26. SABA, ST. EUSTATIUS (STATIA) AND ST. MARTIN

BY

G. A. F. MOLENGRAAFF.

SABA

(with 2 textfigures).

The author has paid a short visit to the island of Saba in the month of April 1885. Saba is the northernmost of the curved row of neovolcanic islands, which stretches from Saba towards Grenada and the Grenadines. This row of islands together with a more or less parallel, though much less marked, outer curved row of non-volcanic islands separate the Caribbean Deep from the Atlantic Ocean.

The island Saba is the upper portion of a much denuded volcanic cone, which rises to a height of 850 m. above sea-level, from a depth of over 600 m. Saba lies at a distance of 4 km., from the northeastern rim of the Saba-bank. The latter forms a remarkable submarine plateau, about 2100 km² in extent. The Saba bank is very flat, and shallow, its depth being partly somewhat less than 20 m. and nowhere more than 50 m. The channel separating the bank from the island of Saba is 4 km. wide and its depth avarages from 600 to 650 m. The submarine slope of the island is steep in all directions, the isobath of 200 and of 500 m. lying at distances of no more than 1¼ and 3½ km. resp. out of the shoreline. The island covers about 16 km²; its slopes are steep in all directions, and it is surrounded at most places by inaccessible, often almost perpendicular escarpments, leaving little room for a narrow beach invariably covered with huge boulders. It stands to reason that the island is difficult of access. There is not one perfectly safe anchorage; the best anchorage is found on the westcoast in a place which is more or less sheltered from the prevailing easterly tradewinds. Rowing boats can attain the land there safely but, even in fair weather, it is rarely possible to reach the shore without getting a wetting from the breakers. From this landing-place a steep path leads to the principal settlement, called the Bottom, lying at an altitude of 215 m. This path is called „the Ladder'' and hence the landing-place itself is generally known as the Ladder.

Another landing-place is found on the south coast, called Fort Landing. It is less sheltered than the Ladder and is only occasionally used when there is no wind blowing.

On the flanks of the main volcanic mountain there are found scattered here and there minor, more or less conical hills; consequently, the island as seen from the distance, although from all directions giving the impression of a huge conical mountain, does not show a simple but a somethat complicated skyline. (See fig. 1 and 2 after CLEVE).

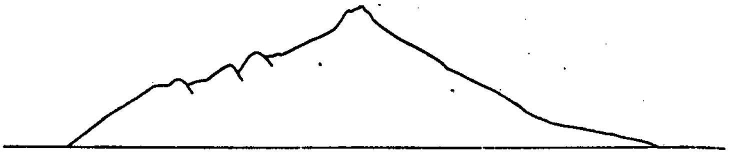


Fig. 1.

The island of Saba seen from St. Eustatius (after CLEVE).

Fig. 2.

Saba seen from St. Bartholomew (after CLEVE).

The remnants of one of the more important subordinate cones now constitute a group of hills, the highest of which is known as Great Hill, which reaches an altitude of 408 m. The greater portion of this subordinate cone has apparently been destroyed by the action of the waves.

The principal settlement, the Bottom, is situated on the lower portion of the southwestern slope of the main cone in a broad valley bounded on the southwest side by Great Hill and on the other side by the main volcanic peak. This valley or hollow is supposed by CLEVE [1]) to mark the place where once the main crater of the island existed, but during my short visit I failed to find facts in support of this suggestion. SAPPER [2]), from the position of the strata of the tuffs in this valley, came to the conclusion that CLEVE's opinion must be rejected.

The main peak of the island is truncated not far from its summit and in this small flat portion, slightly slanting towards the south, a shallow saucer-shaped depression about 200 m. in diameter occurs,

[1]) P. T. CLEVE. On the geology of the north-eastern West Indian Islands. K. Svenska Vetensk. Akad. Handl. IX. Part 12, 1871. See p. 18 of this paper: „To me it appears very probable that this (i. e. the site of the village the Bottom) is the true crater''.

[2]) K. SAPPER. Ein Besuch der Inseln Deminica, Eustatius, Saba und Guadeloupe in Westindien. Centralbl. für Min. etc. 1903, p. 315.

which resembles a crater surrounded by a low rim. It is now almost entirely filled with volcanic debris and ash, which for the greater part are converted into vegetable soil. At my visit of the summit of the peak of Saba on April 23d of the year 1885 I found this craterlike depression and its surroundings adorned by a lovely forest mainly composed of arborescent ferns, palms and some banana's, the latter being planted by the inhabitants. I found it not possible to prove the true nature of this depression with absolute certainly. Nor did SAPPER, on his visit in the year 1903, find it possible to form a definite opinion on the nature of this depression (l. c. p. 315).

The island is composed of lavas and tuffs of andesite (CLEVE's Trachyte) viz: amphibole-pyroxene-andesite, amphibole-andesite and pyroxene-andesite.

Apparently the most copious flow of lava extended from the main cone in a northeasterly direction; it forms now a projecting peninsula known as Flat Point.

CLEVE [1]) has published the following analysis of an andesite of Saba (exact locality not given)

SiO_2	60.80
Al_2O_3	16.34
Fe_2O_3	0.68
FeO	5.14
CaO	6.92
MgO	1.47
Na_2O	6.71
K_2O	1.12
H_2O	0.37
	99.55

HÖGBOM [2]) who has studied the rocks collected by CLEVE gives the following short description of this particular andesite.

„Mkr. In dem hellgrauen Gestein werden makroskopisch weisse Körner von Plagioklas und schwarze Amphibolstengel gesehen.

Mikr. Der mikrotinartige Plagioklas ist ein prachtvoll zonalstruirter Labrador-Oligoklas mit zonal angeordneten Interpositionen und verästelten Grundmasseeinschlüssen. Die Amfiboleinsprenglinge, welche spärlicher und kleiner sind, zeigen tiefbraune bis braungelbe Absorptionsfarben und geringe Auslöschungsschiefe. Kleinere Körner von einem blassgrünen bis gelblichen Augit sind in etwa gleicher Menge wie die Hornblende vorhanden. Die Hornblendeindividuen sind öfters mit einer orientirten Umrandung von diesem Augit versehen. In der

[1]) P. T. CLEVE. l. c. p. 39.

[2]) A. G. HÖGBOM. Zur Petrographie der kleinen Antillen. Bull. geol. Inst. of the Univ. of Upsala, VI, p. 228, 1903.

isotropen Grundmasse liegen reichlich kleine Plagioklasleisten, Augit- und Magnetitkörner."

I have myself examined microscopically rocks of four localities and, agreeing with HÖGBOM's description, I only wish to add the following few remarks from my personal observations. The andesites of Saba, which I have seen, all contain both amphibole and pyroxene; in the majority of them amphibole predominates over pyroxene. The andesite of Corner Ridge, a hill in the eastern portion of the island between Windward Side and Hell's Gate, is dark-coloured and very rich in femic constituents. The brown hornblende in this rock has uncommonly broad opacite-rims. In the valley which leads from the Bottom to Fort Landing I found an andesite. in which under the microscope a few irregular, obviously xenolithic, grains of quartz were observed. At Fort Landing a somethat scoriaceous andesitic lava occurs with much glass in its groundmass.

In the northeastern portion of the island near Hell's Gate the andesite is bleached over a considerable distance and converted into a crumbling rock rich in sulphur, and in places in gypsum. Evidently solfataras have been active here. The sulphur deposit which on the average has a thickness of at least 4 m. has been worked in the years 1882—1884, but the results were not satisfactory. As is generally the case with deposits of sulphur in extinct solfataras the superficial aspect was very promising but the quantity of the available ore was disappointing. The numerous cracks in the strongly decomposed rock which intersect one another in all directions are filled with pure sulphur, and where the cracks are not quite closed they are lined with a crust of well developed crystals. The crystals of sulphur of this deposit are small (1—3 mm. in diameter) but exceptionally rich in forms. They are natural gems, richer in planes than those known from any other localitiy. I have observed [1]) 23 forms on these crystals, the following of which are as yet only known from this locality:

$$\vartheta\ \{031\},\ \delta\ \{221\},\ \gamma\ \{331\},\ \text{and}\ \alpha\ \{313\}$$

The shape of the majority of these crystals is governed by a strong development of the zone of makro-pyramids } 31 n {, rich in forms. In fig. 2 of the paper quoted below the characteristic habit of these unique crystals of sulphur is shown.

ST. EUSTATIUS

(with one geological map and 5 textfigures).

In the year 1885 I spent some time on the Island of Statia and in

[1]) G. A. F. MOLENGRAAFF. Ueber vulkanischen Schwefel aus Westindien. Zeitschr. für Kryst. XIV, pp. 43—48, 1888.

1886 I have published a geological description of this island[1]), from which a great part of what follows is taken.

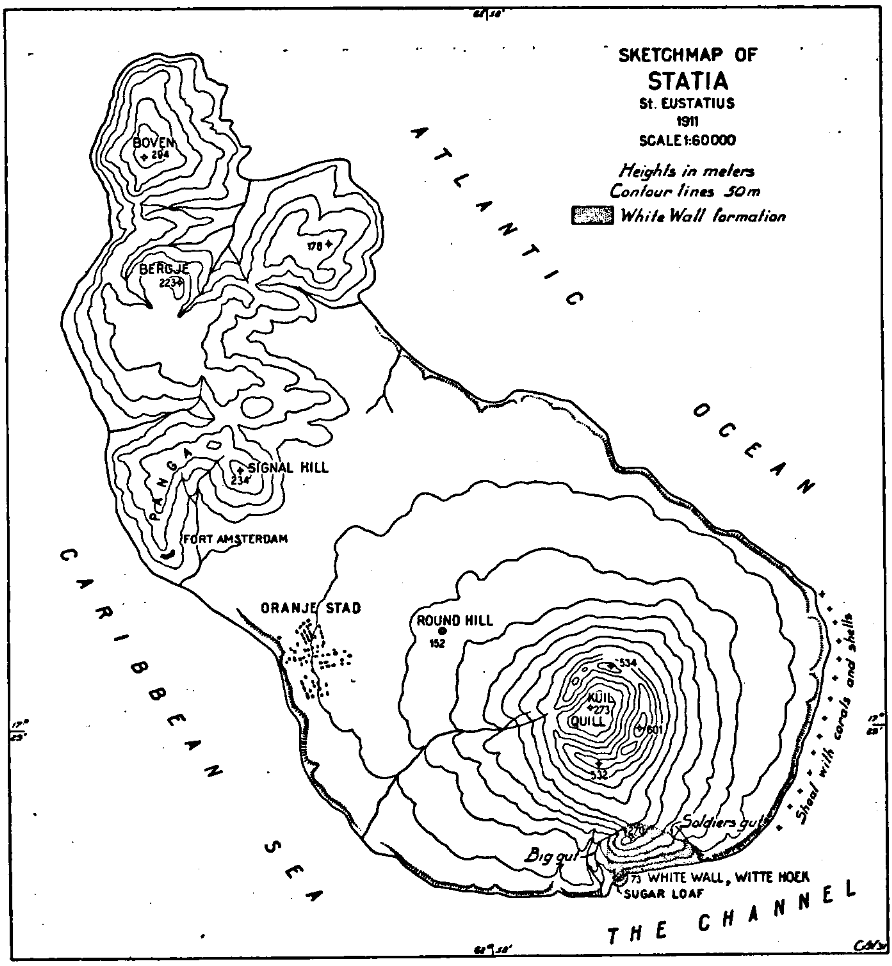


Fig. 3.

Geological sketch of the island of St. Eustatius (Statia) 1: 60.000; topography after the topographical map 1: 20.000 published by the Government, 1911.

The island (fig. 3) has an oblong, pear-shaped form; the axis runs northwest-southeast. The breadth diminishes gradually from southeast to northwest, except in the middle, where the narrowing is a little greater. It is 7,9 km. long; its breadth is: 4 km. in the southeastern part, in the middle 2,6 km. and in the northwestern part 2,7 km.

[1]) G. A. F. MOLENGRAAFF. De Geologie van het Eiland St. Eustatius. Leiden 1886.

Two mountain-groups separated by a broad plain govern the topography of the island. The northwestern group consists of several strongly denuded hills of volcanic origin, of which the highest, called Boven, rises 294 m. above sea-level.

The former centres of volcanic activity cannot with certainty be verified; an exception is made by the horseshoe-shaped ridge Panga, the southeastern part of which is called Signalhill (234 m.), which may be considered the remnant of a former active crater.

These northwestern hills are built up by coarse ejectamenta alternating in several places with flows of andesitic lava, which are clearly visible in the precipetous wave-cut coastcliffs. The prevailing rock is augite-andesite but in the lava of Signalhill hornblende is as frequent a mineral as augite. At Signalhill, according to SAPPER [1]) intrusions of andesite cut through the agglomerates.

The second or southeastern mountain-group consists of one single symmetrically shaped volcano [2]). This main volcano (fig. 3 and fig. 4) of the island possesses a narrow, nearly circular rim, whose height ranges from 378 m. on the west side to 601 m. on the east side. This rim surrounds a deep crater, about 300 m. in diameter. The bottom of the crater is fairly level (273 m.) but is covered by numerous blocks, that have rolled down from the craterwall. The wall of the crater is very steep, in most places unscalable. The bottom, the rim and the top-portion of the outside of the volcano are covered with trees. The outer slope of the volcano is all round the crater near its rim rather steep, but becomes by degrees less steep and finally, either imperceptibly merges into the large plain or ends near the coast abruptly, being cut off by a nearly perpendicular cliff, on the avarage 30 m. high. This gives the volcano of Statia its fine regular shape [3]).

The main crater consists of coarse ejectamenta; these are very large near the rim, where the crater-wall consists of huge ejected blocks of augite-andesite, here and there also of hornblende-augite-andesite, but on the outside of the cone they quickly decrease in size.

The large plain, lying between the two mountain-groups was formerly entirely, now only partly, cultivated. It is constructed of nearly horizontal layers of tuff, as may be seen in the steep cliff along the coast, as well on the side of the Caribbean sea as on that of the Atlantic ocean. These layers principally consist of ash, but besides that of bombs (both autoliths and xenoliths) and of lapilli and pumice.

[1]) K. SAPPER. Ein Besuch von St. Eustatius und Saba. Centralblatt für Min. etc. für 1903, p. 318.

[2]) This vulcano is called by most authors „the quill'', and on maps and charts the same name is used. This word „quill'' is derived from the the Dutch word „kuil'', which means „pit or hollow''. By this word the Dutch colonists of the 18th century meant the crater, and on Dutch maps and plates of that time this name occurs again and again. So the name „quill'' gets a plausible signification.

[3]) On the northwestern slope of the volcano one small hill, called Round Hill (152 m.) forms a slight irregularity in its almost ideal outline. This hill which is now entirely covered with volcanic ash is probably a small parasitical cone.

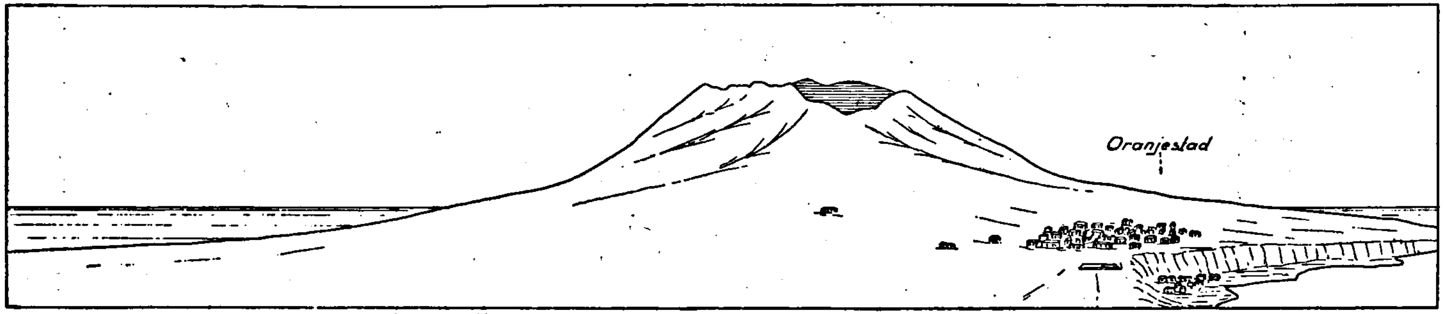


Fig. 4.

Outline of the main volcano of Statia, after a photograph taken from Fort Amsterdam 1885.

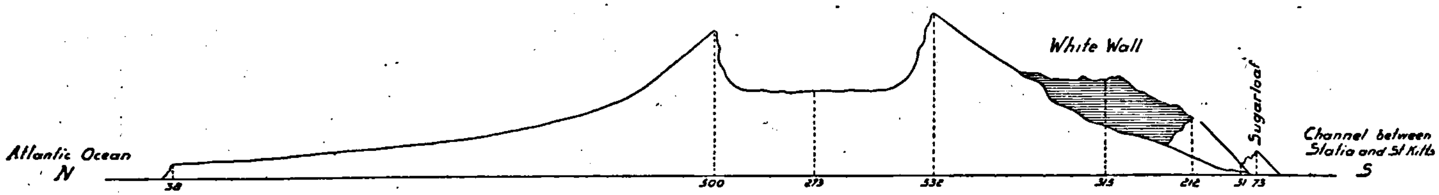


Fig. 5.

N-S section through the crater of the main volcano and the Withe Wall. The shaded portion lies somewhat behind the plane of section.

As has been already mentioned before the volcanic rocks of Statia, like those of Saba, belong to the andesite group. The pumice of the White Wall only makes an exception, and is a dacite-pumice; the same thing, I think, will be the case with the pumice found in the tuff of the main vulcano, but this has not yet been proved by analyses.

A summary of analyses made of the rocks of Saba and Statia has been published by SAPPER [1]) in the year 1904 and by LACROIX [2]) in the year 1926. LACROIX gives in his work an extensive critical study of the character of the lithological province of the Lesser Antilles.

Two points of more than local interest require a short discussion. They are the origin of the White Wall and the composition and origin of the tuffs of the main volcano.

a. The White Wall (Witte Hoek).

On the south side of the island the regular form of the main volcano is interrupted by a high, dazzling white wall of limestone (fig. 5 and 6) rising from the seashore at a steep angle and being visible miles and miles away. As early as the 18th century it was named on Dutch charts and plates the „Witte Hoek" (White Wall). This wall is cut off, as well on the east as on the west side, by a ravine and separated from the tuffs, which do not contain limestone. At a height of 212—270 m. the wall of limestone terminates and on top of it at a height of about 320 m. the same tuffs reappear, which are found all round the volcano. So this limestone formation is quite local and strictly limited to a small section in the southern slope of the main volcano. The peculiar and conspicuous position of the White Wall with regard to the main volcano of Statia is excellently shown in a sketch made by DAVIS [3]) in the year 1928, which is reproduced here in fig. 6.

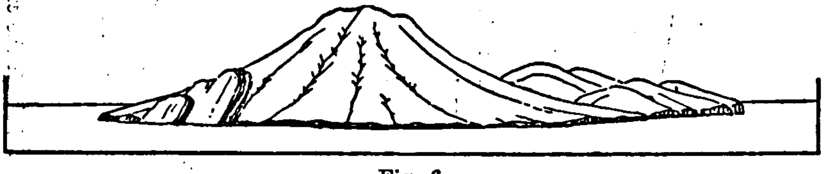


Fig. 6.

White Wall.

A rough outline of Statia, as seen through hazy air from the northwest end of St. Kitts (after DAVIS).

On the west side of the White Wall stands at the shore a picturesque rock, 73 m. high, possibly a faulted portion of the White Wall

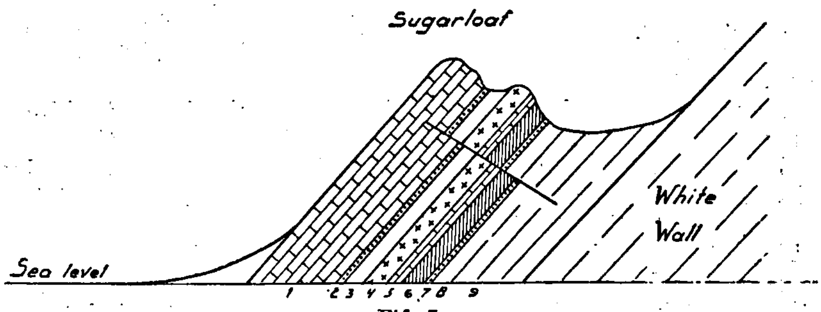
[1]) K. SAPPER. Die vulcanische Kleinen Antillen und die Ausbrüche der Jahre 1902 und 1903. N. J. 1904, II, p. 44—45.

[2]) M. A. LACROIX. Les caractéristiques lithologiques des Petites Antilles. Livre Jubilaire Cinquanténaire Soc. Géol. de Belgique, pp. 387—405. Liège 1926.

[3]) W. M. DAVIS. The Lesser Antilles. Amer. Geogr. Soc. Map of Hispanic America. Publ. No. 2, New-York 1928, fig. on page 58.

itself, named Sugarloaf (fig. 5) which is connected with the White Wall by a narrow saddle (51 m.). The stratification of the Sugarloaf may be easily studied on its east side where an excellent section (fig. 7) is exposed.

The strike of the strata of the Sugarloaf is W 5 S, their dip is 42° south. The strike of the White Wall is near the Sugarloaf also W 5 S, but going eastward deviates a little more towards the north. The dip of the lowest part of the White Wall coincides with that of the Sugarloaf.



Fif. 7.

Sketch of the strata visible in the eastern slope of Sugarloaf 1885; 1, Coralrock; 2, Conglomerate with corals and shells; 3, Pumice tuff; 4, Dacite-pumice; 5, Coralrock; 6, Soft limestone with corals and shells; 7, Conglomerate with some shells and corals; 8, Yellowish tuff; 9, Whitish tuff.

In the before-mentioned section on the east side of Sugarloaf the sequence of the strata from top to bottom is:

1. Coralrock with many shells.
2. Conglomerate, made of fragments of lava, tuff-breccia, and numerous corals and shells, with a partly calcareous, partly tufaceous cement.
3. White pumice tuff.
4. Pure dacitic pumice; this layer is 4 m. thick.
5. Coralrock containing besides corals some shells.
6. Soft limestone, rich in corals and shells.
7. Conglomerate containing a few shells and corals.
8. Yellowish tuff with numerous small fragments of lava and pumice.
9. Whitish andesite-tuff rich in fragments of glass (vitric tuff); this tuff passes gradually into the overlying tuff 8.

The strata below 9 are not well exposed but for certain between layer 9 and the White Wall one more layer rich in corals occurs.

The upper stratum of the White Wall consists of a sheer wall of superficially black-stained coralrock dipping about 43° south. From 130 m. upwards the coral-limestone is covered with some volcanic sand and ash.

Above Sugarloaf the upper end of the sheer wall of coralrock, the proper White Wall (fig. 6), is reached at a height of 212 m. [1]).

Above that altitude the dip diminishes and the formation is much faulted, tuff being exposed in most places underneath the cover of limestone [2]). At an altitude of about 270 m. a broad saddle dipping southward is reached, which forms the divide between the two ravines, indicated on the topographical map as Big gut and Soldier gut, which limit the White Wall respectively to the west and the east. This saddle connects the White Wall with the southern slope of the main volcano. A stratified deposit of gypsum is formed here near the upper end of Big gut and its origin is probably due to the action of a now extinct solfatara on the calcareous tuff and limestone of the White Wall formation.

In the ravine at the eastern end of the White Wall fossiliferous tuffs and coralrock are again found in abundance, but at the time of my visit the effects of mudflows caused by heavy rains, many huge blocks having slid down from above, prevented me from obtaining a clear insight into the stratigraphy.

The interior of he White Wall being then nowhere well exposed and accessible, the true relation between the White Wall and Sugarloaf is still uncertain. Possibly Sugarloaf is a portion of the White Wall itself, being pushed forward by faulting, or having slid downwards, as I have accepted formerly [3]). If so the top-stratum of Sugarloaf should be identical to the outer stratum of the White Wall. But it is equally possible that the strata exposed in Sugarloaf must be regarded as belonging to a higher horizon than that of the White Wall, now almost entirely removed by erosion; in that case a section through the White Wall and Sugarloaf should be a continuous one, the White Wall representing the lower portion and the Sugarloaf the upper portion of the same continuous succession of strata.

This question must be regarded as an open one at present. At all events the attitude and structure of the entire formation as well as the position (fig. 8) of the individual coral-colonies and the shells prove clearly that the strata have been originally laid down in a horizontal position and that later, after the deposition of the uppermost stratum of coralrock No. 1 in Sugarloaf the entire formation has been tilted as one huge slab to its present position, and at the same time has been disturbed, as is shown by the well marked small fault in Sugarloaf and by the numerous faults found in the upper portion of the White Wall.

The direction of the present dip pointing away from the crater of the main volcano gives support to the surmise that the tilting was caused by one, or possibly more than one, eruption of the volcano.

The geological history of this part of the island would in that case have been the following:

[1]) Towards the east this height becomes greater.

[2]) K. SAPPER. Ein Besuch von St. Eustatius und Saba. Centralblatt für Min. etc. für 1903, p. 317, fig. 2.

[3]) G. A. F. MOLENGRAAFF. l. c. p. 29. The complete conformability of the strata of Sugarloaf to those of the White Wall is not favourable to this surmise.

A certain time after the northwestern group of volcanic hills had been formed and most probably its volcanic activity had come to an end, there existed to the southeast of this island a submarine shoal on which, in the shallow sea, mollusca and corals flourished. This shoal probably might be compared to the shoal on which corals and mollusca now prosper, which extends on the present day from the main volcano a certain distance towards the east. Every now and then the

Fig. 8.

Plate-like colonies of Astraeidae having been tilted from their original horizontal position together with the entire formation of Sugarloaf.

organic life on this submarine bank was temporarily destroyed by volcanic eruptions which covered the shoal with their ejectamenta which is clearly to be seen in the section at Sugarloaf. Fragments of andesite, ash and dacite-pumice were nearly exclusively thrown out by these eruptions. The fact, that in the tuff of the main volcano elsewhere on the island a simular pumice is of common occurrence, justifies the supposition, that the volcanic products of which the White Wall and Sugarloaf are partly composed, have been thrown out by the main volcano. In this way a stratified formation was laid down, consisting partly of ejectamenta alone, partly of ejectamenta and limestone with shells and corals. The upper portion of this formation is now visible in the White Wall and Sugarloaf. The entire formation originated probably during a period of slow subsidence, because it is reasonable to suppose, that the successive layers of coralrock in Sugarloaf which now, in the stratigraphical column, are found at distances apart up to 48 m. have been formed at about the same slight depth below sea-level. Finally a violent paroxysmal eruption must have taken place, which probably gave rise to the greater part of the main vulcano and its tuffs, at the same time lifting and tilting a gigantic slab of the above described, then still horizontal submarine White Wall formation to its present position.

Howsoever this may be, the existence of limestone and tuffs with corals and shells to the heigth of about 300 m. above sea-level in the White Wall must be considered a local phenomenon. It is erroneous to draw the conclusion [1]) that the whole island Statia should have been uplifted in post-Pliocene time.

First of all upheavel of the entire island could not possibly explain the strong tilt of the strata of the White Wall and Sugarloaf. Further, nowhere else on the island traces of upheavel of any importance are found [2]).

The first record about the White Wall appears to have been given by MACLURE [3]). He evidently has visited the spot and his description is quoted by CLEVE [4]) as follows: „The whole of this marine desposition dips to the southwest at an angle of upwards of 45 degrees from the horizon, resting upon a bed of cinders, full of pumice and other volcanic rocks, and is immediately covered by a bed of madrepore, sand and cinders mixed together, with blocks of volcanic rocks so disseminated that there can be no doubt of the volcanic origin of the substance above and below the madrepore rock, which may be from five to six hundred yeards thick."

CLEVE, on his visit to Statia in 1869, has not studied the White Wall.

After my visit to the island in the year 1885 only one geologist, K. SAPPER, has, as far as I know, visited the White Wall; this happened in the year 1903. SAPPER [5]) then came to the conclusion that the sedimentary formation which forms the White Wall and Sugarloaf had been deposited on a sloping substratum and that these layers from their

[1]) CLEVE. l. c. p. 20 and later SAPPER and also HOVEY came to this conclusion.

[2]) Some facts to which SAPPER (l. c. p. 318) and myself (l. c. p. 31) have drawn the attention point to slight recent susidence.

[3]) MACLURE. Journal of the Acad. of Nat. Sc. of Philadelphia. Vol. I, Part. I, p. 147.

[4]) P. T. CLEVE. On the geology of the North-eastern West India Islands Kongl. Svenska Vetenskaps Akademiens Handlinger, Bd. 9, Pt. 12, p. 19, 1871.

[5]) K. SAPPER. Ein Besuch von St. Eustatius und Saba. Centrallblatt für Min. etc. für 1903, pp. 314—318.

very origin had been strongly inclined and that they were lifted to their present position by a general upheaval of the island. In the year 1905 SAPPER [1]) explains this opinion more fully. The way in which the shells lie and the individual coral-colonies stand in the layers pleads against this conception.

At my request, in the year 1917, Mr. G. J. VAN GROL, then governor of the island, had photographs taken showing distinctly the position of individual colonies of corals (Astraeidae) with plate-like growth parallel to the present attitude of the layers. Fig 8 is a copy of a pen-drawing made by Professor UMBGROVE at Delft from one of these photographs. After SAPPER had seen these photographs he withdrew his opinion which differed from mine [2]).

In the year 1901 SPENCER [3]) who, as far as I know, has not visited the White Wall himself, in his paper on the physical development of St. Kitts etc., compared the limestone formation of the White Wall with that of Brimstone Hill on St. Kitts. His opinion is that both Brimstone Hill and the White Wall originated from a local upheavel caused by volcanic activity. He concludes l. c. p. 537 „Owing to these two volcanic uplifts, the limestones which underlie the submerged coastal plains may be seen, for they appear nowhere else on these islands."

DAVIS [4]), in his study on the Lesser Antilles, accepts my explanation and gives on page 58 the sketch reproduced in fig. 6. He concludes: „The huge inclined slabs of limestone, known as the „White Wall", in the shore of the cone, appear to have been lifted up from a preexistent submarine bank when the volcano was formed."

HOVEY [5]), in the year 1923, states: „Recent elevation of the island chain (of the volcanic Caribbees) is evident. It is greatest at the north, beach conglomerates occurring at 1500 feet on Statia, 1000 feet on Guadeloupe and at less elevation as one goes southward", without mentioning the facts on which this interpretation is based.

According to my opinion this view is not correct; recent elevation of the entire island of Statia has not taken place at all. Only local elevation probably in Pleistocene time or possibly still later took place at the White Wall, as a result of volcanic action of the main volcano.

The strata of the White Wall and Sugarloaf are very rich in fossils.

[1]) K. SAPPER. In den Vulkangebieten Mittel Amerikas und Westindiens, pp. 184—190, Stuttgart 1905.

[2]) K. SAPPER. Vulkankunde p. 217. Stuttgart 1917. Auf die Hebung eines Vulkansektors in jünger geologischer Vorzeit hat G. A. F. MOLENGRAAFF hingewiesen. Es betrifft den White Wall am Vulkan The Quill am Südende der Insel Statia. Ich selbst hatte allerdings angenommen, dass in den zwischen 2 tiefen radialen Barrancos gelegenen Gebiet Absatz des Gesteins auf steil geneigter Unterlage stattgefunden hätte; aber van GROL's Nachweis, dass die Korallen senkrecht auf den jetzt geneigten Kalksteinen stehen, hat MOLENGRAAFF Recht gegeben.

[3]) J. W. SPENCER. On the geological and physical development of the St. Christopher Chain and Saba Banks. Q. J. G. S. Vol. LVII, pp. 534—543, 1901.

[4]) W. M. DAVIS. The Lesser Antilles. Amer. Geogr. Soc. Map. of Hispanic America. Publ. No. 2, New-York 1928; see pp. 48—58.

[5]) E. O. HOVEY. The Volcanic Caribbees. Proc. of the Pan Pacific Science Congress. Australia 1923, I, pp. 836—837.

The state of conservation both of the corals and the mollusca is perfect and some of the shells found in the tuffs still show traces of their natural colours. I have given in 1886 a list of the mollusca (48 species) which I had collected compared with those (40 species) which CLEVE had collected at Brimstone Hill on St. Kitts in the year 1869. There is an almost complete identity between the two fauna's. All the species are still found living [1]) in the Caribbean Sea. The corals have not yet been determined, and, my collection being small, the list gives only a faint idea of the richness of the fauna which is here preserved.

As to the age of this formation CLEVE is of opinion that it is newest Pliocene, or post-Pliocene.

According to SPENCER [2]) the formation exposed in Brimstone Hill on St. Kitts (and in the White Wall on Statia) appears to correspond to the surface-marls of Sombrero, the upper marls of Anguilla, and those at the Usine of Pointe à Pitre in Guadeloupe. These have about the same thickness, contain a similar fauna, and are regarded as the equivalent of the Lafayette formation of the American continent belonging to the time about the close of the Pliocene Period.

I have taken the age to be post-Pliocene and the state of conservation of the fossils makes me incline to believe that a determination as late-Pleistocene or sub-Recent might be permissible.

The problem of the White Wall is not yet solved and fully deserves closer examination.

b. The composition and origin of the tuffs of the main volcano.

The tuffs of the main volcano can be best studied in the steep cliffs near the coast. Near Oranjestad this cliff is about 42 m. high. It is well stratified, thick horizontal layers of tuff being piled one on the other in very regular succession. Going from below upwards the layers decrease in thickness. Near the beach the average thickness is not less thans 1.50 m. and some of the layers there attain 2 m. whereas in the upper portion of the cliff no layer is found thicker than 60—80 cm.

In each of the layers the component parts are arranged according to their specific gravity [3]); near the bottom more or less sharp-edged blocks of lava and rounded bombs are found with little ash in between, higher the blocks are of smaller size and the percentage of ash increases, still higher the layer consists almost solely of ash, whereas the top-portion of each layer again contains besides ash numerous smaller and larger pieces of pumice. In the lower layers exposed in the cliff exclusively white dacitic pumice is found apparently identical to that of Sugarloaf and the White Wall: higher up dark-coloured pumice predominates over the white pumice.

In several of the layers near Oranjestad, principally in those

[1]) CLEVE. l.c. p. 21 mentions one exception, a Modiolaria closely related to a northern still living species.

[2]) J. W. SPENCER. l. c. p. 537.

[3]) Stricto sensu the velocity they attained in the air falling down after having been violently ejected by the volcano.

occurring 4—15 m. above sea-level, ejected blocks of limestone are not rare. They contain remains of corals and shells which appeared to me to be identical with those found in the White Wall formation. If so, they are probably ejected by the main volcano during the eruption (or eruptions) which destroyed the submarine bank, a tilted portion of which now forms the White Wall.

The arrangement of the ejected material which is found repeated in several of the successive layers which I have examined might be explained in two ways:

1. Each of the layers of tuff now visible in the coast-cliffs might represent a result of one total eruption of the main volcano; the arrangement might then be explained if we accept that each eruption commenced with the ejection of smaller and larger blocks of lava, bombs, and some xenoliths of limestone, besides ash; and terminated with the ejection of abundant fragments of pumice, and of ash. In this case the apparent arrangement after the specific gravity would be in reality a time-arrangement, the pumice indicating the final stage of the eruption.

2. Each of the layers of tuff now visible in the coast-cliffs might represent the result of one single explosion during an eruptive period. In this case all the different fragments now found in one layer should have been ejected at the same time and should have been sorted by the differences in their velocities in the air.

This second explanation, although it would explain the very neat arrangement in the layers satisfactorily, is probably not permissible because the total amount of ejectamenta thrown out by one single explosion in that case would have been too enormous to be readily acceptable. From this explanation would also follow, that the main volcano with all its ejectamenta originated as the result of one single period of volcanic activity, during which also the submarine bank was destroyed, a tilted portion of which now forms the White Wall.

Doubtless a renewed study of the tuffs deposited by the main volcano will be of great interest and may give a clew to the solution of some still dubious points in the geological history of St. Eustatius.

ST. MARTIN.

(with one geological map and 5 textfigures).

Since Cleve has published in the year 1871 his well known memoir on the geology of the northeastern West India islands including St. Martin, and I have given a short sketch of the geology of the island of St. Martin in the year 1887, various authors, Spencer (1901), Högbom (1905), Vaughan (1916 and 1926) and Davis (1926) have added to our geological, petrological and geo-morphological knowledge of this island [1]). A discussion of these papers would go far beyond the limited scope of this paper and I shall therefore restrict myself to giving a summary statement of the contents of my previous publication with corrections resulting from a more detailed examination of the rocks I collected, and additions borrowed from later investigations.

The island of St. Martin, with exception of the western-most portion, is mountainous; two groups of hills with a general trend from S S W to N N E can be distinguished separated by a broad not well defined plain, known as Groote Vlakte or Belle Plaine. Broad valleys extend from this somewhat rolling country towards Groote Baai and Anse de l'Embouchure. Just west of this country the hills of the western group form a fairly well defined range beginning at Fort Amsterdam and Fort Hill in the South, including Sentry Hill (344 m.) and Mt. Paradis (400 m.) in the middle, and terminating in the northeastern point of the island, known as East End Point. Mt. Paradis is the highest point in this range, and also the highest mountain of the entire island. To the west of this range less conspicuously arranged hills belong to this western group of hills.

The eastern group is smaller and only extends as one fairly well marked range of hills from the southernmost point of the island, Pointe Blanche, to the hills north of Oyster Pond, its further continuation being indicated by some rocks projecting from the sea. The highest point in this group is Oostenberg or Naked Boy Hill (300 m.).

The westernmost uninhabited portion of the island, the Low Lands, with the exception of some hills, rises only some metres above sealevel. This portion forms a girdle of land surrounding the large Simson Bay Lagoon which at Simson Bay has a narrow communication with the sea.

The coastline of St. Martin is strongly indented and characterized by the frequent occurrence of deep and broad bays being entirely or almost entirely, separated from the sea by sand bars, thus now forming lagoons. Several of these lagoons e. g. at Philipsberg and at Grande Case, are used as salt-pans and have some economical importance now.

The island of St. Martin (see map fig. 9) consists of a basement of igneous rocks overlain by formations of various age, of which the Pointe Blanche formation, named after Pointe Blanche where it is well exposed, is the most important.

[1]) P. T. CLEVE. On the geology of the North-Eastern West India Islands. Kongl. Svenska Vetensk. Akad. Handl., Bd. IX, No. 12, 1871.

G. A. F. MOLENGRAAFF. Het geologisch verband tusschen de West-Indische Eilanden. Hand. 1e Nat. en Geneesk. Congres Amsterdam, pp. 287—296, 1887.

J. W. M. SPENCER. On the geological and physical development of Anguilla, S. Martin, St. Bartholomew, and Sombrero. Q. J. G. S. Vol. LVII, pp. 520—533, 1901.

A. G. HÖGBOHM. Zur Petrographie der Kleinen Antillen. Bull. Geol. Inst. of the Univ. of Upsala, Vol. VI, pp. 214—233, 1902—1903.

TH. W. VAUGHAN. Some littoral and sublittoral physiographic features of the Virgin and Northern Leeward Islands and their bearing on the Coral Reef Problem. Journ. of the Wash. Acad. of Sc., Vol. VI, pp. 53—66, 1916.

Notes on the Igneous rocks of the Northeast West Indies etc. Journ. of the Wash. Acad. of Sc., Vol. XVI, pp. 345—358, 1926.

W. M. DAVIS. The Lesser Antilles. New-York 1926.

T h e b a s e m e n t o f i g n e o u s r o c k s a n d t h e P o i n t e B l a n c h e f o r m a t i o n. Amongst the igneous rocks of the basement predominates a light-coloured pyroxene-quartz-diorite, in which the pyroxene has frequently been entirely replaced by amphibole. Biotite is generally present and is in places as abundant a femic mineral as pyroxene or amphibole. The crystals of plagioclase are particularly well zoned, the interior portions or phantom crystals often showing a shape different from the present outlines. Orthoclase is always present in varying quantities giving rise to varieties rich in orthoclase belonging to granodiorites and finally to granites.

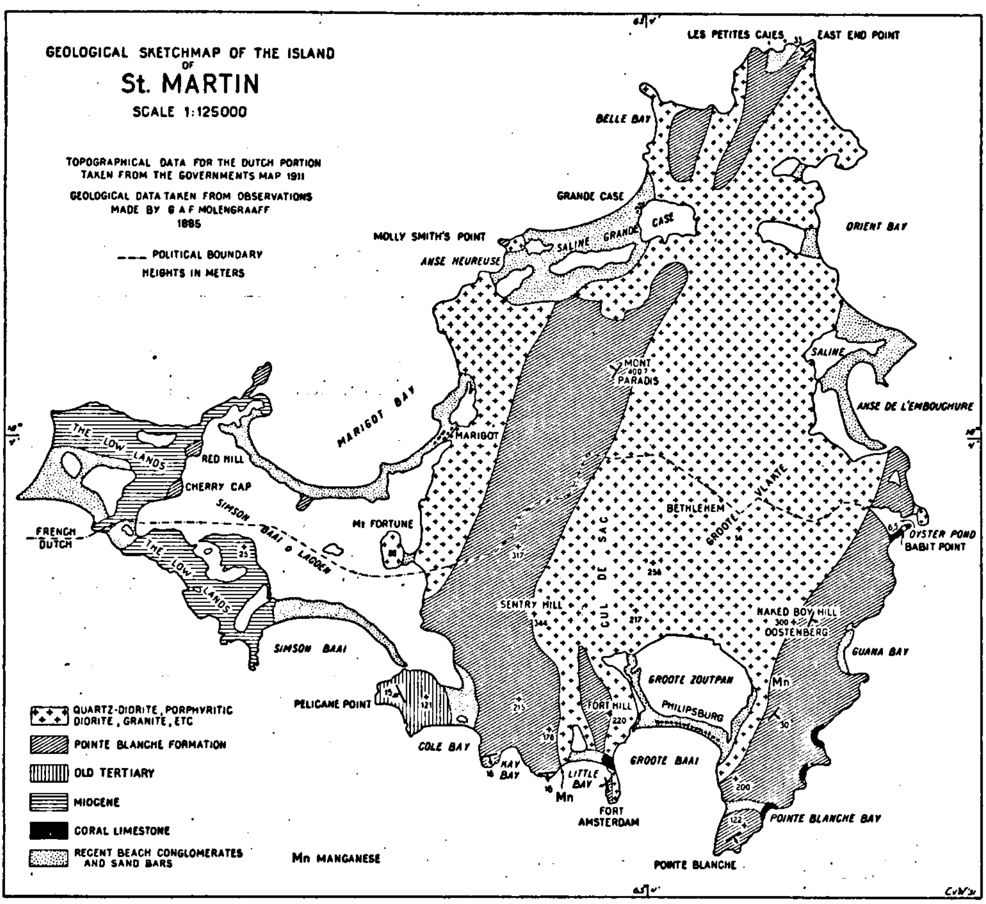


Fig. 9.
Geological sketch-map of the island of St. Martin, Scale 1: 125.000. Topography after the Governmentsmap 1: 20.000, 1911.

In the Great Plain and north of it, and also in several places along the coast spheroidal weathering is well developed in these basement rocks, the less decayed portions forming accumulations of huge rock-balls.

Besides quartz-diorite a somewhat more basic type of rock is of frequent occurrence in the basement; it is a clearly porphyritic diorite containing some quartz only in places; the colour of this porphyritic rock is darker than that of the quartz-diorite and the granite.

The age-relations between the quartz-diorite and the porphyritic diorites is not quite clear yet. In a fine section exposed at the coast in one of the westernmost rockgroups of les Petites Caies (fig. 10) the quartz-diorite encloses near the contact with porphyritic pyroxene-diorite lumps of the latter rock, and thus at that place the quartz-diorite is the younger rock. It is not yet proved, however, that the same relation holds good for other localities.

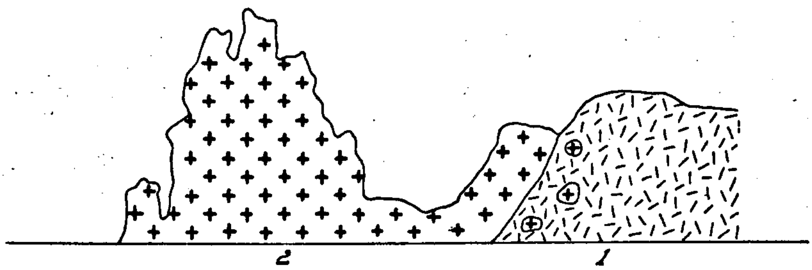


Fig. 10.

Contact exposed at les Petites Caies.
1. Quartz-diorite.
2. Porphyritic pyroxene-diorite.

The Pointe Blanche formation which is the oldest sedimentary formation known on the island, overlies these basement rocks. It is well stratified and the individual layers are remarkably well defined and often differ greatly in colour; this makes that the prevailing very regular stratification is visible and well distinguishable even from a great distance.

On St. Martin the strata are nowhere horizontal but always tilted, the angle of dip varying considerably, from 10—60°. As far as my observations go the strata are nowhere plicated or folded. The strike of the strata and the angle of dip are indicated on some places in the sketchmap (fig. 9).

In the greater portion of the island a NNE—SSW strike prevails, with a dip towards northwest in the western group of hills including the western portion of the Fort Amsterdam peninsula and also at the west coast, and a dip towards southeast in the eastern group of hills and at the east coast. Near and at the south coast the prevailing strike is ENE—WSW with a dip towards south-southeast (fig. 9). The Pointe Blanche formation which, as will be explained below, is strongly metamorphosed consists of a succession of beds of tuff of varying grain ranging from very fine grained ash to coarse tuff-breccias containing fragments of effusive rocks. In several places strata of somewhat crystalline limestone are intercalated between the tuffbeds, e. g. about

30 m. above sea-level near Guana Bay, in the coast-cliffs near East End Point and in the hills between Grande Case and Marigot. I have not found fossils in these metamorphosed limestones.

In some places sheets of diorite-porphyrite and allied rocks are intruded between the beds of the tuff-formation. Near East End Point (fig. 11) one of these sheets is intruded between strata of limestone; the intrusive diorite-porphyrite has been altered by digestion of lime and is rich in epidote and zoisite, and the limestone is converted into hornfels at the contact.

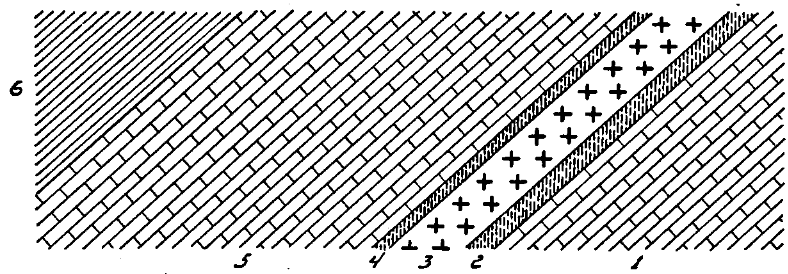


Fig. 11.

Section near East End Point.
1. and 5. Limestone, 5. is one meter thick.
2. and 4. Hornfels. (8 and 4 cm.).
3. Diorite-porphyrite (20 cm.).
6. Tuffs of the Pointe Blanche Formation.

I have found effusive rocks only as fragments in the coarser tuffs, but it is not unlikely that they will occur intercalated in the series of tuffs.

The igneous rocks of the basement are intruded into the overlying Pt. Bl. formation [1]). In some places this intrusive relation is clearly demonstrated. At Belle Bay (fig. 12) the orthoclase bearing pyroxene-biotite-quarz-diorite (the pyroxene being replaced by amphibole) is injected into the Pt. Bl. formation and at the contact blocks of the latter, highly altered formation are detached and taken up in the invading quartz-diorite. Another fine contact between the quartz-diorite and the intruded tuff-formation is exposed at the coast near Molly Smith's Point. The tuff is altered into hornfels. Both at Belle Bay and at this locality the intrusion of the quartz-diorite has been followed by a minor intrusion of granite-aplite which is injected into the tuff parallel with and quite near the main plane of contact.

In some other places the plane of contact between the Pt. Bl. formation and the underlying igneous rock is so even and regular that the impression is given of a sedimentary contact. A good example of such a

[1]) Prof. J. A. Grutterink has examined several of the rocks which I have collected in 1885, especially the contact-rocks. The details given here on these rocks are based on his determinations.

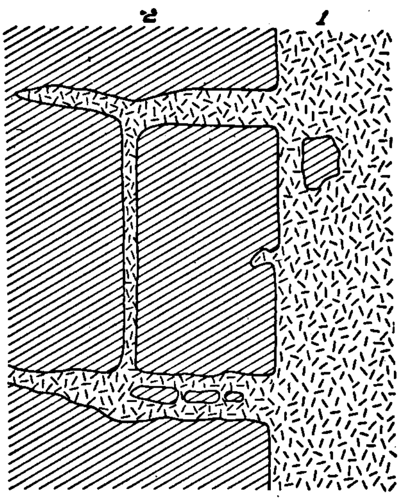


Fig. 12.

Contact between pyroxene-biotite quartz-diorite (1) and the Pointe Blanche Formation (2). Belle Bay.

contact is exposed in the western coast-cliff of Little Bay (fig. 13). Here, as well as at some other localities the lowermost strata of the

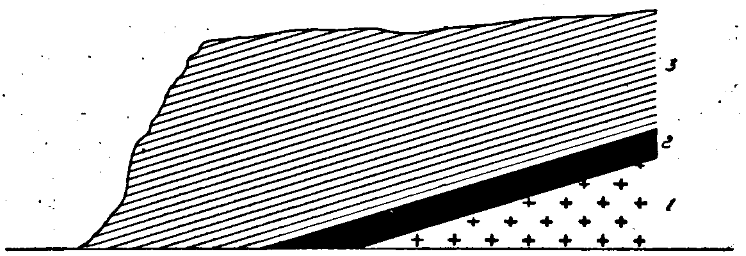


Fig. 13.

Section exposed in the western coast-cliff of Little Bay.
1. Porphyritic diorite.
2. Deposit of manganese.
3. Metamorphosed tuffs of the Pointe Blanche Formation.

Pt. Bl. formation are mineralised and rich in manganese or iron-ore and thus ore-deposits, apparently without economical importance, are formed. But also in this case the underlying igneous rock, a porphyritic diorite, is intrusive.

The decisive proof here and also in all other localities (fig. 14) is afforded by a closer study of the beds of the Pt. Bl. formation. They are strongly metamorphosed up to a considerable distance from the contact and it is doubtful, whether there occur on the island rocks of the tuff-formation which are not at all affected by metamorphism. Near the contact they are invariably recrystallized and converted into hornfels. As a rule the hornfels is rich in felspar, diopside and garnet. Samples of manganese of a locality south of Naked Boy Hill occurring, as at Little Bay, in the lowermost strata of the tuff-formation which overlies the basement rocks proved, on microscopical examination, to contain garnet [1]) in abundance. The rocks of the tuff-formation, besides being greatly affected by contact-metamorphism are also altered by later metasomatic processes, minerals such as amphibole and magnetite being formed by these processes. Prof. H. F. GRONDIJS who examined the manganese ore of St. Martin came to the conclusion that the manganese was introduced in the lowermost strata of the Pt. Bl. formation by hydrothermal solutions, after the period of contact-metamorphism.

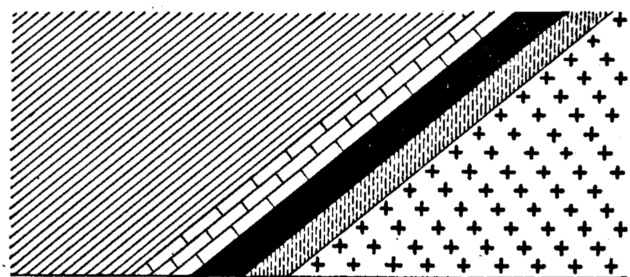


Fig. 14.

Section at the coast between Les Petites Caies and East End Point.

1. Porphyritic diorite, near the contact rich in epidote.
2. Hard flinty hornfels (19 cm.).
3. Iron-ore (22 cm.).
4. Limestone (28 cm.).
5. Metamorphosed tuffs of Pointe Blanche Formation.

Dykes of acid and more basic rocks closely allied to those of the igneous basement cut in several places through the overlying rocks of the Pt. Bl. formation, and are injected into them as well as in the basement rocks.

Due east of Philipsburg, in the coast-cliffs, are found injections of diorite-porphyrite in quartz-pyroxene-diorite of the basement, and somewhat more to the south, dykes of pyroxene-quartz-diorite cut straight through the beds of the Pointe Blanche formation. The hornfels near the contact is rich in diopside, garnet, and felspar. On the eastern slope of Fort Hill dykes of granite-aplite cut through the biotite-

[1]) Closely associated with the garnet another transparant contact-mineral occurs in the manganese-ore; this mineral has been examined by Mr. ter Meulen, who found it to be either hortonolito or a closely related olivine.

granodiorite and nearer to the top also through the Pt. Bl. formation which overlies this granodiorite.

At Anse heureuse a powerful dyke of a granophyric granodiorite carrying tourmaline cuts through porphyritic diorite of the basement, and loose blocks of simular dyke-rocks are found in the rolling country between Grande Case and Oyster Pond.

Fossils have not yet been found in the Pt. Bl. formation and thus its age cannot be proved by direct evidence. In the hilly peninsula between Cole Bay and the extreme southeastern past of Simson Bay Lagoon, which terminates towards the west in Pelicane Point the Pt. Bl. formation which according to SPENCER [1]) at that place has a dip of 40° towards N. W. is unconformably overlain by Old-Tertiary limestone which dips 15° S. W. [2]). From this follows that the Pt. Bl. formation must be of pre-Tertiary age.

In the year 1887 I came to the same conclusion by comparing the Pt. Bl. formation, its mode of occurrence and its general trend with an apparently identical formation occurring on Cuba, San Domingo, Puertorico, St. Thomas and the other Virgin islands, and on St. Barthélemy, concluding that the Pt. Bl. formation is of pre-Eocene, most probably Upper-Cretaceous age. I am still of the same opinion. VAUGHAN [3]) ,in the year 1923, for the older volcanic rocks of St. Thomas, including CLEVE's bluebeache states, that they seem to be of Upper Cretaceous age. This formation on St. Thomas is, as far as I can judge, identical to the Pt. Bl. formation on St. Martin.

The Simson-Bay formation. In the peninsula just south of Simson Bay occurs a thickbedded, hard, indistinctly stratified white limestone; this formation towards the east terminates in a steep escarpment, towards the west it projects into the sea at Pelicane Point. Its total thickness is about 70 m. The limestone dips 15° west-southwest and rests unconformably on the Pt. Bl. formation, as has been mentioned above. This unconformity can be seen very clearly from the extreme south-eastern part of the Simson Bay Lagoon in the steep northern slopes of the peninsula.

The limestone contains undeterminable casts of shells, mostly Gasteropoda, and also Foraminifera. Prof. UMBGROVE, who has microscopically examined this limestone, stated the presence of the following Foraminifera: *Miliolidae, Operculina, Gypsina* and *Alveolina.* The *Alveolina* belongs to the type with apertures arranged in a single row, which is characteristic for an Old-Tertiary age.

The limestone has been prospected unsuccessfully for phosphate of lime. The very limited quantities of phosphate proved to be confined to the vicinity of the numerous caverns and holes which occur in it, and

[1]) J. W. SPENCER. l. c., p. 526.

[2]) According to my observations made in 1885 the dip of the old-Tertiary limestone in about 15° W. S. W.

[3]) T. WAYLAND VAUGHAN. Stratigraphy of the Virgine island of the United States and of Culebra and Viegues Islands etc. Journ. of the Washington Acad. of Science, Vol. 13, p. 306, 1923.

probably the fosfor was extracted from dung of animals, who once lived in these holes. In these holes shells of land-snails and bones of large Rodents of the genus *Amblyrhizza* [1]) have been found.

The Low Lands formation. The greater portion of the Low Lands sonsists of a soft yellowish marly limestone, which lies unconformably in an undisturbed horziontal position on the Pt. Bl. formation .This limestone is of Miocene age. It appears to correspond in character and fauna with the Miocene formation of Anguilla. Both on Anguilla and on St. Martin *Echinolampas Lycopersicus Guppy* is common in this marly limestone.

Pliocene deposits are absent on St. Martin. From the fact, that the Upper-Cretaceous Pt. Bl. formation is much disturbed and tilted, that the Eocene formation is much less tilted, and that the Miocene formation is found in a perfect horizontal position may be concluded, that the island has been affected at least twice by orogenetic movements, once between the Upper Cretaceous and the Eocene time and again between the Eocene and the Miocene time. After the Miocene no disturbances of an orogenetic character have taken place.

Post-Tertiary and recent deposits. The coral-limestones which at sevaral points near the coast (see map fig. 9) are found up to an altitude not exceeding 6.5 m. above sea-level are probably of post-Pleistocene age.

The blown-sand formation found in the sand-bars which separate the lagoons from the sea may have originated in a sub-Recent time but is still now in mode of formation. The same can be said of the calcarynites and recent limestones consisting of shell-detritus with a calcareous cement, which are of frequent occurrence at the coast especially in the bays.

Upheavel and subsidence. As stated above the shoreline of the island of St. Martin is deeply embayed; the deep bays are most probably drowned valleys formed during a period of subsidence.

Positive proofs of such a subsidence have of late been afforded by borings made in the year 1919 in Groote baai with the object of studying methods to improve the condition of Philipsburg as a harbour. These researches were made by Mr. F. S. LANGEMEYER. In several of these borings [2]) in the Great Bay, at distances from the shore not exceeding 250 m., an old land-surface was found at depths varying from 9,1 to 11,6 m. below sea-level. This old land-surface consists of a somewhat ferruginous fairly coarse sandy soil with remains of plants and devoid of traces of marine organic life. The sand above this land-surface is of marine origin and is almost exclusively composed of small fragments of marine organisms. Below the old land-surface no remains of marine organisms were found in the borings.

The latest geological history of the Great Bay and its lagoon (and

[1]) E. D. COPE. On the contents of a bone cave in the Island of Anguilla. Smithsonian Contrib., Vol. XXV, Art. III.

[2]) Mr. F. S. LANGEMEYER has kindly put at my disposal the results attained by him.

also of the other comparable bays and lagoons on the island) may be reconstructed as follows:

In Pleistocene time during the Pleistocene ice-age the sea-level stood considerably lower than it is now. During that time the islands of St. Martin, Anguilla and St. Barthélemy, which all rise from the St. Martin plateau, the well defined edge of which lies 100 m. below sea-level, were united and formed one large mountainous, though finally greatly peneplainized and abraded island. On St. Martin the Great Bay and the Great Saltpan at that time were united and formed one broad valley, in which by fresh running water beds of more or less pure sands and in places also clays were deposited. Such sands and clays are found now in the borings in the Great Bay below the old land-surface. After the close of the Pleistocene the sea-level rose and the drainage in this valley became less perfect, the ground became marshy, the plant-remains were imperfectly oxydized and near the surface a somewhat ferruginous and peaty sand rich in plant-remains was formed This is the old land-surface of the borings in the bay. By continuous rising of the sea-level this great valley was slowly drowned and finally converted into a bay. In this bay the marine deposit was formed which is now found in the borings in the bay above the old land-surface. Later, by the influence of the eastern tradewind the sand-bar or beach of wind-blown sand was formed. This bar [1]) originally was attached to the shore near Pointe Blanche, grew out from there and finally stretched as far as Fort Hill cutting off the upper portion of the drowned valley from the lower, and converting it into a lagoon, which became a natural saltpan.

A small communication remained in existence between the bay and the lagoon at the foot of Fort Hill, permitting the sea-water to enter the natural saltpan during the hot dry season with strong evaporation, and also permitting the outlet of fresh water from the lagoon after heavy rains.

Later man has regulated this in- and outlet and then the Great Saltpan of to-day came into existence. This saltpan as well as several others in the island is still being worked. The two larger saltpans of St. Martin, the Great Saltpan and the Saline de Grande Case, produced during the years 1868—1917 on the average 60.839 barrels of salt annually. The smaller saltpans produced together during the years 1909—1918 25.345 barrels annually.

The best account published on the Salt industry on the island of St. Martin, written by C. J. HUDIG, is entitled: De zout-industrie op het eiland St. Martin. Weekblad De Ingenieur van 24 Mei 1905.

The borings mentioned above only prove that the rise of the sea-level cannot have been less than 11 m. In reality it certainly has been much more. According to VAUGHAN [2]) a submergence in Recent geological time to an amount of about 36 m. (20 fathoms) in the Virgin Islands,

[1]) The town of Philipsburg is built on this sand-bar.
[2]) T. W. VAUGHAN, l. c., p. 62, 1916.

on the St. Martin plateau and on the Antigua-Barbuda-bank, may be accounted demonstrated. In fact this rise of the sea-level on St. Martin forms part of the general well-known rise of the sea-level after the close of the Pleistocene ice-age, which in the tropics must have been most probably about 100 m.

A later much less important change of level of the islands finds its manifestation in the recent coral-reefs, which are found at many places along the coast (see map fig. 9). The maximum altitude to which these coral reefs are found is 6.5 m. above sea-level at Babit Point. This means, that in a time much later than that in which the above-mentioned important rise of the sea-level occured, a sinking of the sea-level of at least 6.5 m. took place. This is probably the same negative movement of the strand-line which DALY [1]) has proved to be world-wide.

[1]) R. A. DALY. A Recent worldwide sinking of Ocean-level. Geol. Mag.. Vol. LVII, pp. 246—261, 1920.