

# NOTES ON THE PHYSIOGRAPHY OF ST. CROIX, VIRGIN ISLANDS.\*

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**ABSTRACT.** The data presented result from four and one-half months field work in St. Croix during a program of test drilling for water supplies. The rocks making up the island are metamorphosed Cretaceous volcanics, including limestones, and intrusive diorite overlain by Tertiary clay, marl, and limestone. Pleistocene alluvium is widespread in the coastal plain area. The distribution of these rocks is shown in a geologic map prepared by the writer. The island was subjected to intense folding during the Antillean Revolution and to a milder compression in post Lower Miocene time. The structure of the Tertiary rocks is described in some detail.

In a discussion of physiography the two previously recognized early Tertiary peneplains are mentioned and evidence of a third early Tertiary cycle of erosion is presented. The evolution of the original post Lower Miocene drainage system of westward flowing streams to the present system of southward flowing streams conforms to the writers interpretation of the structure of the strata making up the coastal plain and is considered to explain the presence of certain outstanding topographic forms. Coastal terraces, emergent reef, and raised beaches, evidence of former higher stands of the sea, are described.

## INTRODUCTION.

### *Scope of investigation.*

A PROGRAM of test drilling for additional water supplies on the Island of St. Croix, Virgin Islands, was initiated in November 1938. The test wells were to be drilled on lands owned by the United States Government through an appropriation made by the Public Works Administration. The writer was assigned to the project and in addition to duties in connection with the drilling program, a detailed study of the geology and hydrology was made in the time available. This paper presents new concepts of the physiography of St. Croix, some of which have resulted from a detailed study of the Tertiary limestone plain, others of which are based upon information obtained in the drilling of deep wells.

### *Acknowledgments.*

During field work and preparation of the report the writer has been greatly assisted by the advice and suggestions of Mr. O. E. Meinzer, Geologist in Charge of the Division of Ground

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Water of the United States Geological Survey. Messrs. T. Wayland Vaughan, L. W. Henbest, and W. P. Woodring made paleontological determinations of material brought from the island. Other members of the Geological Survey have rendered advice and criticism of the manuscript.

Thanks are also due Mr. Boyd W. Brown, President of the Virgin Islands Company, and other officials of that company. Mr. Paul Schweitzer and employees of the Layne-Atlantic Company were helpful in obtaining all possible available data during the program of test drilling.

#### *Location.*

The Island of St. Croix lies about 95 miles south-southeast of San Juan, Puerto Rico, between latitude  $17^{\circ} 41'$  and  $17^{\circ} 46'$  and between longitude  $64^{\circ} 34'$  and  $64^{\circ} 54'$ . It is one of the Virgin Island group of which St. Thomas, St. John, and St. Croix belong to the United States. The island is about 21 miles long. The western part is about six miles wide but the eastern part tapers to a width of less than one mile.

#### *Topography.*

The western part of the island is made up of a mountainous area on the north flanked by a rolling plain on the south. The mountains are broken by many narrow, steep-sided valleys, through which intermittent streams discharge south or south-eastward across the plain. Fewer deeply incised streams flow directly westward in the area between Fredricksted and Ham Bluff. Blue Mountain and Mount Eagle, 1,090 and 1,165 feet above sea level respectively, are the highest peaks on the island. Other peaks attain elevations of 700 to 900 feet above sea level. A very little flat upland exists near Annaly, and streams have carved out two basin-like depressions of limited extent near Mount Eagle and Blue Mountain. Elsewhere high peaks and ridges and steep-sided valleys predominate.

The lowland area bordering the mountains has a diverse topography. Near Fredricksted on the west a gently undulating surface slopes seaward. In the central part of the island rounded hills make their appearance. In the eastern part of the lowland the topography is sub-mountainous. High hills and elongated ridges are common, and near Christiansted, where erosion has been least effective, a north-south belt of

high limestone hills cut by narrow valleys appears superficially to be part of the mountainous area. The lowland is drained by many intermittent streams, most of which trend southward. Salt River, however, discharges to the northeast.

That portion of the island extending eastward from Christiansted, locally referred to as "East End," is also mountainous. Here, however, the maximum elevations are less, the stream valleys are not as sharply incised, and intermontane alluvial areas are of more importance. Two lowland areas extend inland from Southgate Pond and Great Pond but are separated from one another by a low, narrow ridge.

#### *Work of previous investigators.*

Reports on various phases of the geology of St. Croix by American, Danish, and Swedish geologists have appeared intermittently since 1812, when William MacClure's generalized description of the island was published.<sup>1</sup> However, with respect to the subject at hand, special reference to but two papers need be given. The first, "The Building of an Island," by John T. Quin,<sup>2</sup> the village schoolmaster of St. Croix, who wrote a popular account of the island in order to interest his neighbors in the rocks and hills about them, is of importance in that it presents a structural interpretation of the Tertiary limestone plain which has been a stumbling block to later investigators. Detailed work in the Tertiary limestone plain has led the writer to formulate an interpretation quite at variance with Quin's ideas. The writer's conception of the erosional history of St. Croix is dependent upon and evolved from this new interpretation which will be summarized below.

Meyerhoff,<sup>3</sup> in 1927, published on the physiography of St. Croix and presented a detailed description of many of the important geologic and physiographic features. Specifically, Meyerhoff pointed out that the basinal valleys within the mountains at Fountain and in the East End area were carved out of

<sup>1</sup> An excellent annotated bibliography of the publications dealing with the geology of the Virgin Islands, "Geology of the Virgin Islands, Culebra and Vieques," was written by James F. Kemp and appeared in Vol. IV, Part I of the Scientific Survey of Porto Rico and the Virgin Islands and was published by the New York Academy of Sciences in 1927.

<sup>2</sup> Published by the author at Christiansted, V. I., 1907.

<sup>3</sup> Meyerhoff, H. A.: 1927, Geology of the Virgin Islands, Culebra and Vieques; Scientific Survey of Porto Rico and the Virgin Islands, Vol. IV, Part II, New York Acad. Sci.

less resistant intrusive rock, that certain drainage changes had occurred in consequence of damming canyon mouths by alluvial fans and that stream piracy had occurred in several places elsewhere, that the steep slopes extending from Canegarden to St. Johns were cuesta faces, and that evidence of recent uplift is seen in the uplifted recent sands making up Southwest Cape. Meyerhoff's study of the erosional surfaces of St. Croix and his comparison of St. Croix to St. Thomas and St. John has been most helpful and in part this work is a further treatment of problems recognized by him.

#### THE ROCKS.

##### *The Mount Eagle volcanics.*

The mountainous terrane of the island is made up of the Mount Eagle rocks of Upper Cretaceous Age.<sup>4</sup> These rocks have been variously described by different authors but all agree that a large part of the material is volcanic in origin, that much of it is stratified, indicating that the material is water-laid, and that some limestone beds are included in the series. The most common of the Mount Eagle rocks are dark bedded sediments of a slaty appearance, hard, thick to thin-bedded limestones, and bedded tuffs in which individual strata vary from an inch or two to as much as twenty feet in thickness. Volcanic breccias are important in some places. Dikes are rare. Diorite is intrusive into this series of rocks, and underlies the deep basinal valleys between Fountain and River, as well as the lowland area in East End.

##### *The mid-Tertiary clays and marls.*

The limy series of rocks making up the plain between Christiansted and Fredricksted was named the Kingshill series by Kemp.<sup>5</sup> Kemp's description applied to the series of moderately thick-bedded, buff to white limestones alternating with strata of soft yellow marl well exposed at the surface in many places and which have a minimum thickness of 600 feet. Deep drilling (Test Well No. 1) proved the existence of more than 1400 feet of underlying dark blue to gray clays and entirely sub-

<sup>4</sup> Vaughan, T. W.: 1923, "Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Islands, and Notes on Eastern Porto Rico." Jour. Wash. Acad. Sci., Vol. XII, pp. 303-317.

<sup>5</sup> Op. cit., p. 28.

ordinate conglomerates. In the second test well 309 feet of gray clay was found to be underlain by a minimum of 60 feet of hard limestone conglomerate. The basal conglomerate of Test Well No. 2 outcrops in the stream beds west and northeast of the estate at Jealousy. The gray clays do not outcrop anywhere as far as is known. The light colored marl lying at or near the surface will be herein referred to as the Kingshill marl. The dark clays and associated conglomerates are named the Jealousy formation. Microfossils found in drill cutting were studied by T. W. Vaughan and L. G. Henbest and it was found that the Kingshill marl ranges from Oligocene to lower Miocene in age and that the upper portion of the Jealousy formation is Oligocene in age. Mollusks from white limestones in the Kingshill marl were determined to be of probably lower Miocene age by W. P. Woodring.

*The alluvium.*

A large part of the area underlain by mid-Tertiary limy rocks is covered by Quaternary alluvium. The distribution of the alluvium in the mountainous parts of the island is much more limited, as noted on the geologic map, Text Fig. 1.

In the mountainous areas alluvium fills valley mouths along the sea but generally extends only a very short distance inland and is a corollary of the more youthful stage of erosional development of the hard rock areas. South of Christiansted a somewhat larger area of alluvial fill extends northwestward of Surlaine Point. Two other larger areas of alluvium are seen in the vicinity of Great Pond and Southgate Pond, where wide valleys have been carved from less resistant rock.

Within the northern mountain range at Fountain and Hermitage the erosion of similar rocks has resulted in two long valleys floored by alluvium. Within the Hermitage basin a maximum thickness of 40 feet of sandy and bouldery alluvial fill is exposed.

In the East End region the alluvium is made up of sandy and gravelly strata but also contains important amounts of clayey material. The maximum thickness of the alluvium is not known, but it is believed that a minimum thickness of 50 to 100 feet is present in the axial parts of the valleys, and a much greater thickness may be present in the areas underlain by granitic rock.

The Tertiary marl plain, however, shows the most important development of alluvium. At the foot of the mountains from Grove Place to Morningstar, alluvial fans have spread their load across a previously eroded lowland skirting the range. Southward the fans converge and give way to alluvial-filled valleys, but near the southern coast the alluvial valleys flare and coalesce and form a broad, low terrace along the coastline. Between Enfield Green and Whim to the west a broad alluvial area extends from the base of the mountains to the sea, but in the easternmost Tertiary marl belt alluvium fills young valleys which do not extend to the mountains but head in the high limestone hills.

Alluvium also covers much of the broad flat extending from Fredricksted to Spratt Hall.

Within the area underlain by limy rocks the fill contains sand and boulders derived from the older highlands but marly fill derived from the Tertiary rocks covers large areas or may alternate with sandy material in the valleys.

In Test Well No. 3 seventy-three feet of alluvial fill was penetrated. Inasmuch as this well lies along the axis of a major valley near the southern coast, the thickness probably approaches the maximum which might be expected anywhere on the island.

### *Coral Reef.*

The island of St. Croix is almost entirely surrounded by a fringing reef two miles in width along the south coast, but the width generally is less elsewhere. From Ham Bluff to the mouth of Salt River the reef is very poorly developed along a series of young fault scarps.<sup>6</sup>

Submerged reefs or banks are also present and have been discussed by Vaughan<sup>7</sup> and Meyerhoff.<sup>8</sup> A bank generally from six to ten fathoms deep and about one mile wide skirts the present reef along the south coast. For ten miles east of St. Croix this platform broadens and deepens and lies generally 11 to 16 fathoms below the surface. On the eastern extremity of this submarine platform Lang Bank forms a higher elongate

<sup>6</sup> Meyerhoff, H. A.: *op. cit.*, p. 181.

<sup>7</sup> Vaughan, T. W.: 1916, Some littoral and sublittoral physiographic features of the Virgin and northern Leeward Islands and their bearing on the coral reef problem: *Jour. Wash. Acad. Sci.*, Vol. VI, p. 56.

<sup>8</sup> Meyerhoff, H. A.: *op. cit.*, pp. 170-175.

creescent, the terminals of which point westward and enclose East Point, the eastern extremity of St. Croix. Lang Bank lies eight to ten fathoms below the surface and appears to have been a barrier reef at one stage in the islands development.

A still lower reef is also present. It is very narrow and lies generally 12 to 20 fathoms below the surface and rims the next higher bank.

Beyond the reefs the sea floor deepens steeply along the south coast, more steeply east of Lang Bank, and precipitously at Ham Bluff where the bottom descends from 40 to 818 fathoms, over 4600 feet, in one mile.

Remnants of a fossil reef now elevated a few feet above the present sea level are to be seen at Ham Bluff and Cane Bay on the north side, in the vicinity of Cottogarden on East End, and in a very few other places. In some places they are overlain by beach sand.

#### *Beach sand.*

Narrow, discontinuous beaches between rocky headlands characterize the coast of St. Croix. Most of these beaches are of very recent age and are being modified in some degree at present. Meyerhoff<sup>9</sup> has pointed out that most of the Southwest Cape area represents an uplifted area of beach sand. Other fossil beaches of smaller extent have been noted by the writer in the vicinity of Little Princess (northwest of Christiansted) and Cottogarden Bay (East End) and elsewhere.

#### STRUCTURAL GEOLOGY.

The older Mount Eagle rocks were strongly folded in the late Cretaceous or early Tertiary Antillean Revolution and are everywhere steeply inclined. The folding has been complex and the delineation of specific structures is a difficult task. However, for the purposes of this paper details on the structure of these rocks need not be discussed.

Quin<sup>10</sup> has written at length upon the structure of the younger Kingshill rocks which make up the marly plain. He shows that these rocks dip seaward at their contact with the old rocks at the foot of the mountains. The seaward dip is not maintained, however, across the marly plain, and the rocks are folded along various axes as follows: a northeast-southwest

<sup>9</sup> Meyerhoff, H. A.: op. cit., p. 177.

<sup>10</sup> Quin, John T.: op. cit., pp. 20-33.

synclinal axis passing through Rattan in the northeast, a syncline passing northwest-southeast through Golden Grove and another parallel to it through Adventure in the central part of the island, and an anticline passing northeast-southwest through Hannah's Rest, southeast of Fredricksted. These interpretations have been checked by the writer and it was found that the Rattan syncline is present as stated, synclines are present at Golden Grove and Adventure, but their axes do not trend northeast-southwest, and there is no evidence for an anticline passing through Hannah's Rest.

A structural interpretation of the Tertiary limestone area is given below which is in part at variance with Quin's interpretation. It is entirely based upon field observations made by the author and upon data obtained in the drilling of three test wells.

The Tertiary rocks rest unconformably upon an eroded surface of the Mount Eagle rocks. On the north the contact of these rocks lies along the foot of the mountains from Wheel of Fortune to the mouth of Salt River but, due to the masking by aluvium, the contact is sharply defined in only a few places. In the stream beds west of Jealousy, northeast of Jealousy, and at St. George, the boundary was well defined but in no one of these three localities was the actual contact of the basal limestone conglomerate upon the Mount Eagle rocks observed. At St. George the attitude of the basal conglomerate could not be determined but at the other two localities mentioned the dip varied from 15 to almost 40 degrees to the southeast near the contact. The slope of the underlying rock surface was not exposed. The data brought to light by Test Well No. 2 shows that there the older basement rock floor lies 460 feet below the surface, as shown in Text Fig. 2. The surface of the basement rock therefore slopes south-southeastward at an angle of more than 24° in this vicinity.

From the mouth of Salt River to St. John the Kingshill limestones lie upon a gently warped plane which slopes to the southwest about 400 feet per mile or slightly more than 4°.

Between St. John and the Leper Asylum the limestone descends below sea level, but from the Leper Asylum to Cane-garden on the south coast the contact lies above sea level and its location was determined with fair accuracy in a number of places. From the Leper Asylum to Beeston Hill the line of contact rises to an elevation of 350 feet above sea level and lies at a

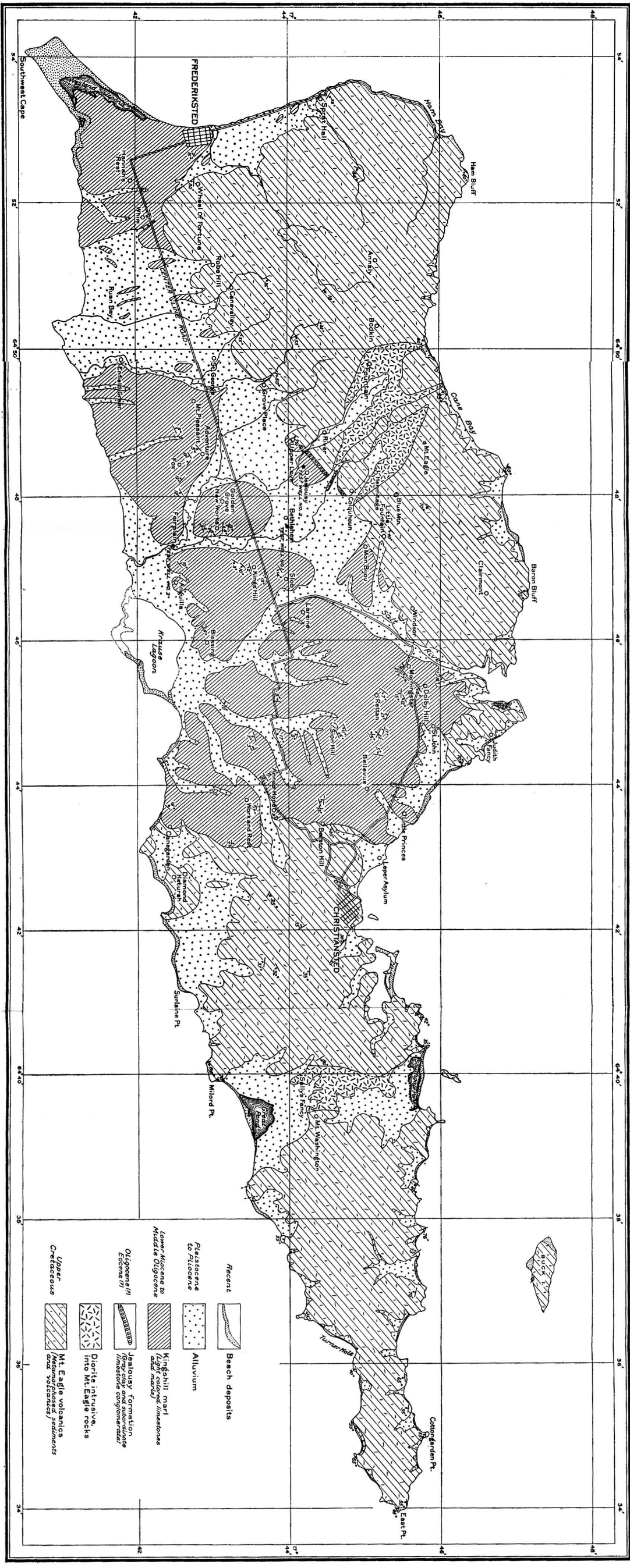


Fig. 1. Geologic Map of St. Croix, Virgin Islands, U. S. A.

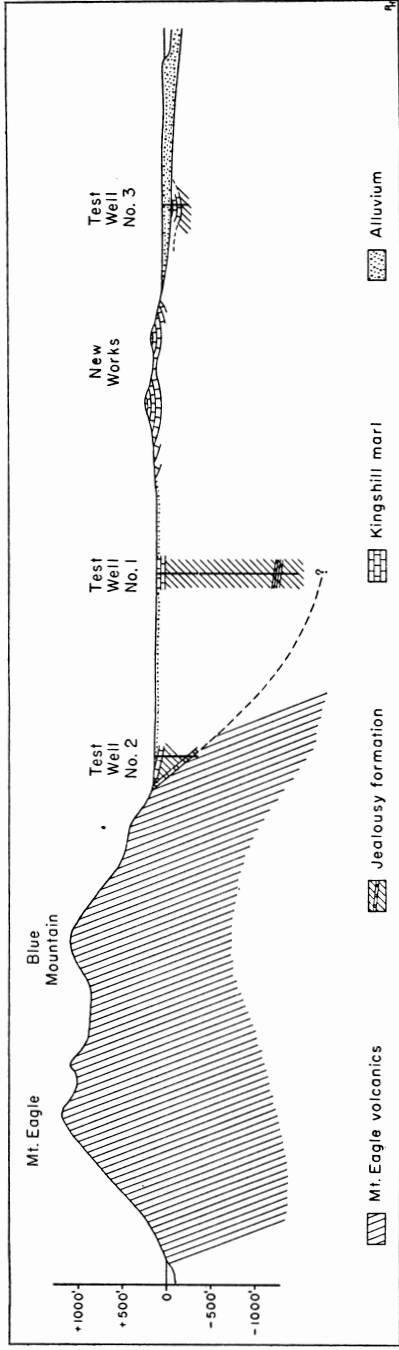


Fig. 2. Cross section of central St. Croix showing location of test wells with reference to geology.

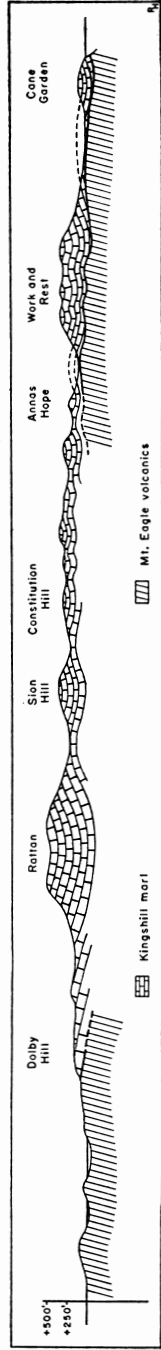


Fig. 3. Generalized cross section of the Tertiary limestone plain, St. Croix, V. I.

comparable elevation on Work-and-Rest Hill to the southeast. At the last named locality the plane of contact slopes westward about 530 feet per mile or  $5\frac{1}{2}^{\circ}$ .

Gentle southwest inclination of the surface of the basement rock can not account for the low elevation of the limestone between St. John and the Leper Asylum, and it is apparent that either the basement rock surface was strongly channeled before the deposition of the limestones or that the basement rock and the limestones were strongly folded after the deposition of the Kingshill marls. Data on the elevation of the base of the limestones in the central part of the island, Text Fig. 2, indicates that these rocks are not greatly infolded and it is therefore believed that the first alternative is correct.

Definitive exposures of the Kingshill marl within the central plain are few. Except along the coast line where the action of waves has produced fine cliff faces, naturally occurring outcrops are very scarce indeed. However, enough data have been obtained to delineate the main structural trends in several different parts of the limestone plain, and these various data are considered sufficient to make possible a characterization of the plain as a whole.

Most instructive localities with respect to the structure of the limestone strata are the two small hills east of Golden Grove. New Works Village lies between the two hills. These hills have been quarried for their blocky limestones and a more or less continuous series of outcrops girdles each hill a short distance below its crest. It is easily determined that these two hills are synclinal and that the breach between them, in which New Works lies, is an anticline. (Text Fig. 2.) The axes of the folds appear to extend east-west or even in a west-southwest to east-southeast direction.

The two hills at Adventure and Fox have a similar origin. The strata are even more gently folded but synclinal structures are certainly present and make the hills. The axes of folding trend more nearly in a northeast-southwest direction parallel with the Center Line Road.

At Kings Hill Police station the strata dip southeastward. There are not sufficient outcrops along the hill extending to the south to state definitely that the rocks are folded as at the two localities discussed above, but a reversal of dip (dip to the northwest) near Auguilla suggests that they are.

Sion Hill to the northeast is also a synclinal hill. The structural axis trends northeast-southwest.

A more or less continuous series of observations taken along the road from Bellevue through Rattan to Dolby Hill indicate that Rattan lies within a much broader syncline whose axis trends north-northeast and south-southwest. As noted above, this structure was mapped by Quin.

Other field observations strongly suggest folded structures but do not define them as conclusively as those already described because exposures are lacking at critical points. The fine series of exposure along Canegarden Bay show that the strata are dipping to the northwest, and it is thought that these rocks form part of a synclinal limb. The prominence on which the estate at Canegarden is located may mark the axis of the syncline. One excellent exposure on the east-facing scarp of Work and Rest Hill suggests that the southerly eminence marks a synclinal axis, and another on the north side of the hill indicates that the northerly point is also a synclinal axis, and that the course of the stream flowing between Work and Rest Hill and Anna's Hope follows an anticlinal crest. These structures are shown in Text Fig. 3.

The fine exposure along the road at Anna's Hope shows the limestone strata dipping southwest. This marks the axis of the synclinal fold which has formed the hill upon which the estate is located.

The structure of the area underlain by the Kingshill marl may therefore be characterized as follows: the rocks in the central and eastern part of the area have been compressed into a series of closely spaced, open folds, the axes of which generally trend northeast-southwest, but departures from this trend are seen at Rattan and at New Works. In the eastern and east central area the folds plunge from  $6^{\circ}$  to  $14^{\circ}$  to the southwest. The axes of the folds at New Works and at Adventure appear to be horizontal. Very little of the structure of the underlying rocks extending from Spratt Hall through Fredricksted to Enfield Green could be learned. The writer agrees with Meyerhoff<sup>11</sup> who questions the presence of the anticline passing southwest through Hannah's Rest which was mapped by Quin.

However, at this point the Tertiary events which brought about the present geological structure may be reviewed. In Oligocene time an area of sedimentation was formed in the deeper portions of which more than 1400 feet of clays accumulated. The basin gradually filled and as waters shallowed an

<sup>11</sup> Meyerhoff, H. A.: *op cit.*, p. 164.

extensive growth of coral covered the area of clayey sedimentation. The line of contact of the limy rocks with the old Mount Eagle rocks from the mouth of Salt River to Canegarden indicates that the basin was trough-like. The depth to bedrock is unknown at Little Princess where the limestones extend below sea level. The trough probably extends west-southwestward under the plain and near Bethlehem lies more, possibly considerably more, than 1400 feet below sea level.

The gentle folding of the sediments along west-southwest to east-northeast axes has already been described. Steeply dipping rocks along the foot of the mountains may be the resultant of a low dip due to deformation and a high initial dip. That component of the dip due to deformation may be greater than usual along the foot of the mountains, where the Tertiary strata were forced against a resistant old land.

Interruptions in the plunge of the axes of folds indicate that the Tertiary limestone plain may be cross-faulted although but little other evidence of faulting is found in the area. However, Vaughan<sup>12</sup> has pointed out that land connections between St. Croix and other islands to the west and north existed in middle Tertiary time and previous to middle Tertiary time St. Croix was probably connected with St. Thomas and Porto Rico by submarine banks. Profound faulting, concomitant with the folding of the Kingshill marl, severed these connections and resulted in the formation of deep fault troughs such as the Anegada Passage off the north coast of St. Croix. The young fault scarp topography along the north coast is evidence that faulting has greatly affected that part of the island. As a working hypothesis therefore, the eastern part of the limestone plain is regarded as a fault block which has been tilted to the south-southwest. The central and western portion of the island may be relatively undisturbed or may have been tilted gently in the same direction.

#### PHYSIOGRAPHY.

##### *Summary.*

The present land surface of St. Croix began to be shaped shortly after the accumulation and deformation of the Mount Eagle rocks of Upper Cretaceous age. In early Tertiary times a land mass much greater in size than the present island of St. Croix was beveled to a rolling plain. Eocene (?) uplift

<sup>12</sup> Vaughan, T. W.: *op. cit.*, p. 316.

and subsequent erosion resulted in a mountainous topography characterized by high relief and moderate ruggedness, and a still later uplift initiated a third cycle of erosion. In middle or upper Oligocene times submergence occurred, and in the deepest valleys clayey sediments accumulated. As the waters cleared and shallowed, great reefs girdled the island, and extensive limy sediments were deposited above the clays. The Oligocene and Miocene sediments thus formed were then gently folded and faulted, and the island was uplifted. Streams tended to follow the old valleys southward out of the mountains, but upon entering the area of folded limestones they were deflected to the west-southwest. This west-southwestward drainage was encroached upon by streams originating along the southern coast, and by a series of stream captures the drainage was deflected generally southward. The 10- to 40-fathom submarine bank was probably cut at this time. A partial inundation of the island followed, terraces were formed along the coast, and the choked stream channels leading to them built up wide, flat valley floors. During Pleistocene times a low stand of the sea ensued and the 6-fathom submarine bank was built. The water level recovered its previous height, but a slight emergence of the land has recently occurred.

These phases of the development of the present topography will be discussed in more detail below.

*The early Tertiary erosion cycles:* The upland surface, about 800 feet above sea level, may be observed to good advantage in the vicinity of Annaly, in the northwestern mountainous part of the island. Here a picture of a once extensive, rolling plain is immediately apparent. An observer looking east from Bodkin is even more impressed with concordant summits and ridges.

Meyerhoff,<sup>13</sup> in his excellent work on the physiography of St. Croix, discusses the correlation of this peneplain with dissected surfaces of the northern islands. He notes that "it appears to be equivalent to the St. John peneplain of the northern islands," which lies at 1,000 to 1,200 feet above sea level. However, there is "no intermediate erosion surface in St. Croix between the upland and the lower peneplain upon which the Coastal Plain was deposited" as has been found in the northern Virgin Islands, hence he tends to regard the upland peneplain of St. Croix as the second cycle level rather than the first

<sup>13</sup> Meyerhoff, H. A.: op. cit., pp. 152-156.

cycle, although he points out that the intermediate cycle may be masked by Coastal Plain deposits or have been destroyed by erosion.

The highest, or St. John peneplain, as he points out, is represented by the upland at Annaly. The next lower peneplain is rather poorly developed but is represented by the gently rolling basin floors near Fountain and Hermitage. The beveled spurs from Little Fountain to Windsor may likewise have been formed during the cycle of erosion. Part of this surface was and still is covered by Tertiary sediments, and it is thought that in the eastern part of the island the second-cycle erosion surface extended from the mouth of Salt River Bay to St. John and from Beeston Hill to Canegarden. The intervening area, St. John to the Leper Asylum, marks the locus of a deep channel belonging to the third cycle of erosion (Text Fig. 4).

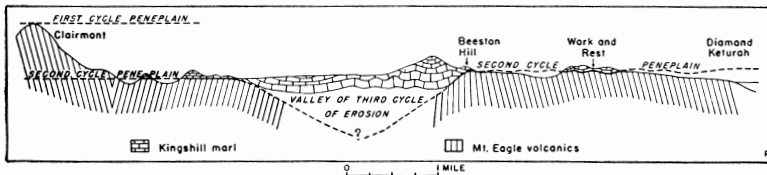


Fig. 4. Cross section showing development of early Tertiary erosion surfaces.

The third cycle of erosion, represented by the channel extending from St. John to the Leper Asylum, is also revealed by the records of the test wells at Jealousy and Bethlehem. The record at Jealousy indicates that the bedrock surface slopes about  $25^{\circ}$  to the southeast in that vicinity in contrast to the gentle slope of the beveled spurs developed in several places along the foot of the mountains nearby. The record of the well at Bethlehem indicates that the slope of the bedrock surface is more than 1,100 feet per mile in a southeast direction.

The meager data at hand, therefore, indicate that the third cycle of erosion has developed a youthful topography within the area of mature topography of the second cycle.

In the East End area, it appears that the highest peneplain has been completely dissected but the erosion surface of the second cycle may be represented by the summits of low hills around Southgate Pond, and that the third cycle of erosion has been effective in cutting the lowland in which Great Pond and Southgate Pond are located.

From geological similarities to Puerto Rico, where a more complete record is available, Meyerhoff<sup>14</sup> postulated that there the peneplain of the first cycle was developed in Paleocene and Eocene (?) time, the second-cycle partial peneplain in Eocene time, and a third-cycle partial peneplain in lower Oligocene time.

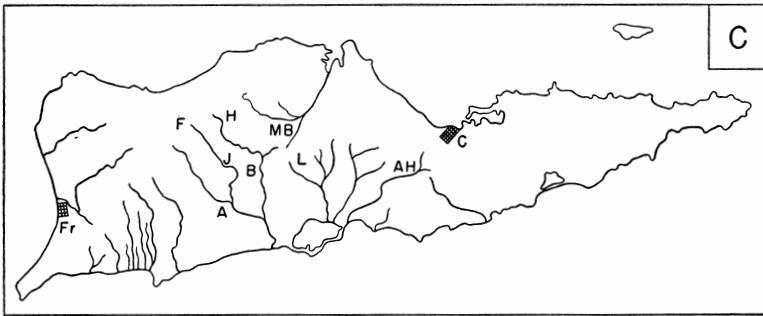
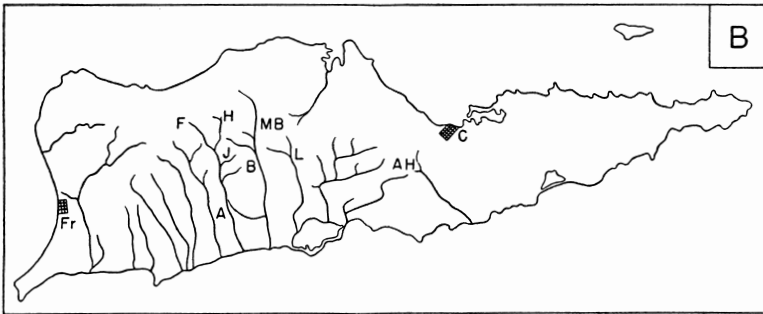
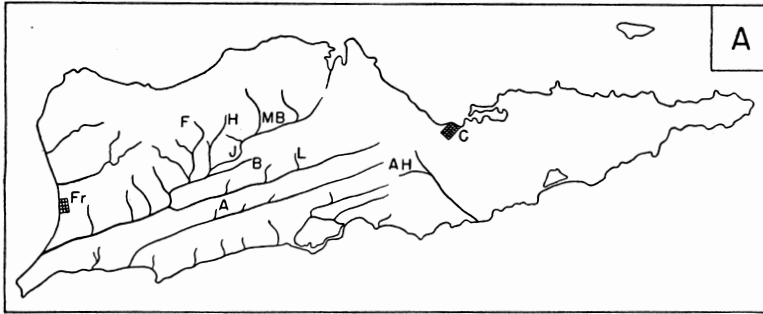
*Development of the drainage pattern:*

After the deposition of the lower Miocene sediments the island was gently folded and uplifted, and streams again began to run their courses. Although the early Tertiary valleys within the mountains were partly filled with soft limestones, stream action quickly excavated them, and in general the old channels are still followed. The streams originating in the northern belt of mountains and flowing southward encountered the folded series of limy rocks at their canyon mouths and became at first consequent upon their westerly slope. They tended to breach the gentle anticlines, however, and became sub-sequent to the structure but still flowed in a west-southwesterly direction. (Text Fig. 5A.) In this stage streams entering upon the limestone plain at Windsor, Little Fountain, Colquhoun, Mt. Pleasant, Upper Love, Grove Place, St. George, Robe Hill, and intermediate points were interrupted and turned to form a large stream parallel to the foot of the mountains, which discharged in the vicinity of Westend Saltpond. Several other smaller and shorter streams paralleled the trunk stream on the south and flowed in the same direction. Salt River was an extremely short, infant stream and flowed northward.

This hypothetical early stream pattern, which is based in large part upon observed structures, is considered to explain the presence of the central St. Croix inner lowland, a broad topographic lowland which lies between the mountains on the north and the rolling hills on the south. It also explains the advanced stage of erosion of the southwestern part of the island, which sharply contrasts with the topographically younger eastern portion of the limestone area. A few streams in the eastern Tertiary marl area still retain the initial drainage pattern and maintain south-southwest courses subsequent upon the structure.

However, small streams normal to the southern coast line began to work headward almost immediately, piracy of the

<sup>14</sup>Meyerhoff, H. A.: op. cit., p. 100.



A - Adventure AH - Annas Hope B - Bethlehem C - Christiansted  
 F - Fountain Fr - Fredericksted H - Hermitage J - Jealousy L - Lareine MB - Mon Bijou

Fig. 5. Sketch maps of St. Croix showing changes in drainage since Mid-Tertiary Time.

westward flowing streams commenced, and the second stage in the drainage pattern (Text Fig. 5B) was attained when the streams working headward from the coast had diverted nearly all the drainage southward. The pattern in the western and central part of the limestone plain was characteristically one of approximately north-south streams with short unimportant tributaries. The eastern portion of the limestone plain received no stream flow from the mountain area on the north or east, and as a result erosion proceeded more slowly, and the initial drainage pattern of streams subsequent upon the structure tended to persist. However, even here many adjustments towards establishing north-south drainage lines were made.

As time went on streams with larger flow or favored by softer rock channels entrenched themselves more rapidly than neighboring streams, and their tributaries were enabled to pirate the less deeply incised streams. The stream carrying the Little Fountain drainage flowed southward west of Mon Bijou and near Bethlehem joined the stream flowing from Hermitage basin. (Text Fig. 5B.) Below Bethlehem, therefore, the stream was larger and cutting its channel at a faster rate than the adjoining stream draining the Fountain Basin, which flowed almost directly southward and discharged west of Fairplain. This latter stream fell prey to a tributary of the former stream and was added to the larger system. In like manner the stream passing west of Adventure was incorporated in the major system.

However, losses were being sustained; the Little Fountain drainage was diverted southeastward past Lareine (a stream here is postulated to explain the low divide at this place) but still later (Text Fig. 5C), the Salt River gnawed headward and one tributary pirated the Little Fountain-Lareine drainage above Mon Bijou and a second tributary advanced southwestward and shortened the Lareine system still further. In the extreme eastern part of the plain remnants of the initial and intermediate stages of stream development still persist. The somewhat archaic pattern of the stream flowing past Anna's Hope will remain unchanged, because the stream itself has captured a portion of the drainage formerly discharging southward past Catherines Rest and is now deeply entrenched.

As noted above, very few changes in drainage pattern within the area of hard rocks have been detected and, in fact, few are

to be expected. However, it may be noted that the Hermitage and Fountain basins exist because of the presence of dioritic rock which is less resistant than the surrounding rock. It is certainly anomalous that the present streams draining those basins leave their soft rock channels and cross harder rocks a short distance before entering the limestone plain. The channel draining Hermitage heads in dioritic rock but leaves the channel extending to Colquhoun and now spills almost directly southward across a hard-rock belt to discharge onto the Tertiary limestones near Jealousy. Similarly the stream draining the Fountain basin has left a dioritic-rock bed and now discharges across harder rock near Upper Love.

It is thought, therefore, that the older channels draining the basin originally extended southeastward along narrow extensions of the less resistant granitic rock mass but that their courses were modified as a result of superposition from the limestone which filled the basins in Miocene time. When the Kingshill limestones were deposited, both Fountain and Hermitage basins were filled with several hundred feet of limy sediments. After the folding and uplift of the island, streams began to flow along courses determined by the topography and structure of the underlying rocks and within the basins being discussed, fairly well developed streams tended to follow the more or less southwest trend of the folded limestone rocks. However, distortion of the general west-southwest structure probably occurred, inasmuch as the limestones were quite thin and rested upon a very irregular surface, and hence the exact course of the initial streams here can not be definitely stated. The stream flowing from Hermitage probably passed south or southwestward past Upper Love. The stream from Fountain may have discharged near Grove Place and was in part limited by the hard rock walls of the limestone-filled basin (Text Fig. 5A). A tributary of the stream flowing past Jealousy on the west, working in a low swale filled with Tertiary rock, pirated the Fountain-Grove Place stream which had uncovered resistant rock in its course at a high elevation (Text Fig. 5B), and also acquired the drainage from Hermitage. These streams cut their channels and were in time superimposed upon rocks of unequal hardness. Because these streams were relatively large and therefore able to actively cut their channels, the channels have been largely maintained to the present. The lower course of the Hermitage

stream, however, was pirated by a stream working northwestward along the narrow belt of softer granitic rocks which extend southeast from Fountain (Text Fig. 5C).

*Erosion of the Tertiary limestone plain:*

The land forms within that part of the island underlain by Tertiary limestone which have resulted from the development of the drainage pattern as outlined above may be classified as follows: an eastern area of early mature topography, a central area of late mature topography, and a western area of old-age topography. The hard rock mountain highlands have lagged and are only a little more advanced in erosional stage than at the beginning of Miocene times.

The eastern limestone area extends from Lareine to the sea. Its dominant feature is a northeast-facing scarp which extends from Beeston Hill to Dolby Hill and which was developed in response to the southwest tilt of rocks in that area. Meyerhoff<sup>15</sup> has noted the terraced effect of this scarp and ascribes the terracing to alternation of strata of unequal hardness. From Beeston Hill southward to Canegarden the scarp has been badly eroded but a well-preserved remnant is seen in Work and Rest Hill. Southwestward of Dolby Hill the scarp is developed along the strike of the northwest limb of the Rattan syncline. Thus the scarp has the form of an arc facing northeast.

Within the area encompassed by the arc a few valleys trend east-northeast and west-southwest. These have been formed by subsequent streams which have breached gentle anticlines; the gap south-east of Beeston Hill and the valley between Anna's Hope and Work and Rest are typical. Ridges developed along synclines are a corollary to anticlinal valleys; Sion Hill and the high ground about Rattan are examples. The many ridges and valleys which trend north and south have little relation to structure but have resulted from a natural evolution of drainage whereby streams seek the shortest path to the sea.

The central part of the limestone plain is a region of late-mature topography and may be characterized as a broad, rolling lowland interrupted from place to place by rounded hills. The "inner lowland" attains its maximum development here and is a broad, gently sloping plain underlain by a variable thickness of alluvium. A belt of limestone hills more than 300 feet

<sup>15</sup> Op. cit., pp. 166, 167.

in elevation lies between the inner lowland and the sea. Some of these are rudely circular in plan, but others are elongate ridges which roughly parallel the main drainage lines. The circular hills are single or composite synclinal ridges, which have been separated into isolated eminences by erosion. They generally have a steep scarp facing north and a gentler slope to the south as a normal consequence of a general southward drainage. Were the drainage northward the now protected southerly slopes would be the steeper. The elongate ridges have developed concomitant with the north-south drainage. The rounded "peaks" which appear along them from place to place probably reflect the structure. Continued erosion will gradually tend to breach the ridges and leave scattered isolated hills.

South of the inner lowland, a few narrow, alluvium filled valleys cut across the rolling hills, but along the coast the valleys widen out into broad, alluvium-covered terraces, which slope gently towards the sea.

The western unit of the area underlain by Tertiary marl extends from Enfield Green westward to the sea. It is a gently southward-sloping plain of a very low relief. Marl lies at the surface in the westerly part of the plain in contrast to the area lying between Whim and Enfield Green, which is almost entirely covered with alluvium.

The beveling of this part of the island to an almost featureless plain took place shortly after the deposition of Miocene sediments, at which time a maximum part of the drainage from the northern range of mountains spilled west-southwestward across this area.

The differences between the topography of that almost featureless part of the plain covered by alluvium and the immediately adjacent area to the west characterized by low rolling limestone hills are not without significance, and have resulted from differences in position relative to the mountains. The alluvium-covered area receives the drainage from Robe Hill, Canevalley and St. George, and streams from those canyons have eroded the few scattered hills that remained after the initial post-Miocene streams had been diverted elsewhere. The result was an almost perfectly beveled plain, which became veneered with alluvium at a later time. The most westerly part of the island, however, receives practically no drainage from the mountains and hence has tended to retain the minimum

topographic relief it had when the main drainage lines of the limestone area were diverted to more easterly courses.

*The coastal terraces:*

The post-lower Miocene erosion of the area underlain by mid-Tertiary marl resulted in a gently rolling to moderately rugged land surface, across which a number of streams had cut relatively deep V-shaped channels. Sea level stood at various depths greater than 40 feet below present sea level and it was during this time the 10- to 40-fathom submarine bank was formed, either by erosion or reef growth or both.

Later there was submergence of the island and the sea stood at an elevation of about 30 feet above present sea level. The streams became choked and alluvial fans spread out over the inner lowland. Along the coast the waves and currents cut cliffs in the limestone hills, and on the rock-cut benches, a series of deltas radiating from the valley mouths built up a broad flat terrace.

The coastal terrace is best observed encircling Krause Lagoon. Here it extends coastwise for more than 4 miles and in places is as much as three-quarters of a mile wide. At Anguilla, in the vicinity of Blessing, and elsewhere, the limestone hills rise abruptly above the terrace and present toward it a rather definite clifflike face.

In the Ruan Bay area the coastal terrace is likewise well developed, but mountainward it merges with the alluvial apron extending from the canyon mouths. No seacut cliffs or nips are present, because in this almost completely beveled area the sea encountered no steep slope to work upon, and the erosional force of the encroaching sea was greatly impaired. A similar terrace extends from Fredricksted to Spratt Hall—it too merges with (and may be partly covered by) the alluvial fans of the canyon mouths.

Remnants of these terraces of small areal extent are recognized in several localities in various parts of the island. At Ham Bay, a particularly fine face of flat boulders in a clayey matrix is exhibited. (Text Fig. 6A.) Other small patches are seen at Cane Bay along the north coast, and at Cottongarden and Turner Hole in the East End area, Text Fig. 6B and C.

Flood plains of streams extend mountainward from the level of the coastal terraces. In many places the wide, flat valleys

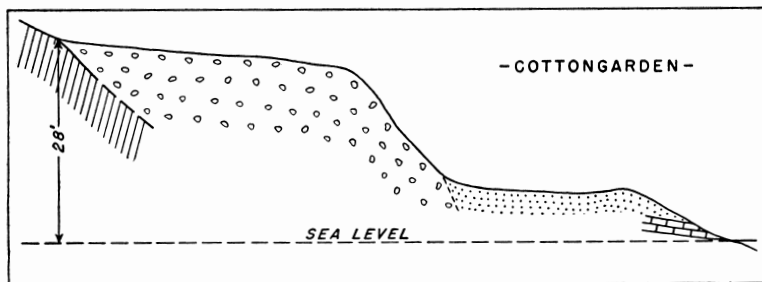
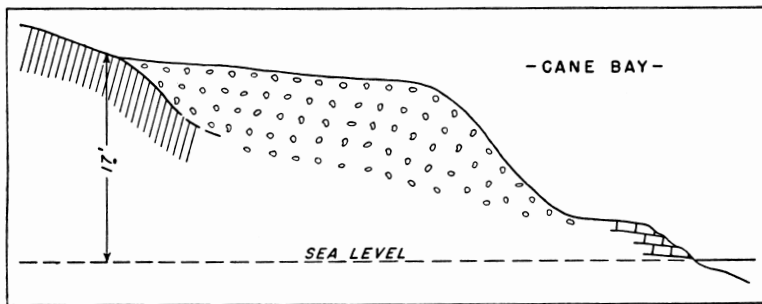
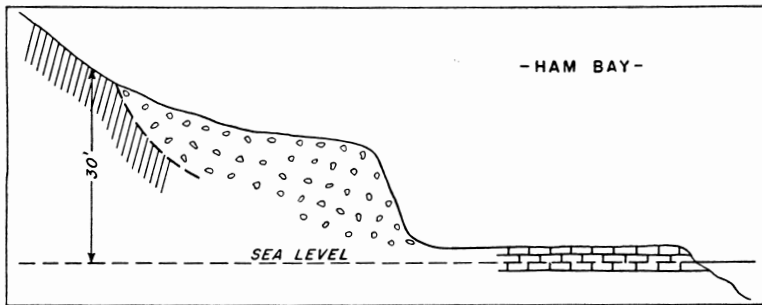


Fig. 6. Geologic sections of coastal terraces.

between low, rounded hills are beautifully formed and attain their greatest development and coalesce laterally to form a continuous plain for over 5 miles parallel to the foot of the mountains along the inner lowland. This plain is traversed from place to place by intermittent streams and locally may slope gently toward these streams. The low, rounded cross-sectional profile characteristic of alluvial fans appears to be lacking or very poorly developed in the area underlain by mid-Tertiary limestone, but typical alluvial fans have been noted in several places in eastern St. Croix.

Comparable effects of relatively recent submergence have been noted in other West Indian Islands. At Guantanamo Bay,<sup>16</sup> a 40-foot terrace is well developed and was probably formed since the beginning of the Pleistocene. In Haiti<sup>17</sup> it is reported that "there is no evidence to indicate that any of the terraces (of the Northwest Peninsula) are older than Quaternary." In Puerto Rico<sup>18</sup> a 40-foot submergence is said to have taken place in Recent time.

A still lower terrace is indicated by the presence of emergent beaches and coral reefs. The beaches are generally of small extent and occupy reentrants between the hard rock spurs, which extend to the coast and form headlands, as at Cotton-garden and Turner Hole, Text Fig. 6. An emergent beach is well developed along the shore north of Little Princess. Meyerhoff has pointed out that Southwest Cape, a late addition to the island, built up of limy sand by the action of ocean currents, has been recently uplifted.

Emergent coral reefs have been recognized only at very low elevations. At Ham Bluff a platform of coral limestone about 30 feet wide lies not more than 3 feet above sea level. An emergent reef is also particularly well displayed at Cane Bay, Text Fig. 6. Elsewhere it is present only in very small patches.

#### SUMMARY OF PHYSIOGRAPHIC HISTORY.

1. Sediments, lavas, volcanic muds and ashes in upper Cretaceous times accumulated upon a submarine bank extend-

<sup>16</sup> Meinzer, O. E.: 1933, Geologic reconnaissance of a region adjacent to Guantanamo Bay, Cuba. *Jour. of the Washington Acad. Sci.*, Vol. 23, pp. 256-258.

<sup>17</sup> Woodring, W. P., and others: 1924, "Geology of the Republic of Haiti." Republic of Haiti, Dept. of Public Works, p. 374.

<sup>18</sup> Meyerhoff, H. A.: 1933, "Geology of Puerto Rico," Monographs of the University of Puerto Rico, Series B, No. 1, p. 179.

ing from St. Croix to Porto Rico. These rocks were folded in late Cretaceous or early Tertiary times and intruded by dioritic magma.

2. A long period of early Tertiary erosion ensued during which the St. John peneplain was formed. Subsequent uplifts are represented by a lower incomplete peneplain and by youthful valleys of a third cycle of erosion.

3. Submergence and accumulation of Oligocene and Miocene sediments. Miocene emergence followed and was accompanied by gentle folding and profound faulting and tilting of fault blocks.

4. Emergence initiated at interval of rapid erosion of the newly deposited limestones. The original consequent west-southwestward drainage of the central plain adjusted itself to a north-south pattern. The inner lowland of the limestone plain was formed by the original west-southwestward flowing streams. The original pattern is preserved in part in the eastern portion of the limestone plain. Anticlinal ridges and synclinal valleys are found in the eastern and central part of the limestone plain. To the west the area is almost completely beveled.

5. Submergence of the island in Quaternary time resulted in the formation of the 30-foot coastal terrace and the aggradation of previously eroded areas.

6. Subsequent emergence of the island is recorded by the narrow 6-fathom bank encircling the living reef.

7. A higher stand of the sea, about 5 feet above present sea level, is recorded by fossil reefs and raised beaches.

8. Sea fell to present level.