importance of the deposits of Navassa, so interesting as a field of scientific observations, will be readily understood by the rare occurrence of so valuable a material in extensive mineral deposits.

However large may become the profits accruing to the Navassa Phosphate Company by the working of so valuable a property, none will be more legitimate, none will be better justified by corresponding returns of agricultural wealth.

APPENDIX.

The following analyses of samples from different cargoes of the Navassa Phosphatic Guano will show its average composition :

CARGO BY SHIP ISLAND LIGHT,

Analyzed by Prof. Way & Evans, of London, England.

Moisture	1.00
Organic Matter	8.70
Sand	2.20
Carbonate of Lime	4.40
Phosphate of Lime	74.70
Oxide Iron, Alumina, &c	9.00
	100.00

DRY SAMPLE OF SAME CARGO,

By Dr. Aug. Voelker, of London, England.

Moisture and Inorganic Matter	9.42
Tribasic Phosphate of Lime	62.82
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Carbonate of Lime	4.63
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Alumina	8.89
Silica	1.52
Phosphoric Acid in combination with Iron and Alumina	5.53
Phosphoric Acid with Magnesia	.37
	100.00

N. B.—The whole of the Phosphoric Acid, amounting to 34.70 is equal to 75.75 Bone Phosphate of Lime.

Like in the formation of many sand stones, those grains agglomerate in lumps cemented together by water carrying in solution carbonate of lime, and by the continuous action of the heat of the climate, become mineralized, undergoing a true metamorphism. In places favorably situated the whole mass has become indurated, the oolitic rock thus formed having sometimes the hardness of Feldspar.

This process of cementation was beautifully demonstrated on several heaps of fine phosphate left for some years standing at a place called Brownstone, from where the first shipments were made from the Island. There I found in many places a hard crust one or two inches thick, presenting already all the appearance and nearly the hardness of the phosphatic rock, the analysis showing that carbonate of lime was the cementing substance.

This mode of formation is also exemplified by the fact that the sides of nearly all the cavities, from which the phosphates have been extracted, are coated with a crust of the hardest phosphate, evidently cemented there more rapidly by the water washing the carbonate of lime, and by the heat more intense on this white rock.

In the process of cementation the carbonate of lime dissolved by the rain water containing carbonic acid permeates through the globuliform grains of the phosphate, and by the action of heat, the water being evaporated, leaves the cementing substance to aggregate those grains and run them into rock, subsequently hardened by the action of the constant elevated temperature of the tropics; a double process of mineralization and metamorphism of recent masses of organic substances. The presence of iron and alumina in those deposits as phosphates, and of the oxide of iron as coloring substance, may easily be accounted for.

It is known that in the inorganic structures of marine animals there is some iron. Herberges found, in Spongia Ursa, 6 to 8 per cent. of protoxide, and in the red corals, about one per cent. of peroxide is present. Although made principally of carbonate of lime, the corals contain a small proportion, besides other substances, of alumina and oxide of iron, which must be found also in the limestone rock made by corals.

VI.—Character and Composition of the Phosphate.

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Analyzed by Prof. Way & Evans, of London, England.

Moisture	1.00
Organic Matter	8.70
Sand	2.20
Carbonate of Lime	4.40
Phosphate of Lime	74.70
Oxide Iron, Alumina, &c	9.00
	100.00

DRY SAMPLE OF SAME CARGO,

By Dr. Aug. Voelker, of London, England.

Moisture and Inorganic Matter	9.42
Tribasic Phosphate of Lime	62.82
Sulphate of Lime	.91
Carbonate of Lime	4.63
Oxide of Iron	5.91
Alumina	8.89
Silica	1.52
Phosphoric Acid in combination with Iron and Alumina	5.53
Phosphoric Acid with Magnesia	.37
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N. B.—The whole of the Phosphoric Acid, amounting to 34.70 is equal to 75.75 Bone Phosphate of Lime.

ANALYSIS BY DR. A. A. HAYES,

State Assayer of Massachusetts.

The sample was a fragment and some rounded grains of varied color, from clay to yellowish brown.

100 PARTS AFFORDED.

Combined Water and Organic Matter	8.20
Bone Phosphate of Lime	79.64
Sulphate of Lime	.35
Carbonate of Lime	6.10
Alumina	2.16
Peroxide of Iron	.80
Sand and Rock	2.60
	99.85

DR. HAYES'S REMARKS.—Part of the so-called Carbonate of Lime is really Crenate of Lime, and the alumina appears as a silicate in the rock, while $79\frac{64}{100}$ per cent. is easily dissolved Bone-phosphate of lime. I have preferred to state the composition of this guano, in a way in which the manufacturer of fertilizers will at once see its value to him, by the great proportion of Bone-phosphate of lime it contains. I may add that this Phosphate when powdered is very easily decomposed by acid, so as to afford the Bi-phosphate of Lime readily.

ANALYSIS BY DR. A. SNOWDEN PIGGOT,

Of Baltimore, Md.

The sample was taken from several cargoes stored together.

Water	3.13
Organic matter	7.69
Sand	2.24
Soluble Silica	0.04
Lime	36.68
Magnesia	0.96
Sesquioxide of Iron	5.75
Alumina	4.65
Alkalis	0.13
Phosphoric acid	36.37
Carbonic acid	1.20
Sulphuric acid	0.64
Chlorine	0.11
	99 59

Of the Phosphoric acid 31.87 per cent. is combined with lime and magnesia, and 4.50 with Sesquioxide of iron and alumina. The Phosphoric acid is equivalent to 78.80 of bone phosphate of lime.

ANALYSIS BY DR. C. ELTON BUCK,

Of New York.

Result of an analysis of Navassa Guano, sample of cargo shipped to New York, July, 1866.

Silica and insoluble matter	2.96
Organic matter	4.05
Moisture expelled at 212°	4.95
Bone Phosphate of Lime	64.13
(Containing Phosphoric Acid, 29.37.)	
Bone Phosphate of Magnesia	1.32
(Containing Phosphoric Acid, 00.71.)	
Phosphates of Iron and Alumina	5.11
(Containing Phosphoric Acid, 3.26.)	
Sulphate of Lime	1.18
Carbonate of Lime	3.50
Oxide of Iron and Alumina	10.09
Lime, with organic acids	1.60
Alkaline Salts and loss	1.11
	100.00
Total Phosphoric Acid	33.34
Equivalent to Bone Phosphate of Lime	72.79

ANALYSES BY DR. G. A. LIEBIG,

Of Baltimore, Md.

I.—Cargo by schooner Yankee Blade.

Moisture	9.66
Carbonic acid	2.45
Phosphoric acid	32.56
Lime	34.00
Indifferent matter	21.33
	100.00

Equal to 71.08 Bone Phosphate of Lime.

II.—Cargo per Co.'s brig Romance—March, 1866.

Moisture	10.70
Carbonic acid	2.00
Phosphoric acid	32.25
Lime	33.85
Indifferent matters	21.20
	100.00

Equal to 70.41 Bone Phosphate of Lime.

III.—Cargo per schooner Bazley—May, 1866.

Moisture	4.70
Carbonic acid	2.00
Phosphoric acid	33.90
Lime	36.81
Indifferent matters	22.59
	100.00

Equal to 74.01 Bone Phosphate of Lime.

IV.—Cargo per ship Herschel—June, 1866.

Moisture	3.24
Carbonic acid	1.55
Phosphoric acid	34.20
Sulphuric acid	0.15
Lime	39.15
Organic matter	8.26
Indifferent matters	13.45
	100.00

Equal to 74.66 Bone Phosphate of Lime.

REMARK.—Those different analyses show most satisfactorily the uniformity of the phosphatic guano in its contents of bone phosphate of lime, and consequently its high value as a fertilizer.

E. G.

NAVASSA

Phosphate Company,

(ORGANIZED SEPTEMBER, 1864.)

Capital 30,000 Shares of $100 par value,

$3,000,000.

Reserve Capital 5,000 Shares.

CASH CAPITAL PAID IN

For 1,000 Shares, at $50 per Share,

$50,000.

OFFICES:

No. 81 John Street, New York.

AND

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Sand and Rock...	2.60
	99.85

DR. HAYES'S REMARKS.—Part of the so-called Carbonate of Lime is really Crenate of Lime, and the alumina appears as a silicate in the rock, while $79\frac{64}{100}$ per cent. is easily dissolved Bone-phosphate of lime. I have preferred to state the composition of this guano, in a way in which the manufacturer of fertilizers will at once see its value to him, by the great proportion of Bone-phosphate of lime it contains. I may add that this Phosphate when powdered is very easily decomposed by acid, so as to afford the Bi-phosphate of Lime readily.

ANALYSIS BY DR. A. SNOWDEN PIGGOT,

Of Baltimore, Md.

The sample was taken from several cargoes stored together.

Water..	3.13
Organic matter..	7.69
Sand...	2.24
Soluble Silica...	0.04
Lime...	36.68
Magnesia..	0.96
Sesquioxide of Iron..................................	5.75
Alumina..	4.65
Alkalis..	0.13
Phosphoric acid..	36.37
Carbonic acid..	1.20
Sulphuric acid...	0.64
Chlorine..	0.11
	99 59

Of the Phosphoric acid 31.87 per cent. is combined with lime and magnesia, and 4.50 with Sesquioxide of iron and alumina. The Phosphoric acid is equivalent to 78.80 of bone phosphate of lime.

ANALYSIS BY DR. C. ELTON BUCK,

Of New York.

Result of an analysis of Navassa Guano, sample of cargo shipped to New York, July, 1866.

Silica and insoluble matter	2.96
Organic matter	4.05
Moisture expelled at 212°	4.95
Bone Phosphate of Lime	64.13
(Containing Phosphoric Acid, 29.37.)	
Bone Phosphate of Magnesia	1.32
(Containing Phosphoric Acid, 00.71.)	
Phosphates of Iron and Alumina	5.11
(Containing Phosphoric Acid, 3.26.)	
Sulphate of Lime	1.18
Carbonate of Lime	3.50
Oxide of Iron and Alumina	10.09
Lime, with organic acids	1.60
Alkaline Salts and loss	1.11
	100.00
Total Phosphoric Acid	33.34
Equivalent to Bone Phosphate of Lime	72.79

ANALYSES BY DR. G. A. LIEBIG,

Of Baltimore, Md.

I.—Cargo by schooner Yankee Blade.

Moisture	9.66
Carbonic acid	2.45
Phosphoric acid	32.56
Lime	34.00
Indifferent matter	21.33
	100.00

Equal to 71.08 Bone Phosphate of Lime.

II.—Cargo per Co.'s brig Romance—March, 1866.

Moisture	10.70
Carbonic acid	2.00
Phosphoric acid	32.25
Lime	33.85
Indifferent matters	21.20
	100.00

Equal to 70.41 Bone Phosphate of Lime.

III.—Cargo per schooner Bazley—May, 1866.

Moisture	4.70
Carbonic acid	2.00
Phosphoric acid	33.90
Lime	36.81
Indifferent matters	22.59
	100.00

Equal to 74.01 Bone Phosphate of Lime.

IV.—Cargo per ship Herschel—June, 1866.

Moisture	3.24
Carbonic acid	1.55
Phosphoric acid	34.20
Sulphuric acid	0.15
Lime	39.15
Organic matter	8.26
Indifferent matters	13.45
	100.00

Equal to 74.66 Bone Phosphate of Lime.

REMARK.—Those different analyses show most satisfactorily the uniformity of the phosphatic guano in its contents of bone phosphate of lime, and consequently its high value as a fertilizer. E. G.