Geology and Ground-Water Resources of St. Croix Virgin Islands

By D. J. CEDERSTROM

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Ground-water resources of a moderately dry Caribbean island

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ABSTRACT

Field work in the island of St. Croix, V. I., was carried on from December 1938 to April 1939 in connection with a test-drilling program for water supplies. The island is 21 miles long and has a maximum width of 6 miles. Its western part consists of a range of mountains flanked on the south by a rolling plain; its narrower eastern part is entirely mountainous. There are only a few small streams. The rolling and flat lands are cultivated or are in grass, and the mountainous areas are either wooded or in grass. The average rainfall of the island is 46.34 inches, but severe droughts and periods of excess precipitation are not uncommon.

The island is made up of rocks of Upper Cretaceous age, mostly volcanic tuffs and limestones known as the Mount Eagle volcanics; diorite intruded into the cretaceous rocks; and Oligocene to Miocene blue clays and yellow marls (the Jealousy formation and Kingshill marl, respectively). Alluvium is widely distributed. The Mount Eagle rocks were strongly folded in early Tertiary time and the Kingshill strata gently folded in post Lower-Miocene time along an east-northeast axis. Three early Tertiary cycles of erosion are recognized. After the folding of the Kingshill marl, streams followed the strike of the folded rocks in a westerly direction, but they gradually assumed southward courses across the marl plain and as a result a western area of old-age topography, a central area of late-mature topography, and an eastern area of early-mature topography have been created. Submerged reefs and emergent reefs and beaches indicate several fairly recent stands of the sea.

Water for human consumption is obtained by collecting rain water in cisterns, but water for other purposes is almost entirely supplied by wells which are generally less than 100 feet deep. Many dug wells are used, but in recent years drilled wells have been constructed. Most of them are discharged by wind-powered pumps of small capacity. Wells are developed in all the rocks mentioned (except coral reef), but the best yields are obtained from the alluvium. A maximum yield of 80 gallons a minute was obtained from a gravel-packed well in the alluvial valley at Fair Plain. Further exploration of the alluvium is recommended. The weathered diorite also appears to be a fairly good water-bearing formation. Test drilling showed that deep water-bearing formations should probably not be expected beneath the Tertiary rocks.

Most of the ground waters of St. Croix contain a moderately high mineral content owing to the solution of rock-forming minerals and the deposition of alkali and salt spray in the soil. Only a few wells are contaminated by sea water. The low hardness of some highly mineralized waters is believed due to base exchange. The most highly mineralized waters are found in the alluvium in areas with alkali soil and in some places in the Tertiary limestones where presumably soluble salts were deposited in those strata. The least

mineralized waters are found in shallow wells in the alluvium near the foot of the mountains and in the areas of dioritic rock. Many well waters in St. Croix, if properly protected from contamination might be entirely suited to human consumption. Although many waters are hard, they are used for domestic purposes. Most waters, even those high in chloride, are reported to be excellent for cattle consumption. Most ground waters in St. Croix cannot be used for boiler feed without treatment but are used for other purposes in the manufacture of sugar and rum.

A brief discussion of the results of test drilling by the National Park Service in 1940-41 is also given.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

A program of test drilling for additional water supplies on lands owned by the United States Government, in the island of St. Croix, V. I., was carried out in the period of December 1938 to April 1939 through an appropriation made by the Public Works Administration. These lands have been put to economic use by the Virgin Islands Co., a quasi-government corporation. The services of the Geological Survey were requested for technical advice, and the writer was accordingly assigned to the project. Sites for drilling were selected, samples of rock penetrated by the test wells were collected, and other duties attendant upon the drilling program were carried out. In the remaining time available the geology and ground-water resources of the island were studied and a geologic map of the island was prepared. (See pl. 1.) An account of the physiography of St. Croix, accompanied by a geologic map, was published in 1941,[1] but in that publication much of the detailed geology and most of the hydrologic data were not considered.

The investigation was made under the general direction of O. E. Meinzer, then geologist-in-charge of the Division of Ground Water. M. D. Foster, Nathaniel Fuchs, E. W. Lohr, L. W. Miller, and W. N. Noble made the analyses of water samples. C. S. Ross made petrologic examinations of thin sections of the rocks. T. W. Vaughan and L. G. Henbest made determinations of Foraminifera and W. P. Woodring and T. W. Vaughan made determinations of macrofossils. Cushman[1a] has published a description of the smaller microfossils found in drill cuttings from the test wells described in this report.

During a drilling project carried on by the National Park Service on St. Croix in 1940 and 1941, data on wells and test holes

[1] Cederstrom, D. J., Notes on the physiography of St. Croix, V. I.: Am. Jour. Sci., vol. 239, pp. 553-576, 1941.

[1a] Cushman, J. A., Tertiary foraminifera from St. Croix, V. I.: U. S. Geol. Survey Prof. Paper 210-A, 1946.

were compiled by Donald G. Hazlett working under the direction of H. E. Rothrock. These data are discussed in an appendix to this report.

ACKNOWLEDGMENTS

The field work was made possible through the kind offices of Mr. Boyd Brown, president, Virgin Islands Co., and willing assistance was given by Messrs. C. Hunt, A. N. Gray, and James Tily of that company. Mr. Jensen and Mr. B. Nelthropp supplied much valuable information on wells throughout the island. Mr. Paul Schweitzer, of the Layne-Atlantic Co., who was in charge of the test drilling, supplied equipment for making pumping tests on existing wells and later donated several photographs, which are included in this report. A great number of local residents contributed information and in other ways helped to make the work in St. Croix a pleasant task.

Thanks are due Brent S. Drane of the National Resources Planning Board and his associates for their efforts in making available much data on the Park Service wells.

LOCATION

The island of St. Croix (or Santa Cruz) is about 95 miles south-southeast of San Juan, P. R., 1,400 miles southeast of New York, 1,000 miles east of Key West, and lies between latitude 17° 41′ and 17° 46′ and between longitude 64° 34′ and 64° 54′. (See fig. 1.) It is one of the Virgin Islands group, of which St. Thomas, St. John, and St. Croix belong to the United States. St. Croix is the largest of these three islands. It is about 21 miles long and 6 miles wide at the center and has an area of 84 square miles. St. Thomas, 40 miles north-northwest of St. Croix, has an area of 28 square miles, and St. John, a few miles east of St. Thomas, has an area of 20 square miles. The town of Frederiksted, with a population of about 2,000, is located on the west end of St. Croix, and Christiansted, with a population of about 3,000, is situated on the north coast in the eastern part of the island.

The island has semiweekly steamship service from San Juan, P. R., by which passengers and freight are accommodated. Much freight is also carried by small sailing vessels. Frederiksted is a regular port of call for a passenger steamship line between New York and South America, and irregular calls are made by other merchant ships. A large number of vessels from many parts of the world call at St. Thomas. Weekly airplane service connects St. Thomas and Miami, and more frequent airplane service is available at San Juan.

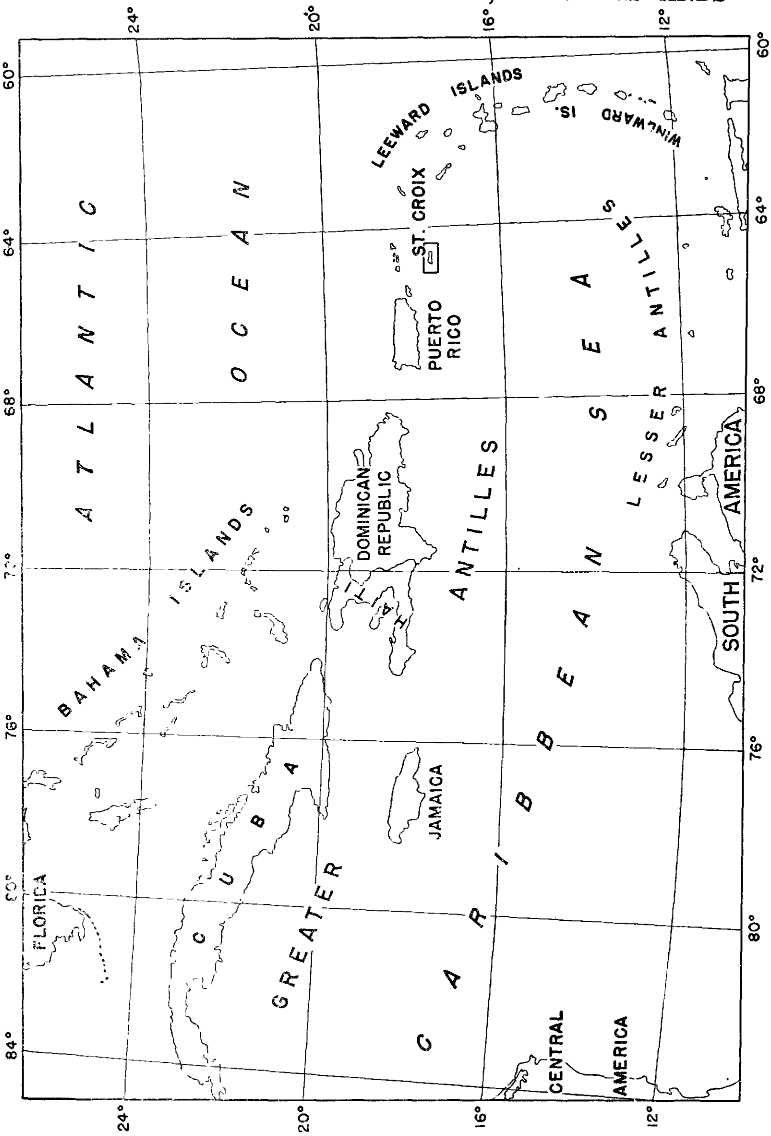

FIGURE 1.—Map showing location of St. Croix.

TOPOGRAPHY AND DRAINAGE

The northwestern part of the island is a mountainous area flanked on the south by a rolling plain. The mountains are broken by many narrow steep-sided valleys, through which intermittent streams flow and continue south or southeastward across the plain. A few deeply incised streams flow directly westward in the area between Frederiksted and Ham Bluff. The highest peaks on the island, Blue Mountain and Mount Eagle, are 1,090 and 1,165 feet above sea level, respectively. Other peaks attain elevations of 700 to 900 feet above sea level. Near Annaly is a very small area of flat upland and near Mount Eagle and Blue Mountain streams have carved out two small basinlike depressions. (See pl. 2*A*.) Elsewhere high peaks and ridges and steep-sided valleys predominate.

On the west near Frederiksted a gently undulating lowland surface borders the sea. In the central part of the island the lowland is wider and is characterized by rounded hills. West of Christiansted the lowland is submountainous. 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 mountain rather than of the lowland area.

That part 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 so sharply incised, and intermontane alluvial areas are of more importance. Two lowland areas separated from one another by a low narrow ridge extend inland from Southgate Pond and Great Pond.

The northern range of mountains is drained by streams that flow to the west and south. With the exception of Salt River the streams flowing northward are very short and unimportant. Most of the streams discharging from the northern range of mountains cross at least a narrow strip of coastal lowland before entering the Caribbean. Few of the streams are permanent. Records on stream flow are not available, but local reports seem to indicate that in times of drought or slightly subnormal rainfall flowing water is found only in the upper reaches of the streams. In seasons of normal rainfall many streams pass underground shortly after reaching the coastal lowland. Some of these reappear at the surface near the coast, and others discharge into the sea as underground streams.

Except in time of, or immediately following, heavy rains most stream beds do not carry flowing water throughout their course.

The coastal lowland is drained largely by streams which originate in the northern range of mountains and flow west or south. The stream flowing from Anna's Hope to Jerusalem, however, originates in the eastern area, and a few lesser intermittent streams originate in the high hills of the eastern part of the coastal lowland. Salt River, in contrast to other rivers, flows northeastward. As indicated above, practically none of these streams are perennial. The short streams in the more arid East End area flow only in seasons of heavy rainfall.

HISTORICAL SKETCH[2]

The Virgin Islands group was discovered by Christopher Columbus on his second voyage to America, in 1493, and according to records he landed on the island of St. Croix on November 14 of that year. The island was inhabited by the Carib Indians at the time of Columbus' visit, but by the time of the first settlement by the English and Dutch in 1625 the Indians had been either killed, driven out, or enslaved and carried away.

In 1645, following the death of the governor of the English colony, there was a bitter struggle between the Dutch and English, which resulted in the departure of the Dutch for other islands.

In 1650 the Spanish governor of the island of Puerto Rico sent an expedition to attack the English colony on St. Croix. During the attack many of the English were killed and of the remainder some were taken prisoner and the others permitted to leave the island. Thus St. Croix was claimed for Spain. Within the year the French captured the island from St. Christopher, and in 1651 sold it to the Knights of Malta. In 1665 it was sold back to the French West India Co., and in 1674 King Louis XIV took over the island as a crown colony. The colonization of the island was not a success, and in 1695 it was abandoned by the French and for the following 37 years was uninhabited.

In the meantime the island of St. Thomas had remained practically uninhabitated. But in 1671 two vessels from Denmark brought colonists to St. Thomas, and to forestall British occupation of St. Croix the Danish West India and Guinea Co. in 1733 purchased that island from the French.

In 1800, as a result of Denmark's identity with French interests in a war between England and France, St. Thomas surrendered to the English, who held the island for 10 months, after which the Virgin Islands again passed back to Denmark.

On December 22, 1807, during the Napoleonic Wars, the Danish West Indies again surrendered to the British, but in 1815 the islands were restored to Denmark in return for the Danish island of Heligoland.

Several minor slave insurrections took place at various times in St. Croix but were quickly stilled. In 1847 a Danish law was enacted proclaiming that at the end of 12 years slavery in the Danish West Indies should cease entirely and that all children born of slaves in bondage should be immediately set free. However, this proclamation only created unrest and on July 2, 1848, an insurrection broke out and the slaves forced the Governor

[2] Evans, Waldo, The Virgin Islands of the United States, a general report by the Governor: U. S. Navy Dept., Washington, D. C., pp. 22-49, 1929.

General to proclaim freedom for all slaves in the Danish West Indies.

During the Civil War, the United States recognized its need for a naval station in the West Indies. Accordingly, in 1867 an attempt to purchase St. Thomas and St. John was made by the United States but the treaty that was drawn up was not ratified by the Senate.

During the Spanish-American War another attempt was made by the United States to purchase the islands, but the treaty failed to be ratified in the Danish upper house.

Finally in 1917 the islands were purchased by the United States for $25,000,000, and the formal transfer took place on March 31 of that year. The islands were at first administered by the Navy Department.

In 1930 when the West India Sugar Factory Co., Ltd., went into bankruptcy the American Red Cross took over the responsibility of caring for the people. In March 1931 the President transferred the Virgin Islands from the supervision of the Navy Department to the Interior Department, and Congress appropriated funds for a program of economic rehabilitation.

POPULATION

In 1940 St. Croix had 11,413 inhabitants, of whom 95 percent were classified as either Negro or mixed. For many years the chief elements in the population of St. Croix were Scotch and Irish planters, Danish Government officials, and Negro slaves and their descendants. In recent years several thousand enterprising Puerto Rican laborers have come to the island. There has also been a slight increase in the white population, chiefly owing to an increase of Government employees from the United States. With the exception of a large proportion of the Puerto Ricans the entire population is English speaking, a condition which prevailed even before the island became a possession of the United States. The native Cruzians speak an easily understood dialect in which the English broad *a* and the Danish rising inflection are dominant elements.

AGRICULTURE AND INDUSTRY

St. Croix has been described as a one-crop sugar-cane island. All other agricultural ventures have failed. Attempts to grow cotton were thwarted by the pink bollworm. Ventures in tomatoes, limes, sisal, onions, and the like proved to be without economic success and were discontinued. Except for the relatively small cattle business, which can employ but a few people, sugar and rum manufacture barely survive as the only industries left to which people can turn in search of employment and are the industries to which the local government must look for tax revenues.[3]

In 1934 a charter was granted to the Virgin Islands Co., a quasi-government agency, to operate agricultural lands and industries in the interest of the government. In November of that year lands comprising several old estates, most of which had been operated by the West Indies Sugar Co. before the Bethlehem Sugar Factory was closed, were purchased by the Federal Government and turned over to the newly formed Virgin Islands Co. This company is making great advances in reviving agriculture on the island.

Progress has been made in the economic rehabilitation of the island by reviving the growing of sugar cane, by homesteading individual families, and by establishing the Virgin Islands Co., which not only mills the cane of small growers, but grows cane itself. In 1939 it grew 1,300 acres of cane. The success of this crop and the general economy still suffer from a tax on sugar and a recent increase in the costs of labor and the natural recurrent adversities of hurricanes and severe droughts.

Some fruits are grown on the island, chiefly plaintains, bananas, guavas, papayas, soursops, sugar-apples, coconuts, limes, and melons. The most common vegetables are sweet potatoes, yams, tanyas, tomatoes, and peppers. Practically all fruits and vegetables are consumed locally.

The growing of sugar cane and processing of sugar are the basis of the most important commercial activity of St. Croix. Even though about 41,000 or 80 percent, of the island's 51,000 acres of land are now given over to grazing, the raising of cattle for export employs only 3 percent of the island's labor. The economic life of the island therefore is almost totally dependent upon the success or failure of the sugar crop.

In the prosperous days before the development of regions better adapted, because of greater rainfall and more fertile soil, to the cultivation of sugar cane, the island was controlled by wealthy planters who operated their large estates with slave labor. The ruins of their estates overlook the old slave villages, which, in spite of their dilapidated condition, are still used by the native field laborers. (See pl. 2*B*.) Of the 20,000 acres of arable land on the island, as much as 18,000 acres were grown to cane in one year. With the decline of sugar prices, St. Croix prosperity

[3] Brown, Boyd J., Report on St. Croix economic conditions: Mimeographed at Christiansted, St. Croix, V. I., 1939.

also declined. Acreages grew smaller, landholders moved away, and finally in 1930 the largest sugar factory closed down and the acreage devoted to cane fell to a minimum of a few thousand acres.[4]

In addition to the chief business of growing sugar cane and processing sugar, the Virgin Islands Co. manufactures rum, a special distillate used in the manufacture of bitters, and alcohol for use in the Government hospitals. Other adjuncts include the operation of a poultry farm and the crushing of rock for road construction.

Besides the two sugar mills of the Virgin Islands Co., the La Grange Sugar Factory is also an important producer. In 1939 only two of the four distilleries on the island were in operation.

An Army air base was built on St. Croix in 1940.

Very little has been done on St. Croix to attract tourist trade.

FLORA AND FAUNA

The island of St. Croix has a tropical vegetation, but owing to the comparatively light rainfall the plant life is not as rich and luxuriant as in other places in the Tropics where the rainfall is greater.

The island was probably at one time entirely covered with thick forests, but in the early stages of development the forest cover was almost entirely removed. In many places, traces of contoured furrows reaching to the highest summits indicate that cane was grown to the very mountaintops. Owing to the decline in prices of sugar and other deterrent factors, land was taken from cultivation and forest growth began to regain its lost ground.

At present forests are characteristic of the northern mountains, the central plain is under cultivation, and the east end of the island is covered in large part with a dense growth of thorny brush. Grasslands, however, are found in all these areas.

Birds and animals are not numerous on the island, but fish are plentiful in the surrounding waters and form an important article of diet of the islanders.

CLIMATE

RAINFALL

A record of the rainfall at St. Croix has been kept since 1852. Figures giving the monthly and average annual precipitation at

[4] Johnson, Arthur F., Preliminary report on the water supplies for properties managed by the Virgin Islands Co., St. Croix, V. I.: U. S. Dept. Interior, Bur. Reclamation manuscript rept., p. 5, May 1, 1937.

Christiansted, Frederiksted, and Kings Hill from 1852 to 1935, inclusive, have been assembled in a report of the United States Bureau of Reclamation.[5]

A graphic representation of the annual rainfall and the accumulated departure from the normal or average rainfall from 1852 to 1938 is shown by figure 2.

TABLE 1.—*Annual mean rainfall on St. Croix from 1852 to 1938*

Year	Inches	Year	Inches	Year	Inches	Year	Inches
1852	47.58	1873	29.62	1894	44.12	1915	65.64
1853	55.05	1874	48.21	1895	55.87	1916	58.92
1854	53.55	1875	30.72	1896	56.13	1917	39.49
1855	50.74	1876	35.80	1897	54.93	1918	46.08
1856	37.49	1877	48.95	1898	50.50	1919	51.52
1857	50.92	1878	48.97	1899	34.09	1920	34.55
1858	49.02	1879	55.16	1900	45.52	1921	35.39
1859	44.08	1880	41.45	1901	65.98	1922	29.10
1860	43.27	1881	57.99	1902	61.39	1923	33.59
1861	58.75	1882	44.28	1903	45.31	1924	51.92
1862	41.27	1883	48.29	1904	37.37	1925	38.43
1863	34.05	1884	44.45	1905	53.05	1926	35.93
1864	39.53	1885	45.71	1906	55.79	1927	55.15
1865	49.52	1886	54.29	1907	38.31	1928	48.43
1866	46.41	1887	47.92	1908	45.09	1929	41.45
1867	46.59	1888	54.82	1909	51.83	1930	40.13
1868	37.79	1889	54.66	1910	43.79	1931	66.11
1869	47.74	1890	30.38	1911	44.20	1932	56.26
1870	51.24	1891	50.36	1912	37.16	1933	71.44
1871	35.90	1892	34.20	1913	38.98	1934	40.98
1872	29.36	1893	56.12	1914	37.53	1935	42.78

From 1852 to 1935, inclusive, the average annual rainfall in St. Croix was 46.34 inches. The average monthly rainfall was as follows:

TABLE 2.—*Average monthly rainfall on St. Croix, 1852-1935*

Month	Inches	Month	Inches	Month	Inches	Month	Inches
January	2.41	April	2.67	July	3.68	October	6.52
February	1.90	May	4.57	August	4.46	November	5.11
March	1.72	June	3.87	September	6.02	December	3.39

The maximum rainfall occurs in May and from August to November; the minimum in February and March.

The lowest recorded annual rainfall was 29.10 inches in 1921, but less than 30 inches of rain was also recorded in 1872 and in 1873. The highest recorded annual rainfall was 71.44 inches in 1933, and more than 65 inches was recorded in 1901, 1915, and 1931.

A severe drought occurred from 1871 to 1876, inclusive. In that period of 6 years the annual rainfall was only once slightly above normal, and the average of those years was 34.94 inches,

[5] Johnson, Arthur F., op. cit., pp. 55-58.

A. BASINAL AREA IN VICINITY OF FOUNTAIN ESTATE.
This steep-walled canyon is carved out of less resistant dioritic rock.

B. VIEW NORTHWESTWARD ACROSS CENTRAL ALLUVIAL PLAIN.
Mount Eagle is in background; Estate Slob is in middle ground.

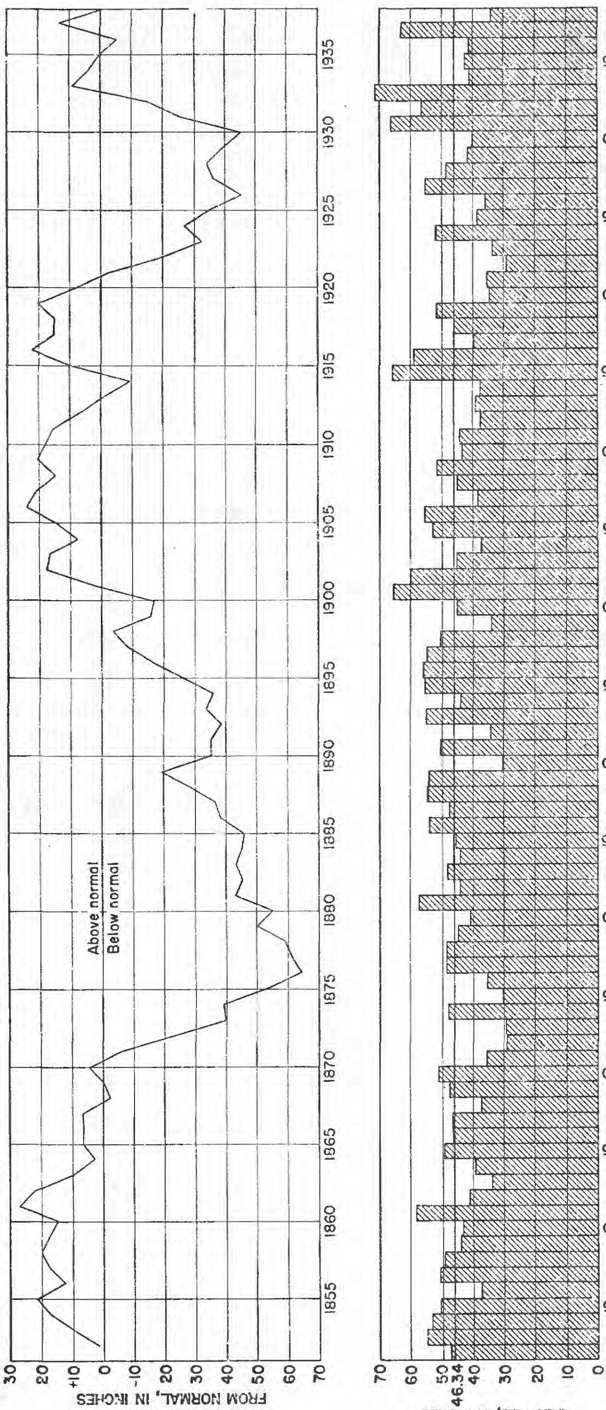

FIGURE 2.—Chart showing annual rainfall and accumulated departure from normal at St. Croix, 1852 to 1938.

or 11.40 inches below normal. Another severe drought is recorded from 1920 to 1926, inclusive, in which rainfall was again above normal only once and the average was 35.56 inches. Other droughts, which were less intense or which lasted only a few years or a single year, are recorded.

However, periods of greater-than-normal rainfall are also evident. From 1886 to 1889 the average rainfall was 52.76 inches, or 6.42 inches above normal; from 1895 to 1898 the average annual rainfall was 54.37 inches; and from 1931 to 1933, inclusive, the average annual rainfall was 64.94 inches, or 18.60 inches above normal.

ACCUMULATED DEPARTURE OF RAINFALL FROM NORMAL

The accumulated departure curve (fig. 2) shows that cycles of subnormal precipitation occurred from 1861 to 1876, 1909 to 1914, and 1919 to 1926, inclusive. These periods of subnormal rainfall were followed by periods of greater-than-average rainfall, the longest of which was from 1877 to 1906, inclusive.

RELATION OF RAINFALL TO SUGAR PRODUCTION

A study of the average yield of land in tons of sugar per acre and of the annual rainfall and accumulated departure indicates that the yield in any year is dependent upon the rainfall of that year or the preceding year or both and is not noticeably affected by the accumulated departure. A high yield was obtained following the heavy rains of 1915 and 1916, by the end of which time the accumulated departure was +21.91 inches, but a comparable high yield was also obtained in 1925 following one year of above-average precipitation that occurred in a dry cycle, when the accumulated departure was —27.15 inches.

GEOLOGY

WORK OF PREVIOUS INVESTIGATORS[6]

The geology of St. Croix has been a subject of study by Danish, German, Swedish, and American geologists since 1817. In that year Maclure wrote briefly on St. Croix[7] and noted the distribution of the older volcanics and younger limy rocks. In 1839 Hovey[8] first used the term "indurated clay" for the older rocks and re-

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[6] Previous work relating strictly to ground water is discussed in a later chapter.

[7] Maclure, Wiliam, Observations on the geology of the West India Islands from Barbados to Santa Cruz, inclusive: Acad. Sci. Philadelphia Jour., vol. 1, pp. 134-149, 1817.

[8] Hovey, S., Geology of St. Croix: Am. Jour. Sci., 1st ser., vol. 35, pp. 64-74, January 1839.

ferred to the marl and limestone as of Tertiary age. Cleve,[9] a Swedish naturalist, studied the Virgin Islands in detail. His publication, which appeared in 1871, describes the older highly folded strata of St. Croix upon which rest flat beds of coralliferous limestone. The origin of the older rocks is given as igneous and igneo-sedimentary, and the presence of gray limestones near Judith's Fancy with poorly preserved fossils is mentioned. A number of fossil shells found in the limestone of Tertiary age are listed. On the basis of the fossils found in St. Thomas, Cleve concluded that the basal strata of the Virgin Islands are of Cretaceous age and stated that "in St. Croix the white marl also seems to belong to Miocene time."

In 1907 John T. Quin[10] of Christiansted, inspector of schools under the Danish government of the islands, had privately printed a popular account of the geology of St. Croix. This publication is accompanied by a geologic map in which the distribution of the older (Cretaceous) rocks and the younger (Tertiary) rocks is sketched. He explained geological processes in a simple fashion in order to interest his neighbors in the rocks and hills about them. However, Quin, an amateur, did not presume to give the whole story of the geology of St. Croix but pointed out that his findings should be amplified and "corrected where necessary."

Boggild[11] observes that at its east end and along its north side, St. Croix is geologically much like the islands of St. Thomas and St. John. There are many mountains of cretaceous volcanic rocks, but the volcanic breccia is less abundant than the stratified varieties of volcanic rocks, such as tuffs. A gray limestone contains a few poorly preserved fossils. Dikes are uncommon. The structure is so complex, and the rocks strike in so many directions that it seems impossible to arrange the strata in an orderly sequence.

Following a paper in which submarine terraces of several West Indian islands are described,[12] Vaughan presented[13] a discussion in which the biogeographic relationship of St. Croix and Puerto Rico is stressed. In this paper the precipitous north shore of St. Croix is referred to as a fault line.

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[9] Cleve, Per Teadore, On the geology of the Northeastern West India Islands: K. svenska vetensk. akad. Handl., Bandet IX, No. 12, Stockholm, 1871.

[10] Quin, John T., The building of an island: Printed in New York by Chauncy Holt and published by the author in Christiansted, St. Croix, 1907.

[11] Boggild, O. B., On the geology of the Danish West Indies: Geog. Jour., publishing the transactions of the Royal Danish Geographical Society, vol. XIX, pp. 6-11, 1907.

[12] Vaughan, T. W., Some littoral and sublittoral physiographic features of the Virgin and northern Leeward Islands and their bearing on the coral reef problem: Washington Acad. Sci. Jour., vol. 6, no. 3, pp. 53-66, 1916.

[13] Vaughan, T. W., Some features of the Virgin Islands of the United States: Assoc. Am. Geographers Annals, vol. 9, pp. 78-82, 1919.

In a report to the Governor of the Virgin Islands in 1923, Kemp[14] referred to the Upper Cretaceous rocks as the Mount Eagle series and the Tertiary rocks as the Kingshill series. Kemp's terms were adopted but altered to Mount Eagle volcanics and Kingshill marl in the writer's previous report, published in 1941.[15] Kemp states that "there is some evidence that these [Kingshill] beds, in the central belt of the island . . . , as noted by the late John T. Quin, Esq., . . . lie in a broad flat trough or syncline whose axis pitches at a very low angle downward to the southwest."

An important paper by Vaughan[16] was published in 1923. Fossils found in the Cretaceous rocks of St. Croix and St. Thomas and fossils found in the limestone of Tertiary age at several localities in St. Croix are listed. The fossils from the Tertiary rocks range in age from middle Oligocene to lower Miocene.

SUMMARY OF GEOLOGIC HISTORY

Vaughan's summary of the geologic history of the islands, in which the place of St. Croix with respect to other West Indian Islands is clearly and concisely set forth, is outlined below:

(1) The presence of shoal-water deposits of Upper Cretaceous age in St. Croix and in other islands on the Virgin Bank show that the major tectonic axis of this part of the West Indies antedates Upper Cretaceous time. These major trends may be even as old as late Paleozoic.

(2) During Upper Cretaceous time most or all of the areas now occupied by land were under water; volcanic activity at that time is proved by the water-laid tuffs and lava flows, which are interbedded with the shoal-water calcareous sediments.

(3) In early Tertiary, probably Eocene, time mountain making by folding occurred and was accompanied by igneous intrusion and probably extrusion of some volcanic rocks.

(4) Early Tertiary mountain making was followed by prolonged subaerial erosion.

(5) In middle Oligocene time a large part of the island was submerged and, with slight fluctuations, remained under water until sometime during the Miocene.

(6) Following the deposition of early Miocene sediments an uplift occurred that brought Miocene and older Tertiary sediments, in places where they are present, above sea level. The

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[14] Kemp, James F., Report to H. H. Hough, Captain, U. S. N., Governor, Virgin Islands, printed at the Naval Station, St. Thomas, 1923.

[15] Cederstrom, D. J., op. cit., pp. 556-557.

[16] Vaughan, T. W., Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Islands, and notes on eastern Porto Rico: Washington Acad. Sci. Jour., vol. 13, no. 14, pp. 303-317, 1923.

Tertiary sediments are tilted and gently flexed, but they have not been so much deformed as the Upper Cretaceous deposits. About this time land connections permitting migration of land animals from Anguilla to Puerto Rico, Haiti, and Cuba probably existed. St. Croix seems to have been connected with Anguilla, St. Martin, and St. Bartholomew.

(7) The period of high stand of land was followed by faulting and folding. Anegada Passage between the Virgin Bank and Anguilla was produced, and the islands assumed very nearly their present outlines.

(8) Following the episode of faulting there was emergence of the land and terracing of the margins of the Virgin Bank, followed by submergence. At places in and near Puerto Rico there has been local emergence owing to differential crustal movement.

(9) The living coral reefs on the Virgin Bank are growing on a recently submerged extensive flat. This flat is geologically an old feature that orginated in large part at least in the long period of erosion following the early Tertiary mountain making.

Kemp[17] in 1927 reviewed in detail the literature pertaining to St. Croix.

Davis,[18] after a brief visit to St. Croix, described the physiography of the island. He classified St. Croix as an island of the second cycle, of which lavas and pyroclastics forming the nucleus of the island are relatively old (pre-Tertiary?) and have been deformed and the island itself is now in the stage of topographic maturity. First-cycle islands are made up largely of younger undisturbed volcanics. The Tertiary limestones of St. Croix are interpreted as lagoon deposits laid down within an encircling coral reef. The absence of early Tertiary sea-cut cliffs is stressed.

A detailed account of the physiography of St. Croix has been published by Meyerhoff[19] and is referred to many times in the text. Meyerhoff's thorough discussion has been of considerable help in providing basic data and in clearly defining important problems.

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[17] Kemp, James F., Introduction and review of the literature on the geology of the Virgin Islands: New York Acad. Sci., Scientific survey of Porto Rico and the Virgin Islands: vol. 4, pt. 1, pp. 48-50, 1926.

[18] Davis, W. M., The Lesser Antilles: Am. Geog. Soc. Pub. no. 2, Map of Hispanic America series, 1926.

[19] Meyerhoff, H A., The physiography of the Virgin Islands, Culebra and Vieques: New York Acad. Sci., Scientific survey of Porto Rico and the Virgin Islands, vol. 4, pt. 2, pp. 145-184, 1927.

GEOLOGIC FORMATIONS

MOUNT EAGLE VOLCANICS

The oldest rocks of the island, which form the high mountain terrain, were named the Mount Eagle series by Kemp,[20] and are designated the mount Eagle volcanics. (See p. 14.) Cleve suggested that they are of Cretaceous age,[21] and since then Upper Cretaceous fossils have been found in them.[22] These rocks have been variously described by different authors. All agree, however, that a large part of the material is volcanic in origin, that much of it is stratified, and that some limestone beds are interbedded with the volcanics. Dark fine-grained massive, laminated, or slaty rocks, hard thin- to thick-bedded limestone, and spotted or porphyritic rocks are most common. In some places masses of volcanic breccia made up of angular pieces of dark porphyry or felsite and rounded scoriaceous stones cemented by a fine-grained greenish felsitic material, are found.

The writer's brief study of the Mount Eagle rocks is sufficient to justify only a very general statement concerning the rock types and their areal distribution. Many of the rocks are strongly metamorphosed and difficult to identify correctly in the field, and in many areas outcrops are almost entirely lacking. It may be said with a fair degree of certainty, however, that metamorphosed bedded tuffs are the most widespread rocks in the Mount Eagle volcanics. Two types of these tuffs are present, both of which have wide distribution. One type, a massive fine-grained homogeneous black rock that resembles slate, makes up much of the west end of St. Croix. This rock is exposed in outcrops at Jolly Hill and is quarried as road material near Creque Dam. The other type of metamorphosed tuff, a bedded rock somewhat resembling a volcanic flow, is believed to make up most of the eastern part of St. Croix. It also is fine-grained but much less so than the slaty rock and on weathered surfaces many of the flowlike rocks have a felsitic texture.

Unmetamorphosed tuffs were found at a few places. A bed of yellow tuff about 20 feet thick is exposed along the coast between the mouth of Salt River and Judith's Fancy. Elsewhere beds of unmetamorphosed tuff are only a few inches to a foot thick.

Volcanic flows are present at some places but are thought to be

[20] Kemp, James F., Introduction and review of the literature on the geology of the Virgin Islands: New York Acad. Sci., Scientific survey of Porto Rico and the Virgin Islands, vol. 4, pt. 1, p. 49, 1926.

[21] Kemp, James F., idem, p. 19.

[22] Vaughan, T. W., Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Islands, and notes on eastern Porto Rico: Washington Acad. Sci. Jour., vol. 13, no. 14, pp. 303-317, 1923.

less abundant than metamorphosed tuff. Volcanic breccia is, however, common in the Mount Eagle volcanics. Breccia is particularly well developed in the vicinity of Barons Bluff and is interbedded with tuff and limestone at many other places.

Mention should be made of the "blue beach." This term was originally used by Cleve[23] in 1871 to apply to a conglomerate or breccia having angular pieces of dark porphyry or felsite and rounded scoriaceous stones cemented together by a greenish matrix, probably derived from decomposed hornblende which is widely distributed in St. Thomas. The term has since been used loosely and now is used by the natives of St. Croix to apply to all the older dark indurated rocks of the island.

Thick-bedded fine-grained black crystalline limestone forms a large part of the section along the south flank of the northern range of mountains. Thinner bedded limestone of grayish hue, with which thin to thick beds of dark tuffaceous material are intercalated, is present at many places between Christiansted and Vagthus Point (Waiters Point, also known as Watch Ho) but appears to be much less widely distributed elsewhere.

Cleve[24] reported poorly preserved fossils from thin-bedded limestones at Judith's Fancy, northwest of Christiansted. His determinable Cretaceous fossils were found in limestone interbedded with volcanics on the island of St. Thomas. Vaughan[25] determined that fossils found in the limestone strata of the Mount Eagle near Vagthus Point were of Upper Cretaceous age.

DIORITE INTRUDED INTO MOUNT EAGLE VOLCANICS

Meyerhoff[26] pointed out that basin-shaped valleys within the mountainous area between Fountain and River estates (pl. 3) and the broad depression extending from Southgate Pond across the island to Great Pond are underlain by dioritic rock, which is intrusive into the Mount Eagle volcanics. They are differentiated from the volcanics on the geologic map. (See pl. 1.)

The most common rock in the Fountain and Hermitage Basins is a light-colored coarsely crystalline diorite. In most exposures it is deeply weathered and crumbles in the hand. Fresh material taken from a boulder indicates that this rock consists largely of plagioclase feldspar with minor augite altered to chlorite.

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[23] Cleve, Per Teadore. On the geology of the Northeastern West India Islands: K. svenska vetensk akad. Handl., Bandet IX, No. 12, Stockholm, 1871.

[24] Cleve, Per Teadore, op. cit.

[25] Vaughan, T. W., Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Island, and notes on Eastern Puerto Rico: Washington Acad. Sci. Jour., vol. 13, p. 305, 1923.

[26] Meyerhoff, H. A., op. cit., p. 158.

A less common type of diorite has a texture similar to that described above but contains a larger proportion of dark minerals, and the feldspar itself is darker. The feldspar is andesine. Augite constitutes more than 25 percent of the rock; little hornblende and magnetite are present. All the minerals are quite fresh, and only minor sericitization of the plagioclase has occurred. This rock was seen in place as an orbicular unweathered mass within the common deeply weathered more feldspathic diorite.

A hard black fine-grained crystalline rock is present as a selvage bordering the diorite west of Fountain estate and makes up the larger part of the narrow southeast dikelike extension of the diorite underlying that basin. This rock shows little evidence of weathering. It consists of 50 percent augite, 40 percent plagioclase, and 10 percent magnetite, and is properly termed a gabbro. The feldspar is excessively calcic and contains from 90 to 92 percent anorthite. Augite is scattered uniformly throughout the slide as small blebs and fewer larger fragments. It seems likely that this rock is an early differentiation product resulting from the chilling of the intrusive magma by the wall rock. Absorption of limy sediments may account for the excessive lime content of the feldspars.

A sample of light-colored diorite similar in appearance to the diorite of Fountain and Hermitage Basins collected near Southgate, East End, was found to be made up of andesine feldspar and hornblende. The latter mineral makes up about 25 percent of the rock. Augite appears to be entirely absent. The rock also differs from the diorite found near Fountain in that the feldspars are strongly zoned.

Gabbro was not found in place nor as float in the area between Southgate Pond and Great Pond. Outcrops are exceedingly poor, however, and it cannot be said with certainty that gabbro is absent.

Dikes are rare in the rocks of St. Croix. One dike that intrudes the diorite near Colquhoun is about a foot wide and trends N. 50° E. It was composed originally of plagioclase feldspar and hornblende but is now badly altered.

The northern British and American Virgin Islands are reported to be made up almost entirely of rocks similar to those described above. Some differences between the northern islands and St. Croix are apparent from the descriptions given by Cleve,[27]

[27] Cleve, Per Teadore, op. cit.

Högbom[28], and Earle[29]. In the northern islands the intrusives may be of smaller extent and have a wider range in composition, dikes are more common, bosses are present on the British Islands, and contact metamorphism of the sediments surrounding the intrusives is pronounced in some places.

JEALOUSY FORMATION

It was formerly thought that the white and cream-colored limestones and marls, similar to those exposed throughout the central plain, made up the entire Tertiary section of the island. When dark clay was encountered in the Castle Burke well[30] at depths of 90 to 260 feet it was assigned to the Kingshill marl and the top of the basement rocks was estimated to be at a slightly greater depth. The drilling of the deep test wells showed, however, that in the central part of the plain the Kingshill marl is underlain by a dark clayey formation that is known to be a minimum of 1,398 feet thick. The maximum thickness is not known because the base has not been reached.

In the test hole drilled near Bethlehem (well 41, table 3, and pl. 1), in which 1,398 feet of dark clayey strata lying below the Kingshill marl were penetrated, the lowest stratum consists of 305 feet of gray clay in which a few streaks of limestone, not more than a few inches in thickness, are present. Five feet of calcareous conglomerate overlies the gray clay. The conglomerate is made up of rounded and subangular boulders of Mount Eagle volcanics (Cretaceous) in a limy matrix. Eighty-five feet of gray clay overlies the conglomerate, and above that 16 feet of calcareous conglomerate is present. A core of the conglomerate showed that soft clayey partings were present. Above the upper conglomerate stratum 987 feet of greenish gray clay is present. As in the deepest clay stratum, thin streaks of limestone are found, but in this stratum the limestone streaks do not occur throughout the thickness but are localized within a zone 293 to 387 feet from the bottom of the stratum.

The sediments described in the preceding paragraph have been named the Jealousy formation, and the section penetrated in the test well near Bethlehem, as described, is the type section.

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[28] Högbom, A. G., Zur Petrographie den kleinen Antillen [a contribution to the petrography of the Lesser Antilles]: Geol. Inst. Univ. of Upsala Bull., vol. 6, pp. 214-232, 1905.

[29] Earle, K. W., The geology of the British Virgin Islands: Geol. Mag., vol. 61, pp. 339-351, 1924.

[30] Johnson, Arthur F., Preliminary report on the water supplies for properties managed by the Virgin Islands Co., St. Croix, V. I.: U. S. Dept. Interior, Bur. Reclamation, manuscript rept., p. 29, May 1, 1937.

Near Jealousy estate the Jealousy formation is much thinner, 368 feet, but as determined in test drilling (well 39, table 3, and pl. 1), 61 feet of hard calcareous conglomerate lies immediately above the basement of the Mount Eagle volcanics. The remainder of the section is dark clay, but the clay here contains much more sandy material than at Bethlehem. It seems likely that at places the sand and boulders may be present as thin strata free of clay, but this was not apparent in drilling by the rotary method.

A calcareous conglomerate underlying the Kingshill marl is exposed in stream beds west and northeast of Jealousy. It is believed that this conglomerate is the basal conglomerate of the Jealousy formation and that it may be correlated with the calcareous conglomerate underlying the dark clays in well 39.

With a marked change in the conditions favoring the deposition of the Jealousy formation, the soft clays of that formation were easily eroded and overlapped by the younger Kingshill marl; the basal conglomerate of the Jealousy formation was more resistant, however, and the overlap was not complete where the basal conglomerate had been laid down at a relatively high elevation along the sloping sides of the depositional basin. It may be noted that in most places along the contact of Tertiary and Cretaceous rocks the overlap was complete, and the Kingshill marl rests directly upon Mount Eagle volcanics.

Samples of drill cuttings of the Jealousy formation were submitted for the study of the larger microfossils. According to the findings of T. W. Vaughan and L. G. Henbest, the Jealousy formation is of Oligocene age. The large forms determined by Vaughan and Henbest are given on page 25. The small Foraminifera found in the well cuttings collected on St. Croix were given special study by Cushman.[31] The results of Cushman's study have been published recently. Cushman states that the age of samples from test wells at Jealousy and Fairplain and from the upper part of the test well at Bethlehem "seems to be definitely Miocene" and in the lower part of the test well at Bethlehem the Oligocene was probably penetrated.

KINGSHILL MARL

DESCRIPTION AND DISTRIBUTION

The rocks forming the plain between Christiansted and Frederiksted were named the Kingshill series by Kemp.[32] They are

[31] Cushman, J. A., The Tertiary Foraminifera of St. Croix, V. I.: U. S. Geol. Survey Prof. Paper 210-A, 1946.

[32] Kemp, James F., Introduction and review of the literature on the geology of the Virgin Islands: New York Acad. Sci., Scientific survey of Porto Rico and the Virgin Islands, vol. 4, pt. 1, p. 28.

now designated the Kingshill marl. (See p. 14.) The results of drilling show that the marl making up much of the surface of the coastal lowland forms only a small part of the total section above the Mount Eagle volcanics.

The Kingshill marl consists of buff-to-white moderately thick-bedded limestone, alternating with soft cream or white marl. The limestone is hard and rather brittle and forms fairly good cliffs; the marl is softer and does not stand well. These strata are well exposed along the south coast line and in many of the small quarries formerly operated for building stone. At many places the limestone has a structureless appearance, and where made up of corals and coral debris the bedding planes of the limestone are obscure. Below Enfield Green the limestone is riddled by small solution holes. Similar solution holes have been seen elsewhere, and it is suggested that perforated limestone of this kind may yield water to some wells drilled into the Kingshill marl. At Work-and-Rest hill and Dolby Hill a small proportion of subangular detrital material is included in the basal part of the formation. The pebbles are less than an inch in diameter, and the average size is considerably smaller.

The thickness of the Kingshill marl, where exposed just west of Christiansted along the scarp extending from Beeston Hill to Dolby Hill, may be more than 600 feet. At Fair Plain, where the Kingshill marl forms hills that attain an elevation of about 200 feet above sea-level, the marl extends to about 180 feet below sea level (well 45b, table 3), making the thickness here about 400 feet. Elsewhere the known thicknesses are less. The subsurface thickness of the Kingshill marl in the wells drilled is as follows: Jealousy (well 39), 91 feet; Castle Burke (well 34), 90 feet; Bethlehem (well 41), 108 feet; Colquhoun (C-15), 77 feet; and St. John (C-20), 87 feet.

East End area.—The geologic map prepared by the writer shows mid-Tertiary strata present only west of a north-south line drawn through Christiansted. Meyerhoff,[33] however, has found what appears to be evidence that these strata are represented in the area to the east. "In the east half of the island, coastal-plain deposits were found *in situ* at only one point—a small patch above Milord Point, on the south coast; but a few weathered Tertiary corals were picked up in the alluvium in two of the larger valleys fronting the Caribbean (north of Longford estate and in Cottongrove Valley)."

[33] Meyerhoff, H. A., The Physiography of the Virgin Islands, Culebra and Vieques: New York Acad. Sci., Scientific survey of Porto Rico and the Virgin Islands vol. 4, pt. 2, p. 161, 1927.

The writer has not seen the outcrop at Milord Point. However, on the north coast, just east of Cottongarden, a deposit of calcareous conglomerate fills a narrow reentrant in the Mount Eagle volcanics. The base of this deposit lies a few feet above sea level. Inasmuch as remnants of a raised sand beach of Recent age are found nearby, the conglomerate is interpreted to be a facies of that deposit.

GEOLOGIC AGE

Vaughan[34] has written an account of studies of fossils from outcrop samples of the Kingshill marl along the base of the northeasterly facing scarp between Christiansted and St. John. The strata at Evening Hill (near the Leper Asylum) and at Montpelier (near St. John) were found to be of probable upper Oligocene age although there is a possibility that they may be lower Miocene. At Anna's Hope, several hundred feet higher stratigraphically, the horizon was determined to be lower Miocene. Fossils collected from the Kingshill marl at a locality two-tenths of a mile southwest of Wheel of Fortune estate house (near Frederiksted) are assigned to the middle Oligocene.

The following list of Tertiary fossils collected by T. W. Vaughan is given here for comparison with fossils found at other localities:

Station 8647. One and four-tenths sea miles in a straight line from Christiansted lighthouse, on the south side of North Shore road at Evening Hill. Probably upper Oligocene.

Foraminifera:

Amphistegina sp.

Heterostegina antillea Cushman. Also Antigua and northeastern Mexico.

Heterosteginoides sp. cf. *H. antillea* Cushman. Also Anguilla.

Station 6850. Montpelier (east). Collected by John T. Quin. Foraminifera identified by J. A. Cushman. Probably upper Oligocene.

Foraminifera:

Alveolina sp. Also Saint Martin.

Orbitolites duplex Carpenter? Also Saint Martin.

Spiroloculina sp. Also Saint Martin.

Also indeterminable species of *Quinqueloculina, Triloculina, Globigerina,* and *Amphistegina.*

Mollusk:

Orthaulax sp. cf. *O. aguadillensis* Maury.

Station 8648. North Shore road, Montpelier (east). Probably upper Oligocene.

Foraminifera:

Amphistegina sp. Compare above, station 8647.

Peneroplis sp.

Gypsina globulus (Reuss). Also Anguilla; Recent.

[34] Vaughan, T. W., Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Island, and notes on eastern Puerto Rico: Washington Acad. Sci. Jour., vol. 13, pp. 309-311, 1923.

Station 6851. Anna's Hope estate, along the road. Foraminifera identified by J. A. Cushman. Miocene, possibly very low Miocene.

Foraminifera:

Clavulina sp. cf. C. *parisiensis* d'Orbigny. Also Culebra formation of Panama Canal Zone.

Clavulina sp. cf. C. *communis* d'Orbigny. Also Culebra formation of Panama Canal Zone.

Nodosaria sp. cf. N. *insecta* Schwager. Also Culebra formation of Panama Canal Zone.

Uvigerina sp. (?)

Orbulina sp.

Globigerina sp.

Truncatulina wuellerstorfi Schwager. Also Culebra formation of Panama Canal Zone, also Recent.

Siphonina sp. cf. species from Oligocene of the United States.

Pulvinulina sp. cf. species from Oligocene of the United States.

Asterigerina sp. cf. species from Oligocene of the United States.

Amphistegina sp.

Ellipsoidina sp.

Corals:

Obicella sp. cf. a species from the lower Miocene of Trinidad and Vieques Island.

Psammocora sp. cf. a species from the Miocene of Trinidad. Other species of this genus are known from the lower Miocene of Trinidad, Vieques Island, and the Dominican Republic.

Station 8649. Two-tenths of a mile southwest of Wheel of Fortune estate house; collection made on north slope of a low hill. Middle Oligocene.

Foraminifera:

Rotalia sp. Abundant.

Amphistegina sp. compare with station 8648.

Lepidocyclina morgani Lemoine and R. Douvillé: Also Cuba.

Carpenteria americana Cushman. Also Cuba.

Corals:

Astrocoenia decaturensis Vaughan. Also Antigua; Bainbridge, Ga.

Gomiastrea reussi (Duncan). Also Antigua.

Cyathomorpha tenuis (Duncan). Also Antigua; Hill's "Pepino formation" of Porto Rico and other places.

Goniopora microscopica (Duncan). Also Antigua.

The writer collected fossils from limestone in the Kingshill marl capping the hill overlooking and one-half mile southwest of Judith's Fancy, 3 miles northwest of Christiansted. The strata in which these fossils occur are within 30 feet of the base of the Kingshill marl in this area, but as the Kingshill was laid down here upon an uneven surface of Mount Eagle volcanics the horizon represented may be stratigraphically much higher than the lowest beds of the Kingshill, where they rest upon blue clay of the Jealousy formation. The Tertiary macrofossils from this locality were determined by W. P. Woodring and T. W. Vaughan and are listed below:

Foraminifera:
- *Sorites?* sp.

Coral:
- *Stylophora* sp.

Mollusks:
- Gastropods:
  - *Natica?* sp.
  - *Cerithium?* sp.
  - *Turritella* cf. *T. crocus* Cooke
  - *Orthaulax?* sp.
  - *Olivella* sp.
  - "*Marginella*" sp.
- Pelecypods:
  - *Sacella* sp.
  - *Arca?* sp.
  - *Anadara* sp.
  - *Glycymeris* sp.
  - *Lithophaga* cf. *L. nigra* d'Orbigny sp.
  - *Aequipecten* sp.
  - *Ostrea* cf. *O. cahobasensis* Pilsbry and Brown
  - *Glans?* sp.
  - *Lucina?* sp.
  - *Semele?* sp.
  - *Tracycardium* sp.
  - *Laevicardium* sp.

With reference to the mollusks, Woodring reports that: "Others are represented, but even generic identification is uncertain. The age is Miocene, probably lower Miocene, and probably of the same age as the Quebradillas limestone of Puerto Rico."

Samples of cuttings taken at various depths while the test-drilling program of 1938-39 was being conducted were submitted to F. G. Henbest and T. W. Vaughan for determination of Foraminifera. Nothing older than upper (?) Oligocene appears to be represented by the fossils found. Further, as the boreholes were drilled by the rotary clay-seal method and muds from higher horizons were later recirculated when the test hole had attained greater depth, much mixing of material has doubtless taken place.

In samples from test well 41, at Bethlehem (see the following list), Oligocene Foraminifera were first found at a depth of 580 feet, or 497 feet below the base of the Kingshill marl. In samples from test well 39, at Jealousy, Oligocene forms were encountered at a depth of 90 feet, or 1 foot above the base of the Kingshill marl. In test well 45a, at Fair Plain, Oligocene Foraminifera were found in cuttings taken at 100 feet, or 108 feet above the base of the marl. It would appear that the most important fact to be gained relative to the age of the strata is that the Oligocene-Miocene contact falls within the Kingshill marl and is at least 108 feet above the base of that formation at Fair Plain.

The microfossils that have been identified by Vaughan and Henbest are listed below. With a few exceptions, which are noted, they are Foraminifera and were collected from test holes at Bethlehem, Jealousy, and Fair Plain. Genera or species not previously known from St. Croix are marked by an asterisk.

Well 41, Bethlehem (contact of Kingshill marl and Jealousy formation at 108 feet).

Miocene (22 to 1,450 feet):

Globigerina sp.
**Siphogenerina lamellata* Cushman.

Oligocene (580 to 1,450 feet):

Miogypsina sp. cf. *M. cushmani* Vaughan.
Heterostegina sp.
**Heterostegina iraelskyi?* Gravell and Hanna.
Carpenteria? (fragment).
Amphistegina sp.
**Nullipores* (calcareous algae).
**Operculinoides* sp.
Adeonelopsis (a bryozoan).
**Archaias* sp. cf. *A. aduncus* (Fichtel and Moll).
**Spiroclypeus?* sp. (resembles a species found in Martinique and Trinidad).
**Lepidocyclina* sp. cf. *L. forresti* Vaughan.

Well 39, Jealousy (contact of Kingshill marl and Jealousy formation at 91 feet).

Miocene (10 to 360 feet):

Globigerinids.
Siphogenerina lamellata Cushman.
Polymorphinid.

Oligocene (90 to 390 feet):

Miogypsina, spp. probably 2 species.
Archaias? (fragment).
Gypsina sp., the form called *G. globulus* (Reuss).
Amphistegina sp.
**Robulus* sp.
**Lithothamnium* (calcareous algae).
Carpenteria sp.
**Borelis* sp.
**Lepidocyclina* sp., aff. *L. waylandvaughani* Cole.
**Operculinoides,* spp. probably 3 species.

Well 45a, Fair Plain (contact of Kingshill marl and Jealousy formation at 208 feet).

Miocene (at 90 feet):

Globigerina sp.

Oligocene (100-130 feet):
- *Amphistegina* 2 spp.
- **Operculinoides* sp.
- *Carpenteria* sp.
- *Gypsina* sp. cf. *G. globulus* (Reuss).

FACTORS INFLUENCING DEPOSITION OF JEALOUSY FORMATION AND KINGSHILL MARL

The manner of formation of the Tertiary sediments is a matter of some interest. It is thought that the basal calcareous conglomerate of the Jealousy formation may have been formed within the very narrow fringing reef which grew up the slope as the encroaching sea slowly rose to higher and higher elevations. The coarser material brought out of the highlands by the streams was trapped and the boulders and pebbles incorporated in limy lagoonal muds. Calcareous conglomerate is forming in this manner along the shore at Judith's Fancy at present. Although coarse material was trapped in muds close to the shore of the encroaching sea, suspended matter was carried out beyond the narrow reef and was deposited in the deeper waters.

The quantity of fine clay thus deposited was great, and it seems evident that streams emptying into the deep trough underlying the central plain must have drained a land mass of much larger extent than the present island of St. Croix. It likewise seems evident that if the deep channel in which the Jealousy formation was deposited is an erosional channel, it could hardly have been created by any drainage system confined to as small an area as the present island of St. Croix. Vaughan's statement[35] that St. Croix seems to have been connected with Anguilla, St. Martin, and St. Bartholemew subsequent to early Miocene time may be recalled at this point. The trough that received the sediments may have been partly landlocked. Certainly the predominantly fine sediments indicate absence of strong ocean currents.

Not all the coarse material was trapped by the encircling reefs, however, for near the old shore line several strata in the clay of the Jealousy formation contain a moderate amount of sand, pebbles, and boulders. The test well at Bethlehem showed that at two horizons the clayey section is interrupted by thin calcareous conglomerate. The widespread deposition of limy strata might be attributed to a temporary cessation of, or decreasing rate in, the submergence during which time coral growth flourished or deposition of lime was brought about on a warm shallow-water

[35] Vaughan, T. W., Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Island, and notes on eastern Puerto Rico: Washington Acad. Sci Jour., vol. XIII, p. 316, 1923.

shelf. However, the occurrence of boulders of the Cretaceous rock at a distance of perhaps half a mile or more from the shore is not as easily explained. Wave action during storms or proximity to the mouth of a major tributary may help to account for this distribution.

Following the deposition of sediments of the Jealousy formation, a marked change in conditions took place and the limy Kingshill rocks were next laid down. The dark clays of the Jealousy formation neither interbed with nor grade into the Kingshill marl; and, where known, the contact between the two formations is abrupt. It is suggested that the rate of submergence was much slower at the time the Kingshill marl was laid down than when the Jealousy formation was deposited, and therefore corals fringing the shore were enabled to grow outward and encircle the island and contribute to the formation by reef growth and creation of lagoons in whose warm waters limy mud collected. At the same time erosion of the land areas proceeded at a much slower rate, and the moderate amount of fine suspended material carried out into marine waters was incorporated with limy mud to form a light-colored marl.

ALLUVIUM

Alluvium covers large parts of the area underlain by mid-Tertiary rocks, but its distribution in the mountainous regions of the island is limited.

In the mountain areas bordering the sea alluvium fills the valley mouths 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 from Catherine's Rest to 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. According to Mr. B. Nelthropp, who has drilled many wells in St. Croix, the alluvial cover in the East End region is clayey to the extent that it acts as an impermeable cap rock over the fractured Mount Eagle strata, and water is generally present

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in these strata under artesian rather than water-table conditions. The maximum thickness of the alluvium is not known, but near the head of Cotton Valley (well C-28) it is 69 feet thick and at Cottongarden (well C-29) it is 83 feet thick. Slightly greater thicknesses may be present in other places.

The Tertiary limestone plain, however, shows the most important development of alluvium. At the foot of the mountains from Grove Place to Morningstar, streams have spread their load across a previously eroded lowland skirting the range. (See pls. 2*B* and 3*A*.) Southward, alluvium-filled valleys thread a range of hills (pl. 3*B*), but near the south coast the alluvial valleys coalesce to form a broad low terrace along the coast line. Between Enfield Green and Whim to the west a broad alluvial area extends from the base of the mountains to the sea (pl. 4*B*), but in the easternmost Tertiary limestone belt, alluvium partly 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 Frederiksted to Spratt Hall.

Within the area underlain by limestones, the fill contains sand and boulders derived from the older rocks of the highlands, but marly fill derived from the limy rocks of the Kingshill marl covers large areas or may alternate with sandy material in the valleys. In the test well at Fair Plain (45a) the following alluvial material was encountered: 33 feet of fine sand becoming coarser with depth, 24 feet of clay containing some sand and gravel, 5 feet of coarse sand and gravel, 8 feet of clay, and 3 feet of sand and gravel. Near Bethlehem (well 41) the alluvial material consisted of 18 feet of yellow marl overlying 7 feet of coarse sand and gravel. In the Hope and Ruan Bay areas surface exposures show that the fill is more marly than sandy, although many scattered subangular pebbles and cobbles are present.

In well C-8, at Fair Plain, 83 feet of alluvial fill was penetrated. It should be noted that an equal thickness of alluvium is present filling the short valley at Cottongarden. Hence it does not necessarily follow that in seeking sandy alluvial water-bearing formations exploration must be confined to valleys heading inland several miles; steep-sided short valleys may also contain favorable thicknesses of alluvium. The small catchment and storage area of the short valleys, however, should be considered in relation to the quantity of water desired.

STRUCTURE

The Mount Eagle rocks of Upper Cretaceous age have been strongly folded and are everywhere steeply inclined. The folding has been complex and the delineation of specific structures is a difficult task. Certain generalizations can be made, however, on the basis of limited observations by the writer, which give some picture of the problem presented by these rocks.

In the extreme eastern part of the island most of the rocks dip to the south or southwest. At Mount Fancy there are subordinate local folds whose axes trend northwest-southeastward. South of Christiansted a syncline trending northwest-southeastward is present, and another synclinal axis of similar trend extends from Rustoptwist to Kirkegaard Hill. In northwestern St. Croix the attitude of the older strata was determined in a number of places, as noted on the geologic map (pl. 1), but it is not possible to interpret the structure of the region as a whole on the basis of the limited data at hand. Both Vaughan[36] and Meyerhoff[37] point out that the north shore of St. Croix is characterized by steep cliffs extending to great depths and attribute this feature to faulting in Miocene or post-Miocene time. Other structures are probably present, but it is felt that data at hand are too meagre to define them properly.

Quin, in his popular account of St. Croix,[38] recognized the northwest-southeastly trend of the folds in the Mount Eagle rocks. However, his plotting of many structural axes is founded on what seem to be scattered observations. It can be shown that enough of his observations are incorrect to cast doubt on the advisibility of accepting all his structural interpretations. Detailed and painstaking work is needed to establish the geology of the old rock areas more precisely.

Quin[39] has written at length upon the structure of the younger (Kingshill) rocks which make up the marl plain. He states that these rocks dip seaward from their point of contact with the Mount Eagle rocks at the foot of the mountains. The seaward dip, however, is not maintained across the marl plain, for the rocks are folded along various axes, which are as follows: A north-

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[36] Vaughan, T. W., Some littoral and sublittoral physiographic features of the Virgin and nothern Leeward Islands and their bearing on the coral reef problem: Washington Acad. Sci. Jour., vol. 6, no. 3, p. 56, 1916.

[37] Meyerhoff, H. A., The physiography of the Virgin Islands, Culebra and Vieques: New York Acad. Sci., Scientific survey of Porto Rico and the Virgin Islands, vol. 4, pt. 2, p. 181, 1927.

[38] Quin, John T., The building of an island: Published by the author in Christiansted, V. I., pp. 44-52, 1907.

[39] Idem, pp. 20-33.

east-southwest 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 Frederiksted. These interpretations have been checked by the writer, who found that the Rattan syncline is present as stated, synclines are present at Golden Grove and Adventure, but their axes do not trend northeast-southwestward, and there is no evidence for an anticline passing through Hannah's Rest.

A structural interpretation of the Tertiary limestone area which is based upon field observations made by the author and upon data obtained in the drilling of three test holes is given below. Positive data are not everywhere available, but a sufficient number of exposures do exist to delineate the main structural features and establish the structural habit of the limestone rocks.

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 Two Williams to the mouth of Salt River, but owing to the alluvial cover 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 is well defined, but in no one of these three localities was the actual contact of the basal calcareous conglomerate of the Jealousy formation 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° to the southeast near the contact. The slope of the underlying rock surface was not exposed.

The data brought to light by the test well at Jealousy (well 39) shows that there the older basement rock floor lies 460 feet below the surface. (See fig. 4.) The surface of the basement rock therefore slopes south-southeastward at an angle of more than 24° in this vicinity.

The contact of the Tertiary rock with the older rock is seen also 2½ miles northeast of Jealousy in the stream bed at the crossroads between Morningstar and Concordia. A small exposure opposite the abandoned pumping station about two-tenths of a mile northeast of the crossroads may be of considerable significance. Here, in a small pit, is a succession of buff limestone, overlain by 3 feet of limy conglomerate carrying pebbles 2 inches in diameter, and 1 foot of clayey sandstone, which in turn is overlain by white limestone. These strata strike east and dip 85°N. The significance of this outcrop is not understood, but it certainly suggests that more deformation has taken place, locally at least, than is generally apparent.

From the mouth of Salt River to St. John, limestone of the Kingshill marl lies upon a warped plane that slopes gently to the southwest. As far as could be determined, north of Dolby Hill the plane slopes 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 comparable elevation on Work-and-Rest hill to the southeast. Exposures on the north side of Work-and-Rest hill indicate that here the plane of contact slopes westward about 530 feet per mile, or 5½°.

Gentle inclination to the southwest of the surface of the basement rock cannot 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 channeled by erosion or diastrophically deformed before the deposition of the limestones, or the basement rock and the limestones were strongly folded after the deposition of the limestone (Kingshill marl). Data on the elevation of the base of the limestones of the Kingshill in the central part of the island (fig. 3) indicate that these rocks are

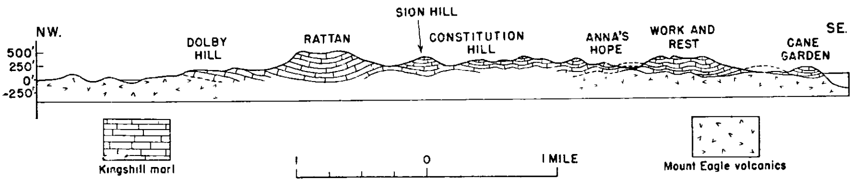

FIGURE 3.—Generalized geologic section showing structure in the eastern part of the Tertiary marl plain.

not greatly infolded, and it is therefore believed that they were laid down upon a highly irregular surface.

Exposures of limestones of the Kingshill within the central plain are few. Except along the coast line, where the action of waves has produced fine cliff faces, along roads and trails, and in the several small quarries dotting the hillsides naturally occurring outcrops are very scarce indeed. Even there many of the rocks exposed are marly or massive, and determination of their attitude is impossible. Enough data have been obtained to delineate the main structural trends in different parts of the limestone plain, and the data are considered sufficient to make possible a characterization of the plain as a whole.

The two small hills east of Golden Grove 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. These two hills are synclinal and the breach between them, in which New Works lies, is an anticline. (See fig. 4.) The axes of

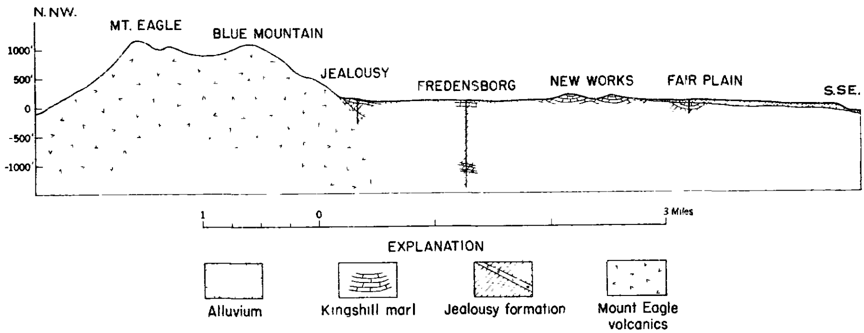

FIGURE 4.—Cross section of central St. Croix showing location of test wells with reference to geology.

the folds appear to extend in a west-northwesterly to east-southeasterly 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 form 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 to the two localities discussed above, but a reversal of dip (dip to the northwest) near Anguilla suggests folding.

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

A more or less continuous series of observations taken along the road from Bellevue through Rattan to Dolby Hill indicates that Rattan lies within a much broader syncline whose axis trends north-northeastward to south-southwestward. 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 exposures along Cane Garden Bay show that the strata dip to the northwest, and it is thought that these rocks form part of a synclinal limb. The prominence on which Cane Garden estate is located may mark the axis of the syncline. Other scattered observations suggest that Work-and-Rest hill and Anna's Hope are on synclinal axes and that the course of the stream flowing between them follows an anticlinal crest.

The structure of the area underlain by limestones of the Kingshill 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-southwestward, but departures from this trend are seen at Rattan and at New Works. In the eastern and east-central areas the folds plunge from 6° to 14° 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 Fredricksburg to Enfield Green could be determined. The writer agrees with Meyerhoff,[40] who questions the presence of the anticline passing southwest through Hannah's Rest, which was mapped by Quin.

In the deeper portions of the Oligocene sedimentation area, more than 1,400 feet of clays accumulated. The basin gradually filled, and as waters shallowed an extensive growth of coral covered the area of clayey sedimentation. The contact between the clay of the Jealousy formation and the calcareous Kingshill marl is abrupt and appears to denote a marked change in conditions of sedimentation. The line of contact between the limy rocks and the Mount Eagle volcanics from the mouth of Salt River to Cane Garden indicates that the basin was troughlike. The depth to bedrock is unknown at Little Princess, where the limestone extends below sea level. The trough probably extends west-southwestward under the plain and near Bethlehem. In the central part of the island the base of the Kingshill marl lies 60 feet above sea level at Jealousy, 10 feet above sea level at Castle Burke and Bethlehem, and 180 feet below sea level at Fair Plain. These facts may be taken to indicate that the rocks have not been greatly deformed but were only gently folded in the manner already described. It is believed that if the trough had resulted from deformation after sedimentation the base of the limestones would lie at least several hundred feet lower at Bethlehem and Castle Burke than at Jealousy and Fair Plain. The basal conglomerate of the underlying Jealousy formation is 60 feet thick, and some of the clay strata higher in the series contain imbedded pebbles and boulders.

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[40] Meyerhoff, op. cit., p. 164.

This fact seems to indicate that steep slopes were already present at the time of deposition of the Jealousy formation.

The gentle folding of the sediments along west-southwest to east-northeast axes has already been described. Mild compressive forces threw the Tertiary strata into a series of folds in most of which the dips are less than 12°. Steeply dipping rocks along the foot of the mountains may be the result 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 mass.

It has been noted that the direction of plunge of the axes of folds varies. It has also been brought out that at Work-and-Rest hill and Anna's Hope the folds plunge to the west-southwest at a minimum of 5°, or 400 feet per mile. If this plunge were uninterrupted the base of the Kingshill marl at Fair Plain should lie 2,500 feet below its present position. Therefore, the plunge to the west has been interrupted by faulting or cross folding. There are no data at hand that tend to show which of these possibilities is more probable. There is very little evidence of faulting, although Quin figures some normal faults, of not more than a foot or two of displacement, which are exposed in the cliffs along Cane Garden Bay, and the writer has noted a small normal fault north of Rattan which trends north-southward and is inclined 65° to the west.

However, evidence of the young scarp topography along the north coast shows that faulting has profoundly affected the island, and as a working hypothesis the eastern limestone area is regarded as a fault block that has been tilted toward the south-southwest. The central and western parts of the island may be relatively undisturbed or may plunge gently in the same direction.

PHYSIOGRAPHY

The physiography of St. Croix has been dealt with in a previous publication[41] and need be only summarized in this paper.

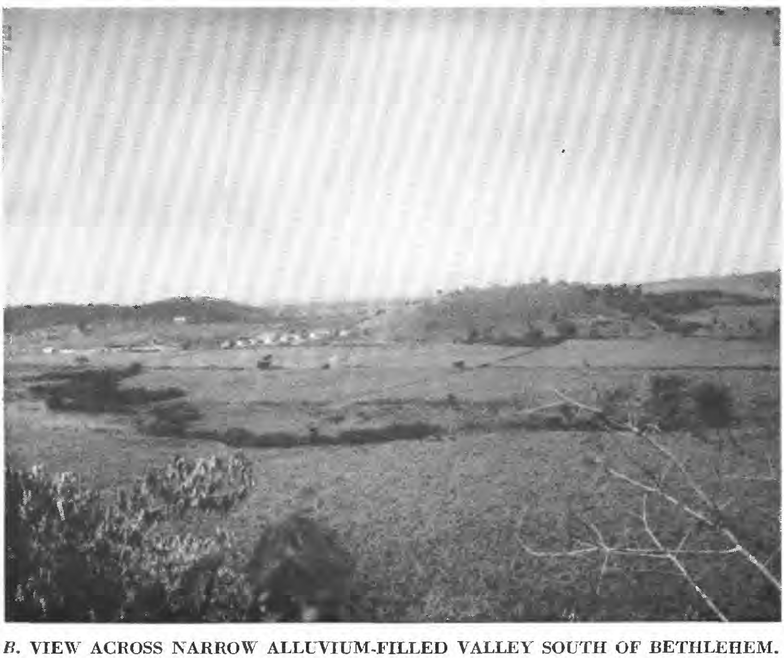
EARLY TERTIARY EROSION CYCLES

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 time a land mass much greater in size than the present island of St. Croix was beveled to a rolling plain. Remnants of this surface are seen in

[41] Cederstrom, D. J., Notes on the physiography of St. Croix, V. I.: Am. Jour. Sci., vol. 239, pp. 553-576, 1941.

A. VIEW NORTH-NORTHEASTWARD ACROSS INNER LOWLAND FROM FOX ESTATE.

Blue Mountain is in left background. This lowland is largely veneered with alluvium, and here the courses of more deeply buried valleys leading out of the mountains can be determined only by shallow test drilling.



B. VIEW ACROSS NARROW ALLUVIUM-FILLED VALLEY SOUTH OF BETHLEHEM.

Narrow valleys of this type are excellent areas for wells of moderate yield.

A. VIEW SOUTHWARD ACROSS WESTERN PLAIN SOUTHEAST OF FREDERIKSTED.

Topographic relief is low, and the locations of more deeply filled valleys leading from the mountains, if present, are not apparent.

B. EMERGENT CORAL REEF AT CANE BAY, NORTH SIDE.

the high upland at Annaly.[42] Eocene(?) uplift and subsequent erosion resulted in a mountainous topography characterized by high relief and moderate ruggedness. The gently rolling basin floors near Fountain (pl. 2A) were created at this time.[43] The beveled spurs at elevations less than 250 feet above sea level from Little Fountain at Windsor may likewise have been formed during this cycle of erosion. In figure 5 part of this surface of the

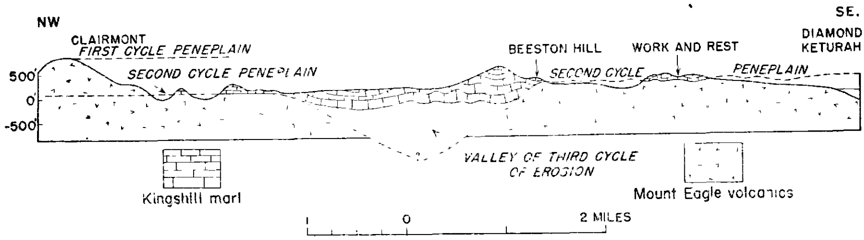


FIGURE 5.—Section showing development of early Tertiary erosion surfaces along eastern edge of marl plain.

second cycle is shown to be covered by Tertiary sediments. A still later uplift initiated a third cycle of erosion. This erosional cycle is represented by the channel in the Cretaceous rocks between St. John and the Leper Asylum. The records of wells indicate that the channel extends westward through the central part of the limestone plain (fig. 4).

From geological similarities to Puerto Rico, where a more complete record is available, Meyerhoff[44] postulated that the peneplain of the first cycle was developed in Paleocene-Eocene(?) time, the second partial peneplain in Eocene time, and the third-cycle partial peneplain in lower Oligocene time. In middle or upper Oligocene time 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.

DRAINAGE PATTERN

Streams flowing southward from the mountains tended to follow the old valleys, but upon entering the area of folded limestone they were deflected to the west-southwest. This west-south-

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[42] Meyerhoff, H. A., The physiography of the Virgin Islands, Culebra and Vieques: New York Acad. Sci., Scientific survey of Porto Rico and the Virgin Islands, vol. 4, pt. 2, pp. 152-156, 1927.

[43] Meyerhoff, H. A., op. cit., p. 100.

[44] Idem.

westward drainage was encroached upon by streams originating along the south coast, and by a series of stream captures the drainage was deflected generally southward.[45] Vestiges of the early drainage pattern are present in the eastern part of the limestone plain.

LAND FORMS

As a result of the drainage pattern outlined above three types of topography have been developed in the area underlair by the limestone of Tertiary age. The western area of old-age topography is almost featureless. The central area of late-mature topography is characterized by synclinal valleys and rounded anticlinal hills and ridges, and the eastern area of early-mature topography, is predominantly a region of ridges and valleys trending southwestward or south-southwestward. The hard-rock mountain highlands have resisted erosion and are only a little more advanced in erosional stage than at the beginning of Miocene time.

Erosion of the gently folded strata which plunge gently southwestward has created steep northeastward-facing scarps extending from Cane Garden to St. John. The distinct terracing seen in places along this scarp has been ascribed to the alternation of strata of unequal hardness, but possibly some of these high terraces may be due to higher stands of the sea[46] for which other evidence has not been recognized.

SUBMERGED CORAL REEF

The island of St. Croix is almost entirely surrounded by a fringing reef, 2 miles in width along the south coast but generally narrower elsewhere. From Ham Bluff to the mouth of Salt River the reef is very poorly developed along a series of young fault scarps.[47]

Submerged reefs or banks are also present and have been discussed by Vaughan[48] and Meyerhoff.[49] A bank generally from 6 to 10 fathoms deep and about 1 mile wide skirts the present reef

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[45] Cederstrom, D. J., op. cit., p. 567-571.

[46] Meinzer, O. E., Geologic reconnaissance of a region adjacent to Guantanamo Bay, Cuba: Washington Acad. Sci. Jour., vol. 23, pp. 256-258, 1933. Woodring, W. P., and others, Geology of the Republic of Haiti: Dept. Public Works, p. 374, 1924. Stearns, H. T., Ancient shore lines on the island of Lanai, Hawaii: Geol. Soc. America Bull., vol. 49, pp. 615-628, 1938.

[47] Meyerhoff, H. A., op. cit., p. 181.

[48] Vaughan, T. W., Some littoral and sublittoral physiographic features of the Virgin and northern Leeward Islands and their bearing on the coral reef problem: Washington Acad. Sci. Jour., vol. 6, p. 56, 1916.

[49] Meyerhoff, H. A., op. cit., pp. 170-175.

along the south coast. For 10 miles east of St. Croix this platform broadens and deepens and lies generally 11 to 16 fathoms below the surface. On the eastern extermity of this submarine platform Lang Bank forms a higher elongate crescent, the terminals of which point westward and enclose East Point, the eastern extremity of St. Croix. Lang Bank lies 8 to 10 fathoms below the surface and appears to have been a barrier reef at one stage in the development of the island.

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. The narrowness of this bank suggests that it is covered in part by the higher and younger bank, which is quite well developed. Meyerhoff has suggested that the higher bank was largely formed by subaerial erosion.[50]

Beyond the reefs the sea floor drops steeply. Along the south coast, a descent from 27 to 123 fathoms in one-half mile is typical. East of Lang Bank there is a descent from 13 to 435 fathoms in about a mile. Even more precipitous slopes characterize the north side, and at Ham Bluff the bottom drops from 40 to 818 fathoms, over 4,600 feet, in 1 mile. A depth of 2,412 fathoms, 14,472 feet, is recorded about 8 miles north of Ham Bluff.

COASTAL TERRACES AND BURIED VALLEYS

The post-lower Miocene erosion of the area underlain by the Kingshill marl resulted in a gently rolling to moderately rugged land surface, across which a number of streams had cut relatively deep V-shaped channels. The sea stood at different levels 40 feet or more below the present sea level. The 6- to 10-fathom submarine bank is correlated with one of these levels.

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 overloaded, and alluvium 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 broad, flat terraces.

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-fourths of a mile wide. At Jerusalem, Hope, Anguilla, 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 extend-

[50] Meyerhoff, H. A., op. cit., p. 183.

ing from the canyon mouths. (See pl. 4*A*.) A similar terrace that extends from Fredricksburg to Spatt Hall merges with, and may be partly covered by, the alluvial fans of the canyon mouths. The low rolling land bordering the sea from Christiansted to St. John may also have been beveled at this time.

Remnants of these terraces of small areal extent are recognized in several localities in other parts of the island.

Flood plains of streams extend mountainward from the level of the coastal terraces. In many places wide, flat valleys between low, rounded hills are well developed. They 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. (See pl. 3*A*.) Insofar as the ground-water resources of St. Croix are concerned, the coastal terraces and inland alluvial plains present special problems since these deposits effectively conceal the axes of the deeply channeled buried valleys in which are intercalated the better graded sandy strata that yield water freely to wells.

EMERGED CORAL REEF AND BEACHES

At the time of a still more recent 10-foot stand of the sea, beaches and coral reefs were formed which are now emergent. 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 Cottongarden, Turner Hole, and along the shore at La Grande Princess, northwest of Christiansted. Meyerhoff[51] has pointed out that Southwest Cape, built up of limy sand by the action of ocean currents, has been recently uplifted.

Emergent coral reefs of this stand of the sea 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. Emergent reefs are also particularly well displayed at Cane Bay (pl. 4*B*.) Elsewhere they are present only in very small patches. Plate 9.—Emergent coral reef at Cane Bay, north side.

SOURCES OF WATER SUPPLY AND USE OF WATER

RAIN WATER

Practically all water used for human consumption on the island of St. Croix is rain water which has been stored in cisterns. In most places this water is caught on the roofs of buildings and piped to a storage tank, but in places (pl. 5*A*) concrete catchment basins have been constructed.

[51]Meyerhoff, H. A., op. cit., p. 177.

Villages to house labor for the Virgin Islands Co. have been recently built or rebuilt or are planned at Adventure, Bethlehem, Castle Burke, Fredensborg, Golden Grove, Jealousy, Lower Love, New Works, Peter's Rest, Sion Farm, and Slob. In these villages each home is provided with its individual cistern for drinking and cooking water. Complete plans also call for a much larger community cistern of 10,500 gallons at each village with provisions for catching the overflow from private cisterns and from a community house.

In times of severe drought a great many cisterns become empty, and wells supplying water for domestic purposes may go dry. At such times an entire village supply may be brought in by barrel and donkey cart and carried in in oil tins on the heads of villagers.

STREAM FLOW

Stream flow is used in only a few places. The city of Fredericksted has dammed the stream flowing into Spratt Hall, about 1½ miles east of the coast, at an elevation of 700 feet above sea level. This water is piped to the city, but it is used for purposes other than human consumption. The water is reported to be turbid at times, and the reservoir goes dry in periods of drought either through leakage of the reservoir, reduced stream flow, or both.

Remains of an old dam are present at Orange Grove, above Frederiksted. Water from this reservoir was piped to La Grange in years past. Details of the amount of water furnished or why the dam was abandoned are not known. A small dam is still standing in River Gut a short distance below the estate houses, and although apparently in good repair it is now badly silted and not in use. Water from this reservoir was formerly piped to the West India Co. sugar factory at Bethlehem. Central Factory, previous to 1924, was supplied with water from Salt River, but the amount furnished is believed to have been very small. Use of Salt River was discontinued because of its poor quality for boiler feed.

WELLS

Wells supply the remainder of water used on the island. Throughout most of the island water from wells is generally used for domestic purposes other than for human consumption. In a very few places the water from wells is occasionally used for drinking purposes. Cattle are nearly everywhere supplied with water from wells.

There are a few manually operated or power-driven pumps for discharging water. In most places the water is discharged by wind-powered pumps either into storage tanks, or into troughs of small capacity for drinking water for cattle. At Fredricksted, Christiansted (see pl. 5*B*), and other places water may be drawn by bucket. Large masonry tanks are used in many places to store well water, but some old cane mills have been sealed and also put to use as reservoirs. Many of the wells, both dug and drilled, are poorly constructed, are not sufficiently deep, or are improperly located with respect to geological conditions and therefore yield very meager supplies and fail in times of drought.

SPRINGS

There are only a few small springs in St. Croix. One spring, which issues from the canyon wall opposite Little Grange, is used to supply cattle with drinking water. The spring at Envy, which issues from strata of the Kingshill marl, is put to similar use. Another small spring is said to issue from the Kingshill marl strata below Beeston Hill. The sump at Castle Burke is fed by seeps from surface gravels along River Gut as well as from surface flow.

WATER SUPPLIES AT CENTRAL FACTORY

At Central Factory, where both sugar and rum are produced, some water is used in the maceration of the cane when the juice is extracted. Additional water is used to bring the juices up to a constant value when the molasses is run into fermentation vats for the production of rum.

The water requirements at Central Factory when rum or alcohol is being produced vary somewhat with operation, but in August 1940 it was estimated that nearly 49,000 gallons a day was needed, of which 7,000 gallons a day was furnished by wells 81a and 81b. In normal seasons an 800,000-gallon cistern supplies a reasonably large part of the needed water, but in periods of drought the cistern supply is depleted. In the drought of 1940 some well water and rain water were pumped from Bethlehem Factory.

WATER SUPPLIES AT BETHLEHEM FACTORY

At the recently modernized Bethlehem Factory, where only sugar is produced, much of the maceration water is recovered. However, there is demand for boiler make-up water to replace or dilute steam condensate, which amounts to over 38,000 gallons per day, or 5,720,000 gallons for a full-capacity working season of about 3½ months.

In 1939 a cistern of 1,000,000 gallons capacity was built. This cistern and wells at Fair Plain and Jealousy and sumps at Castle Burke and Bethlehem are the sources of water supply for the factory and for villages near Bethlehem.

SUMMARY

The present facilities for the recovery of rainfall water, stream flow, and ground water are generally sufficient in periods of normal or above-normal rainfall to supply most needs. However, the island is subject to frequent and severe droughts, and in periods of drought the lack of water becomes acute. Many wells go dry or decrease in yield, stream flow diminishes or disappears, and vital cistern supplies may become totally depleted. At such times, the normal tempo of the island is badly deranged and great personal inconvenience to all classes of persons, loss of stock and crops, and shutdown of distilleries and cane mills may occur.

WELL CONSTRUCTION

DUG WELLS

The majority of wells on St. Croix are dug wells. Most of those located either in the alluvium or in the Mount Eagle rocks are less than 40 feet deep, but those developed in the soft Tertiary rocks may be of greater depth. Eleven or more dug wells in Tertiary rock are 90 feet deep or deeper. The deepest of these is at Constitution Hill, where it is reported that the total depth of the well was 225 feet.

Dug wells in the alluvium are prevented from caving by masonry walls generally constructed of hard limestone blocks quarried from the Kingshill marl or boulders of the Mount Eagle rocks. Below the alluvial cover, wells are not cased.

Many of the dug wells, particularly the older ones, have stone towers erected over them (pl. 6*A*) to support wind vanes for the operation of the pump. The individualism and architectural beauty of the diverse types of well towers are features of the island. Other dug wells are generally protected at the surface by a masonry or concrete curb.

DRILLED WELLS

In recent years many 8-inch wells have been drilled in St. Croix with a small cable-tool rig. All the producing wells are less than 100 feet deep, but the abandoned well at Peter's Rest School was carried to a depth of 200 feet. These wells are generally finished without screens. Where water is obtained from sandy alluvium it is to be expected that the maximum yield is not obtained and that the wells may be short-lived because of clogging.

Wells drawing water from sandy formations should be equipped with modern high-grade manufactured well screens, the openings of which are of such size that the coarser one-third of the sand stratum is retained. Upon agitation the finer two-thirds of the sand is drawn into the well and removed by bailing. By these means a permeable coarse sand or gravelly envelope is built up around the screen and the flow of water into the well is at a maximum.

Well screens are ordinarily used in wells in sandy formations which are intended to develop a maximum amount of water. A casing is driven to the top of the sand, and an open hole is made through or into the sand. The screen is then lowered inside the casing until it is opposite the water-bearing stratum, after which it is sealed to the casing with a lead packer. Where it proves impossible to drill open hole into the sand, casing must be driven through or into the sand to the proper depth before the screen is placed. After the strainer is placed the casing is jacked back to uncover the screen, and the screen is sealed. Development of more than one stratum may be more complicated.

After the screen is set and sealed, the well should be developed by strong intermittent pumping for a few hours or a few days, depending upon the conditions encountered. Intermittent pumping draws out the fine-grained material, which tends to restrict the flow of water into the well. The backflow from the pump line when the pump is shut off agitates the sand in the vicinity of the well screen and thereby loosens it so that it will be removed when the pump is again started up. By these means the maximum amount of water is obtained from the well.

A properly constructed well in the alluvium can only be constructed by a driller who has a reasonable amount of equipment with which to work.

Screens cost anywhere from $3 or $4 a foot to $20 or $30 a foot depending on the diameter of the screen, the type of manufacture, and the metal of which the screen is made. The cost of a well in alluvial formations may be increased from $50 to $500 by the installation of such a screen. However, the increased water supply resulting from proper well construction and from the use of proper well equipment cannot be overestimated in St. Croix, where good wells are few and where water in reasonably large quantities is obtainable in only a few places.

As far as is known, no benefit would be derived from installing screens where weathered Mount Eagle volcanics, diorite, or Kingshill marl is penetrated. The importance of intermittent pumping at a maximum rate when a hole is completed in these formations should be emphasized since it is believed that this is not commonly practiced.

So far as well construction is concerned, most of the wells in the Mount Eagle rocks and the diorite are relatively shallow, and the exploration for an increased supply at depths of from 100 to 200 feet has not been attempted in most places.

Most of the drilled wells and some recently constructed dug wells are pumped by wind power provided by the ordinary steel-girder type of tower and vanes.

A well was drilled by the rotary method at Fair Plain in 1939 by the Layne-Atlantic Co. for the Virgin Islands Co. (See pl. 6*B*.) An uncased hole was drilled to 225 feet, an operation made possible by circulating a drilling fluid the consistency of a thin mud. The fluid was pumped down inside the drill rods, out through openings in the bit, and up along the space between the rods and the hole. This fluid plasters the walls of the hole and prevents the caving of the walls and at the same time carries out the drill cuttings. The hole was reamed to 36 inches to a depth of 73 feet (the bottom of the lowest water-bearing stratum), and a 36-inch casing was set to the top of the water-bearing strata. A string of 10-inch casing and 8-inch strainer was then set in the hole. Gravel was filled in the space outside the string of casing and strainer and inside the 36-inch hole and casing.

Very few data on the drilling operations of the National Park Service (CCC) project in 1940-41 are at hand. Drilling was done by a light rotary rig, presumably in the usual manner. Casing set was 8 or 6 inches in diameter. It is believed that modern manufactured well screens were used where sand formations were developed but elsewhere, as in weathered Mount Eagle volcanics, perforated pipe was used for well screens.

OCCURRENCE OF GROUND WATER

PREVIOUS INVESTIGATIONS OF GROUND WATER

Prior to 1817 Maclure[52] visited St. Croix and in addition to publishing the first brief description of the geology of the island noted that "The west end and middle of the island are low and covered with a shell limestone and madrepore rock. The founda-

[52] Maclure, William, Observations on the geology of the West India Islands from Barbados to Santa Cruz, inclusive: Acad. Sci. Philadelphia Jour., vol. 1, pp. 134-149, 1817.

tion on which this rock reposes is a stratum that retains water . . ."

Although many other geologists visited St. Croix in the following years[53] no attention seems to have been given to the ground water. After the American occupation of these islands in 1917 the desire to provide an adequate water supply for military establishments and later for sugar mills and for irrigation focused attention on the possibility of obtaining larger and more dependable supplies of water than that previously furnished by streams and cisterns.

T. W. Vaughan, of the Geological Survey, was the first geologist to make a study of the ground-water resources of the Virgin Islands, and in his report to the Governor of the Virgin Islands, June 20, 1919, he made the following statement:

> There is in no one of the Virgin Islands of the United States nor in eastern Puerto Rico any arrangement of rocks that would make possible the presence of artesian water in any appreciable quantity. No water-bearing formation extends from Puerto Rico under the Virgin Bank. In general the rocks of St. John, St. Thomas, Culebra, Vieques, and eastern Puerto Rico are composed of sedimentary rocks that have been tilted and folded so that the angle of inclination of the beds in many places exceeds 45° or even 60°. In places the beds are practically vertical. Furthermore, these sediments are cut by igneous rocks that came into their present position while in a molten state. These intrusive rocks would interrupt the underground movement of waters, were other conditions favorable to the presence of artesian supplies. Water from artesian sources in any appreciable quantity in the Virgin Islands or in eastern Puerto Rico is physically impossible, and any money expended on test wells would be wasted.

The above report was written with St. Thomas in mind, but it applies to those areas in St. Croix that are made up of the Mount Eagle rocks.

In connection with Vaughan's work on St. Croix in 1919 a number of water samples were collected by H. Rydeen and analyzed in the laboratories of the Geological Survey.[54] All of these have been included in the present report.

Kemp in 1923[55] reviewed the ground-water prospects of St. Croix and summarized the water-bearing characteristics of the rock formations. The alluvial flats opposite valleys and amphitheaters in the mountains and hills were suggested as good sites for small wells.

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[53] Kemp, James F., Introduction and review of the literature on the geology of the Virgin Islands: New York Acad. Sci., Scientific survey of Porto Rico and the Virgin Islands, vol. 4, pt. 1, pp. 1-69, 1926.

[54] Vaughan, T. W., Ground waters of St. Croix, V. I.: Unpublished manuscript, U. S. Geol. Survey, 1919.

[55] Kemp, James F., Report to H. H. Hough, Captain, U. S. N., Governor, Virgin Islands: Printed at the Naval Station, St. Thomas, Apr. 6, 1923.

In "A report on St. Croix's water prospects,"[56] H. A. Meyerhoff presented more detailed data on the water-bearing character of the formations.

With regard to the surficial alluvium Meyerhoff points out that below River and Fountain estates the presence of wash derived from the diorite renders the material more permeable than in most other places and that the difficulty of impounding water immediately west of Jealousy and the intermittent character of the stream near River are good evidence of the permeability of this material.

The limy rocks of the Kingshill marl are described as being exceedingly unfavorable.

The basal conglomerate (of the Jealousy formation) was suggested as a possible aquifer, and exploration of that stratum was recommended.

In a report on the various possible sources of additional water supply for the properties owned by the Virgin Islands Co., Johnson,[57] of the United States Bureau of Reclamation, discussed the possibility of increasing the supply by wells. He added but little to what was already known of the geology and hydrology, relied in large part on Meyerhoff's findings, and made further recommendations on the basis of Meyerhoff's report discussed above. He recognized the better-than-average yields of the New Works and Fair Plain (45b) wells and recommended developing the alluvial valleys west of Kings Hill and west of Golden Grove.

GENERAL CONDITIONS[58]

Ground water occurs in voids, cavities, fissures, and pore spaces in various types of rocks and saturates the ground up to a variable height known as the water table. If the material is fine-grained, the earth above the water table is more or less moistened by water drawn up from the zone of saturation by the action of capillarity, whereby small communicating interstices form irregular capillary tubes through which water is drawn up by molecular attraction, acting against gravity, and is held in this suspended position at a height above the water table where the two opposing forces are in equilibrium. This is known as the capillary fringe. In clean gravels the fringe may be practically absent, but in silt or clay loam it may be as much as 8 feet thick (fig. 6).

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[56] Quoted by Johnson, Arthur F., Preliminary report on the water supplies for properties managed by the Virgin Islands Co., St. Croix, V. I.: U. S. Dept. Interior, Bur. Reclamation, manuscript rept., pp. 65-67, 1937.

[57] Op. cit., pp. 48-49.

[58] Meinzer, O. E., The occurrence of ground water in the United States: U. S Geol. Survey, Water-Supply Paper 489, 1923.

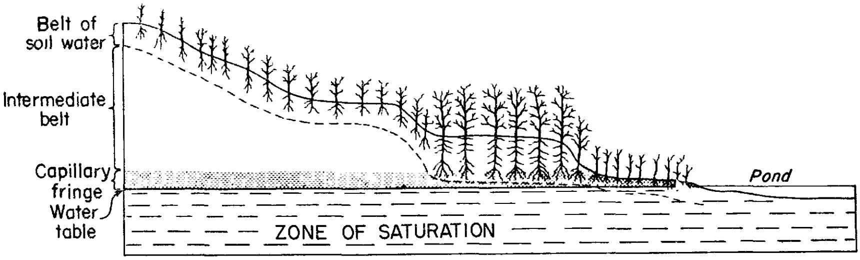


FIGURE 6.—Diagrammatic section showing the zone of saturation and the three belts of the zone of aeration.

Between the capillary fringe and the belt of soil moisture the earth contains only a very little water. This is called the zone of aeration. At and near the surface the earth generally contains a somewhat greater amount of water, and this zone is known as the zone of soil moisture.

Where the zone of saturation lies close to the surface, the zone of aeration may be absent.

Some of the water falling upon the earth percolates into the ground and tends to accumulate in the zone of saturation. Where the water table is high the ground water tends to move toward lower elevations. It may continue to move underground until it reaches the sea, or it may discharge as springs at the surface and contribute to the flow of streams (fig. 7, *A*), evaporate, or be transpired by vegetation.

When in periods of drought, the water table declines and falls below the levels of the springs and streams, the springs and streams become dry. (See fig. 7, *B*.) In and near the mountains in St. Croix ground water flows into the streams, but across the

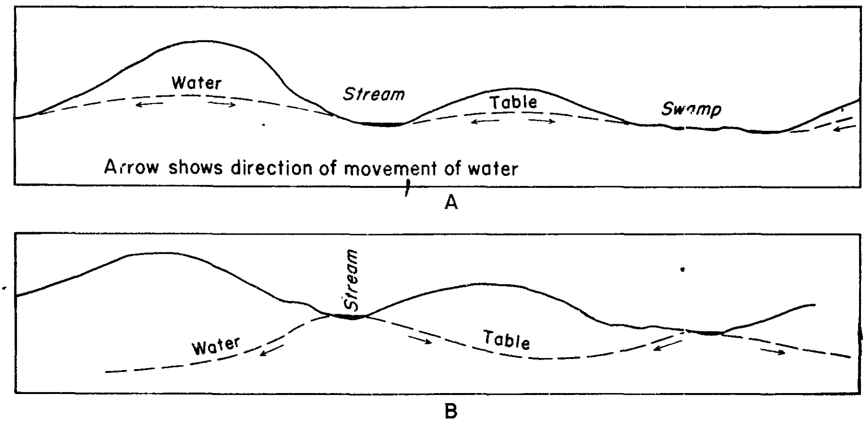


FIGURE 7.—Diagrammatic sections showing the movement of ground water: *A*, In times of normal or excessive rainfall; *B*, In times of deficient rainfall.

central plains the water table generally is below the stream beds and many surface streams are "lost" in crossing this plain. Near the sea, at very low elevations the stream beds are again lower than the water table and the streams reappear. Water falling as rain at Fountain estate, therefore, may at first be absorbed by the soil but may move underground a short distance and pass into River Gut. After flowing at the surface for a short distance it may become lost in sands and gravels below Jealousy, move underground for several miles, and finally reappear at the surface below Fair Plain. Elsewhere, spring-fed streams from the mountains disappear before they reach the gravelly plain and discharge into the sea without ever coming to the surface, as in the valley between Jolly Hill and Little Grange.

Under artesian conditions water occurs in strata sealed off from the surface by overlying beds of impermeable material, such as clay. The water-bearing stratum fills with water back to the intake on higher ground and hence is under pressure. Below the intake area water will rise in wells which penetrate this saturated stratum. If the ground is low enough the well may flow. Much of the water in the deeper alluvium-filled channels in the central plain and elsewhere occurs under artesian conditions, but almost nowhere is the artesian head sufficient to cause the wells to flow. The diagram, figure 8, illustrates this phenomenon.

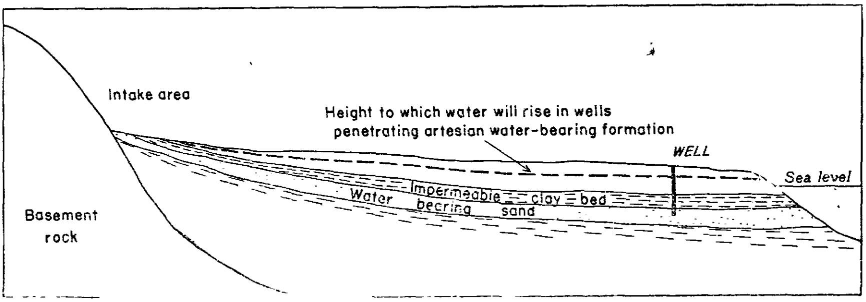


FIGURE 8.—Diagrammatic section showing artesian conditions.

GROUND WATER IN THE MOUNT EAGLE VOLCANICS

A few wells within the mountainous area in western St. Croix obtain water from the hard-rock formations.

Little Grange lies along the wall of a narrow valley draining a relatively large part of western St. Croix and is located above the canyon mouth at an elevation of about 130 feet above sea level. A drilled well (6, table 11) at this estate penetrated 30 feet of "gravel" and 20 feet of hard rock. The water level in the well is not known, but the well yields an adequate amount of

water for cattle and is pumped about 30 hours a week by a power-driven deep-well pump.

The stream flow just above Jolly Hill was measured on January 11, 1939, and found to be about 180 gallons a minute. This flow, in addition to a flow of perhaps 25 gallons a minute entering the main gut at Jolly Hill, disappears entirely before reaching Little Grange, one-half mile downstream. It seems indicated therefore that exploration of the hardrock valley floor east of Frederiksted by wells might prove profitable.

A drilled well (16) 62½ feet deep is located in a canyon mouth at Robe Hill. The water level was 7 feet below the stream bed. At Valbygaard, near the mouth of the next canyon to the east, the water level in a 32-foot well (18) was about 18 feet below the stream bed, and at Cane Valley estate, higher in the same valley, the water level in well 17 was about 1½ feet below the surface of the stream bed. Similar relations prevail at the River (36) and Grove Place (26) estates. These wells, including those at Little Grange, take advantage of the underflow moving down the valleys from the higher collecting grounds in relatively restricted channels in the decomposed rock of the stream beds. The well at Grove Place extends to a depth of 11 feet below the stream bed. It goes dry in periods of low precipitation. The well at Robe Hill is probably the only one drilled deep enough to take real advantage of the underflow in periods of drought. It is thought that water-bearing fissures might be encountered down to a depth of 100 or even 200 feet.

The chloride content of waters from these shallow wells in hard rock is relatively low, and in three wells the water contained less than 150 parts per million of chloride (6, 16, 17, 18, 26, table 11).

In the vicinity of Christiansted are several wells that may obtain water from the weathered upper part of the older rock formation. In the city itself are several public wells from which water is drawn by buckets (pl. 5*B*). Water from well 91, located in Water Gut, is highly mineralized. Well 90, at the foot of Strand Street, yields water in which the total mineral content is more than twice as great (table 9). This difference is considered to be due to the fact that the former well is located along a minor drainage line where a greater volume of underflow and surface flow has tended to prevent the accumulation of salts in the ground.

Several wells at Hermon Hill supply water for cattle and a small distillery. One well (85) is located in the valley between Alderville Hill and Hermon Hill at an elevation of about 175

feet above sea level. The well is 90 feet deep, and the water level was 58 feet below the surface on January 22, 1939. This well is reported to yield 1,200 gallons a day even in periods of drought. In well 86, in the valley head south of Hermon Hill at about the same elevation, the water level was 61 feet below the surface, but it is reported that during and following periods of heavy rains the water level rises to within 20 feet of the surface. This latter well penetrated 2 feet of clay, 58 feet of sandy rotter rock, and 12 feet of solid rock. Although this well does not fail in periods of drought, a third well (87) on the estate located at a lower elevation one-half mile to the south does fail in periods of drought because the well is not sufficiently deep.

A drilled well (116) at Granard, 2¼ miles south-southeast of Christiansted, encountered rock beneath 18 feet of alluvium. The water level is reported to be 10 feet below the surface. At Longford, about 1½ miles to the east of Granard and likewise located about 50 feet above sea level on a low plain sloping gently toward the sea, a well (114) 83 feet deep is reported to have flowed when it was drilled in 1930. When measured in 1939 the water level was 38 feet below the surface. Water is delivered from the well by a gasoline-powered pump having a capacity of 15 to 20 gallons a minute, and the well is reported always to yield an ample supply of water for stock and domestic use. This well may penetrate bedrock within a short distance of the surface.

The well (112) 45 feet deep at Nugent estate penetrated 44 feet of clayey alluvium and 1 foot of rock. Mr. B. Nelthropp, who has drilled many wells on the island, states that in the East End area in general the slightly consolidated clayey alluvium is an impervious formation and water under low artesian head is obtained from the weathered bedrock beneath the alluvium. This statement is of interest when the soil map of St. Croix is studied.[59] This map shows that the greater part of the level or gently rolling intermontane area in the East End is surfaced by clays or clay loams, whereas the gravelly soils are confined to narrow valleys or occur as fringes on the steeper slopes above the clay areas. These facts may indicate that in general most of the alluvial material contains notable proportions of clay and that the alluvium might be expected to be relatively impervious.

At Hartman (well 111, table 11) the "rotten rock" was encountered at 20 feet below the surface. At the time the well was visited the wind-powered pump was delivering about 2 gallons

[59] Thorp, James, Soil survey (reconnaissance) of St. Croix Island, V. I.: U. S. Dept. Agr. Tech. Bull. 315, 1932.

a minute and the water level in the well was 39 feet below the surface.

No data are available on the well at Petronella (110).

Wells 89 and 88 lie in the alluvium-filled lowlands between the hills bordering Altoona lagoon. Well 89, north of St. Peter estate, encountered "rotten rock" at about 40 feet. Water stands 16½ feet below the surface in this well. At Mount Welcome water is probably also derived from weathered bedrock as the well is 82 feet deep. The water level is reported to be 20 feet below the surface.

The chloride content of water from wells in the East End section of St. Croix differs considerably.

Wells at St. Peter (93), Catherine's Rest (117) and Hermon Hill (85) yield water containing less than 300 parts per million of chloride. The other wells discussed have a higher chloride content, according to field tests; at Granard (116), Nugent (112), and Hartman (111) the water contained 780, 645, and 1275 parts per million, respectively. The reason for these differences is not everywhere apparent. A moderate chloride content, as in water from well 85 at Hermon Hill, may be the result of relatively great underflow in a restricted rock-cut valley or of water flowing to the well only through hard-rock formations. A high chloride content appears to be due to the fact that some or much of the water which enters the well has percolated through alluvium or other material in which alkali salts have been more or less concentrated[60] by high evaporation, low rainfall, and poor underground drainage. It is not believed that the water in any of the wells referred to above has been contaminated by sea water.

GROUND WATER IN THE DIORITE

Well 38, known locally as the Kobel well, three-fourths of a mile north of Jealousy estate, is 63 feet deep and ends in dioritic rock. Here about 10 feet of fill overlies the deeply weathered rock. Water enters the well below the casing, which extends to a depth of 57 feet. On February 3, 1939, the water level stood 10.90 feet below the top of the casing, which is about 11 feet above the stream bed on the banks of which the well is situated.

A pumping test was made on the well to determine the water-bearing characteristics of the deeply weathered diorite. The well yielded 19½ gallons a minute with 15 feet of drawdown at the end of a 6-hour pumping period. More water could probably be

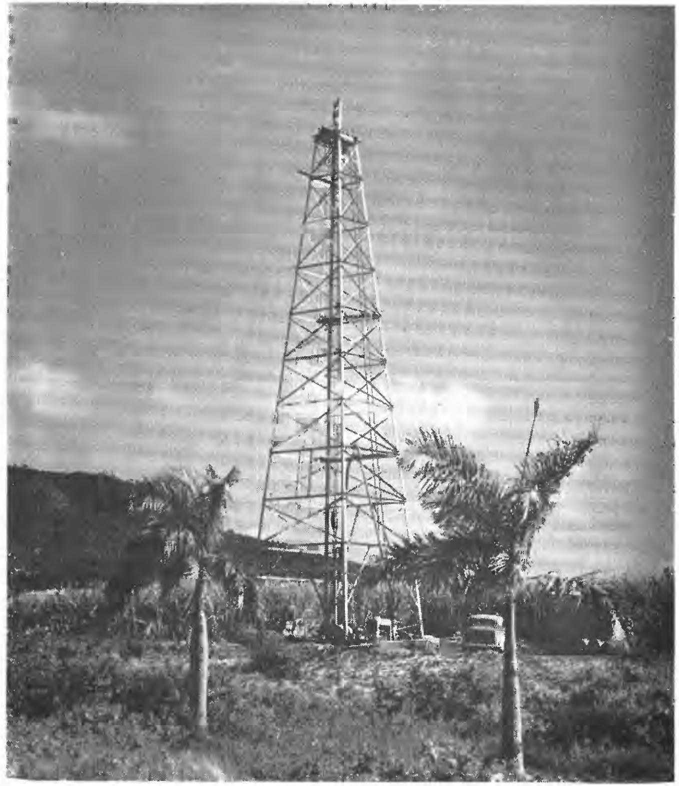
[60] The soil map of St. Croix referred to above shows that alkali soils commonly occur at the lower elevations within the alluvial areas in East End. Other areas are probably less alkaline.

A. ARTIFICIAL CATCHMENT BASIN AT MARY'S FANCY.

Windmill pumps water from underground cistern. Old wind-powered cane-mill tower and stack of more recent steam-powered cane mill is at right. Photograph by Paul Schweitzer.

B. MUNICIPAL WELL, WATER GUT, CHRISTIANSTED.

A. OLD WELL TOWER AT STRAWBERRY.
Modern wind vanes have been installed. Photograph by Paul Schweitzer.



B. ROTARY RIG AT TEST WELL NO. 2 NEAR JEALOUSY.
Note proximity of well to mountain at left. Photograph by Paul Schweitzer.

obtained at this place by drilling additional wells or by constructing a well in such a way as to provide a greater intake area. If the weathered diorite is too rotten to allow firm seating of the casing at a depth of about 20 feet, it might be advantageous to install perforated or slotted pipe of a smaller diameter than the hole below 20 feet and fill the space between the hole and casing with sized small gravel. It is also possible that fissures and cracks which would further increase the capacity of wells developed in the dioritic rock might be encountered at greater depths, and additional wells in this formation should be carried to a depth of about 300 feet unless it is found by careful testing that increases in yield do not occur with increases in depth of hole or that water from depth is highly mineralized.

It is reported that in the drought of 1940 this well continued to yield about 2,000 gallons a day. In view of the pumping test referred to above it would seem likely that the installation of a low-capacity power pump on this well and substitution of a 3- or 4-inch pipe line for the existing ½-inch line would be profitable. By this means the supply at Bethlehem Factory might be increased from 5,000 to 10,000 gallons a day.

At Southgate a drilled well (100) 80 feet deep probably draws upon weathered diorite. It is believed that the diorite here is as good a water-bearing formation as the rock penetrated by Kobel well, but no data on the capacity of the well are at hand. However, it is reported to have furnished the wind-powered pump with ample water in the 1940 drought.

There is good reason to believe, considering the record of the Kobel well and the performance of wells in coarsely crystalline rock areas in general, that a moderate quantity of water could be developed by properly constructed wells in the Fountain Basin and to a lesser extent in the Hermitage Basin to the east. Likewise it may be expected that water in moderate quantity could be obtained from properly constructed wells penetrating the dioritic rock in the region around Southgate and southeast of Sally's Fancy in East End.

GROUND WATER IN THE KINGSHILL MARL

About 25 wells in St. Croix obtain water from the limestone of Tertiary age which makes up the plain between Frederiksted and Christiansted. The wells vary considerably in depth. A few wells less than 20 feet deep may obtain water from the limy rocks, but most of the wells are deeper and at least two wells are more than 200 feet in depth. Most of the wells are dug wells and eight of the dug wells are more than 100 feet in depth. The dug well at Constitution Hill is more than 225 feet deep. The wells are protected near the surface by natural stone masonry but are not cased below the surficial alluvium. In recent years a few 8-inch open-end wells have been drilled.

The limy Kingshill rocks lie at lower elevations near the coast than they do at the foot of the mountains, but details on the structure of the central plain are incomplete and although it is believed that only one to two specific strata yield the water encountered in wells, this cannot positively be determined.

Water in wells in the Tertiary limestones stands from a few feet to 20 feet above sea level near the south coast. Northward, water generally stands at higher elevations, and along the foot of the mountains the water level in times of normal rainfall may lie within relatively few feet of the surface. At Mary's Fancy, in the higher area in the eastern part of the plain, the static water level is as much as 250 feet above sea level.

Water-bearing limestones of the Kingshill marl are characterized by small solution holes at Paradise (well C-5). Rock of this type has not been reported in other wells. Strata with small solution holes have been noted in a very few places in road cuts and stream banks. It is possible also that in many wells water is derived from openings along bedding planes and fissures which have resulted from structural deformation.

The water-bearing limestones of the Kingshill marl may be largely replenished along the foot of the mountains by surface streams and by underflow from the mountains. Recharge across the limestone plain is probably hindered in many places by a cover of clayey soil, but elsewhere direct downward percolation of rainwater may take place.

A detailed description of representative wells is given below.

At Frederiksted seven dug wells (9a-9g) supply the greater number of the residents with water for some domestic uses. The wells along the shore are only 10 feet deep, but those on higher ground are deeper. Along the coast the water level is within one-half foot of sea level, but at a distance of 800 feet east of the seashore the water level may be as much as 4 or 5 feet above sea level.

As the water here is a body of fresh water floating on sea water it might be expected that there would be danger of salt-water contamination, particularly during those times when the water-bearing formations receive little fresh-water recharge or when relatively large amounts of water are taken from the well.

An analysis of water from well 9g (table 5) shows that more magnesium is present than calcium and suggests that the mineralization is in part due to the mixing of fresh water with sea water. However, the high nitrate content of this water indicates considerable pollution, and it is more likely that the chloride is the result of pollution rather than mixing with sea water.

The water level in the dug well (12) at Camporico, on the limestone plain southeast of Frederiksted, stands a few feet above sea level. The well is reported to be a dependable source of a moderate amount of water even in periods of severe drought.

At Whim (14), Concordia (13), and Hope (15), shallow wells in which the water level stands within a few feet of the surface in periods of normal rainfall are developed in the limestone area. However, these wells are too shallow to be dependable in times of drought. Thus far, according to local reports, no efforts have been made to deepen these wells at such times of low water levels.

It should be noted that an attempt to secure an adequate water supply by a deeper drilled well, made in the vicinity of Hope, was unsuccessful. It is reported that the well was carried to a depth of more than 100 feet, but no water-bearing strata were encountered.

A drilled well 42 feet deep at Cain (22) obtained an entirely adequate supply of water for stock. The water level stood within 2 feet of the surface when the well was visited by the writer. The well is located at an elevation of 90 feet above sea level within one-half mile of the foot of the northern range of mountains. This well is reported to have been abandoned in 1940, but it is not known whether clogging or excessive lowering of the water table was the cause of failure.

The well at Diamond (24), 90 feet deep, lies at a slightly greater distance from the mountains than the well at Cain. Water rises in this well to within 32 feet of the surface or about 53 feet above sea level.

At Enfield Green, which is located about midway between Diamond and the south coast, water rises to within 31 feet of the surface, or probably less than 10 feet above sea level. With respect to location and water level, it is similar to the well at Camporico.

Data on the maximum yield of these wells is not available. The well at Diamond (24), however, is reported to continue to yield an adequate supply even in periods of drought. The amount discharged from the well is limited by the capacity of the wind-powered pump and probably at no time exceeds 3 gallons a minute.

The dug well 37 feet deep at Paradise (29) is reported to yield less than 2 gallons a minute.

A spring issuing from limestones at Envy (31) along the south coast has a flow estimated to be 30 or 40 gallons a minute. The occurrence of this spring suggests the presence of channels in the limestones capable of yielding moderately large quantities of water.

The well (32) at Manning Bay, less than one-half mile northeast of Envy, is probably dug in alluvium. However, the presence of the spring at Envy suggests that the alluvium here may be receiving water from the limestone rocks rather than from the underflow passing down the valley at Fair Plain.

Wells in the limestone rocks are also present along the south coast at Jerusalem (61) and Cane Garden (62). The water level in these wells is approximately 22½ to 18½ feet above sea level, respectively. The former well is reported to yield an ample supply in periods of drought.

A number of wells in the more easterly part of the plain obtain water from the Tertiary limestone for domestic use and for stock. Well 54 at Mary's Fancy extends to an elevation of 190 feet above sea level, and water rises in the well to 93 feet below the surface or to about 245 feet above sea level. At other places the wells reach strata nearer to sea level and water does not rise as high, generally less than 100 feet above sea level, and, as indicated above, as the coast is approached the water may stand less than 20 feet above sea level.

At Sion Farm it is reported that, with the present installation, well 68 yields 2,000 gallons a day even in periods of severe drought. Mr. Robert Skeoch reports that for the past 30 years the well at Diamond (55) has always yielded an ample supply, estimated as at least 2,000 gallons a day. The well extends nearly to sea level, and the water stands probably as much as 35 feet above sea level in the well in seasons of abundant rainfall. The Ruby well (57), one-half mile north of Diamond, is 103 feet deep and extends to about 100 feet above sea level. Water stood at 94½ feet below the surface (110 feet above sea level) when the well was visited by the writer. If the wells at Diamond and Ruby are developed in the same ground-water body, the slope of the water table is more than 110 feet per mile. A similar apparently high gradient is present in the vicinity of Enfield Green and Cain. Certainly this is a very high gradient, and it seems possible that perched bodies of ground water exist above the body of fresh water occurring a short distance above sea level.

There is reason to believe that in wells located some distance from the coast, where the water level is normally from 50 to 100 feet above sea level or higher, the water level varies widely from season to season and year to year. Measurements or estimates of depth to water in a number of wells were made by Mr. H. Rydeen on June 4 and 5, 1919, in conjunction with a report on the water supply of the island by T. W. Vaughan. At Strawberry, where the water level stood at 116 feet above sea level when measured by the writer in December 1939, the water level was reported by Rydeen to have been 27½ feet higher in June 1919. The water level at Ruby stood about 116 feet above sea level in 1939 and was reported by Rydeen to have been 20½ feet higher in June 1919. Rydeen also notes that at Constitution Hill the water level was 190 feet from the surface or 110 feet above sea level. In 1939 this well was dry at 225 feet below the surface.

On the other hand, only slight differences in the depths to water in coastal wells at Jerusalem and Cane Garden are noted. Rydeen's figures indicate that the water levels in these wells bordering the coast were 3½ and 7½ feet higher in 1919 than in 1939. It is further reported by Mr. Hazlett, Associate Geologist of the National Park Service, that on January 1, 1941, the water levels at Jerusalem and Diamond (55) were 3½ feet lower than when measured in December 1939, on which date water levels stood at 22½ and 35 feet above sea level, respectively. Measurements by Hazlett were taken during a period of severe drought. It is reported that at Spanish Town the water level declines only a foot or so in times of drought. The water level is normally only a few feet above sea level.

The chloride content of the waters in these wells ranges from 150 to 950 parts per million except for two wells, which are even higher in chloride content. The quality of water will be discussed in detail in another chapter.

A few wells (72, 74) are developed in the Tertiary limestone rocks along the coast northwest of Christiansted. The drilled well at La Grande Princess may encounter limestone beneath a shallow alluvial cover. It is reported that in 1936 the water level was 3 feet below the surface, or about 37 feet above sea level. The dug well at La Grande Princess is located at a somewhat higher elevation. This well is 33 feet deep, and water stood at 28 feet below the surface, or about 27 feet above sea level. The well had not been pumped in 3 months. In the unused dug well at St. John the water level is 32½ feet below the surface, or about 57½ feet above sea level.

The wells at La Grande Princess yield highly mineralized water. It appears probable that the mineralization is due to salts in the water-bearing formations rather than to contamination by sea water since the water levels are quite high above sea level.

In general, the Kingshill marl is a poor water-bearing formation, although several wells with very low yields are of considerable value in furnishing water to livestock.

GROUND WATER IN THE ALLUVIUM

NORTH SIDE

Only a few wells from the mouth of Salt River westward are developed in the Quaternary deposits. In one well (77), located just south of Greig Hill on low swampy land, water stands slightly above sea level. This well is pumped every day by a low-capacity gasoline-powered pump and furnishes ample water for cattle. The water is highly mineralized. A second shallow well (78), pumped by a wind-powered pump, is located on the coast northwest of Greig Hill. As closely as could be determined, water stood about 1 foot above sea level in this well. The chloride content of the water is relatively low—378 parts per million.

EAST END

Several shallow wells (95–97) are located at the east end of Altoona lagoon at slight elevations above sea level. Water levels stand as high as 6 or 7 feet above sea level in these wells. When these wells were visited the chloride content of the water from two wells was relatively low, but the chloride content of the water from a third well was about 950 parts per million. The reason for this difference is not understood, but it is thought that since the windmill pump was operating in the third well and not in the first two, more highly mineralized water was being drawn into this well from the immediately adjacent salt pan bordering Altoona lagoon.

Another well (98) in this general area, just south of Darby Hill, yields water containing more than 1,000 parts per million of chloride.

In a dug well (99) at All-For-The-Better, at the head of the broad valley carved in dioritic rock embracing Southgate Pond, water stood 29½ feet below the surface, or about 60 feet above sea level. This well is probably developed in the alluvium but may reach the weathered bedrock beneath.

Two wells are present in a similar topographic and geologic situation at the head of the broad southward-facing valley embracing Great Pond. In well 109, 35 feet deep, the water stands 33 feet below the surface, and in periods of drought the water level falls below the bottom of the well. Well 108 is a drilled well 76 feet deep and obtains water from sandy strata about that depth. In constructing this well, much of the sand was cased off to prevent sand clogging. The chloride content is somewhat higher in the shallower well water, being 544 parts per million.

In a shallow well (101) at Green Cay, along the north coast, water stands about 2 feet above sea level. This well supplies more than 300 cattle with water even during periods of drought. The chloride content is relatively low. This well may be in the path of greatest underflow down the valley, otherwise it might be expected that the mineralization would be higher.

The well (102) at Mary's Fancy is poorly situated on the east side of Cotton Valley and yields a water containing about 600 parts per million of chloride. If it were located more westerly in the path of greatest underflow the water might be lower in chloride.

Three wells are located at Great Pond estate. Well 105 is developed in a narrow strip of beach sand just west of Mount Fancy. The well near the great house (106) is developed in alluvium and encounters rock at 24 feet below the surface. The water here has a chloride content of more than 1,700 parts per million. The water level had declined at the time the well was visited to within a foot of the bottom of the well, and the yield of the well was decreasing. A third well (107), 40 feet deep, is in the broad valley one-half mile northwest of the great house. Water stood 6⅓ feet from the surface at the time the well was visited. The well is not used and is reported to furnish only a limited amount of water.

In summary, small supplies of rather mineralized water are obtained from shallow wells developed in alluvium along the coast in the East End area. In some of these waters (wells 78, 95, 96, 97) contamination or the danger of contamination by sea water is apparent. Other well waters (wells 70, 71, 77, 98) are highly mineralized because of salts in the sediments from which the water is taken. Wells (93, 94, 101) which are located on or near the main channels of underflow from large drainage areas yield more dependable supplies of water, and the water obtained is relatively low in mineral content. Water levels fluctuate more widely in response to local seasonal rainfall in the wells on higher ground. Wells that are too shallow (109) go dry in periods of drought.

CENTRAL PLAIN

The alluvium that occupies the valleys and broad depressions in the central marl plain supplies fair amounts of water of relatively moderate mineral content to a number of shallow dug wells and to a few deeper drilled wells.

In most of these wells the water level is within 15 feet of the surface. Further, most of the wells are so shallow that in times of drought the water level may fall below the bottom of the well and the well go dry. The deeper drilled wells are generally dependable sources of water even in times of drought.

North of Frederiksted three wells take advantage of the underflow coming down from the large drainage area in the mountainous western part of St. Croix. The wells at Williams (4) and Wheel of Fortune (10) supply water for domestic use and for cattle. The chloride content of the water in the well at Williams is only 112 parts per million but is 410 parts in the well at Wheel of Fortune. In the dug well just south of La Grange factory (8) the water level was 8 feet below the surface, or about 30 feet above sea level. This well, 15 feet deep, is reported to yield 200 gallons a minute for periods of several hours.

It seems likely that this area just north of Frederiksted, which is at the mouth of a valley carrying a fairly large underflow, is a particularly favorable locality for the development of moderate to large supplies of water. The underflow coming down the valley varies, of course, but except in periods of protracted droughts it may be as much as several hundreds of gallons a minute. If moderately large amounts of water are to be pumped in this area, as for a municipal supply for Frederiksted, care should be taken not to draw the water level down to sea level, as a general lowering of water levels will tend to bring in salt water and endanger the quality of the supply. For maximum yield and efficiency and to lessen the danger of chloride contamination, any moderately large quantity of water discharged should be pumped from several widely spaced wells rather than that the total amount be taken from one well.

It seems evident that a fairly large supply of water might be also obtained between Spratt Hall and Williams since this area too receives underflow from a drainage area extending eastward to Annaly.

From Whim to Mount Pleasant very little is known concerning the thickness of the alluvium and its quality as a water-bearing formation. Most of the wells obtaining water from the alluvium here are shallow and fail in periods of drought. However, if favorable thicknesses of alluvium are found in this area, it seems likely that supplies of water may be obtained which would be an improvement over many of the existing supplies. Dependable supplies of small quantities of water are reported to be obtained from wells at Cain (22), Diamond (24), and Enfield (23). Although these wells are said to penetrate the marls and limestone of the Kingshill it is conceivable that much of the water available to them has been carried down from the mountains as underflow in the alluvial cover. It seems possible that deep alluvium-filled channels in these underlying rocks from which somewhat larger amounts of water could be obtained might be located. Areas receiving the greater part of the underflow from the mountain valleys terminating at Grove Place, St. George, and below Cane Valley will probably be the most favorable places to prospect. The fact that streams from the mountains become dry even before they reach the alluvium but reappear as the coast is approached indicates that subsurface flow is normally of importance in this area.

The inner lowland from Plessen to Mon Bijou and the valleys extending southward from the inner lowland to the sea are filled with a variable thickness of alluvium. In this area three shallow wells, four deeper wells, and two springs furnish water for several villages and for cattle.

The streams discharging across the alluvial plain from the mountains are lost beneath the surface a short distance below the mouth of the valleys. Water appears in their courses from place to place; for example, the stream near Fair Plain flows on the surface. A short distance below the South Side road the flow was roughly measured at 50 gallons a minute. This measurement was taken late in March in the dry season. A short distance below the place at which the above mentioned measurement was taken the surface flow increased considerably.

The discharge south of the South Side road represents only a small part of the water taken into the ground at the foot of the mountains inasmuch as important losses are sustained all along the stream courses by evaporation where the water level is at or close to the surface. Further, it is known from logs of wells that deeper sands and gravels, separated from the surface sands by relatively impervious clays, are present in the major valleys traversing the central plain, and these undoubtedly carry off much of the drainage from the mountain area.

At Plessen (28b) and near Castle Burke (34b) water is pumped from springs issuing from the surface sands. The spring at Plessen yields a water containing 316 parts per million of chloride. It is said never to go dry. At the Castle Burke sump from 10 to 20 gallons a minute is pumped continuously in seasons of normal rainfall, but in periods of drought the yield is considerably less. However, since water (in somewhat smaller quantities than normal) was available from the Castle Burke sump in the 1940 drought, it seems indicated that the water levels may not fall very greatly in this vicinity in periods of deficient rainfall and that moderate quantities of water should be available to properly located shallow wells in this area at all times. As the water from Castle Burke sump is of very low mineral content (see table 10) and as ground water occurs near the surface even in times of drought, this area should be explored to determine the location of the deepest part of the ancient-filled valley leading southward from Upper Love. Here the greatest thickness of coarse sands will be found, which should provide an excellent supply of water to properly screened wells.

A dug well, not more than 20 feet deep, is located along the stream bed near Fredensborg. Normally this well yields about 7 gallons a minute per 8-hour day. In times of drought, however, it is practicable to pump the well only about 3 hours a day. The chloride content of the water is high but not excessive, being 452 parts per million.

The extent of variation in water-level is illustrated by several measurements made on the Golden Grove dug well. Rydeen noted that on June 2, 1919, the water level was 10 feet below the surface. On December 9, 1938, the water level was 14½ feet below the surface. This was in a season of normal light rains. During the following dry period, water levels fell, and on March 25, 1939, the water level was about 18½ feet below the surface. Hazlett reports that in January 1941 the water level in the well had declined to about 24 feet below the surface.

It seems apparent that since the level of near-surface water is subject to wide variations in this locality (and perhaps in other localities some distance from the foot of the mountains) every effort should be made to continue shallow wells through the water-bearing sands to the underlying impervious formation, either clay or marl, in order that water be available to pumps at all times. This can be accomplished easily by drilled wells using casing and screen but may be impossible with dug wells.

Deeper sand strata are developed in the axial part of the valley between Fredensborg and Fair Plain. Drilled wells at New Works (44) and at Fair Plain (45b) encounter coarse gravel about 58 feet below the surface. Water is present under artesian head and rises to within 14 feet of the surface in the latter well. These wells are not screened, nor are they developed to the fullest extent possible. Yet the latter well, at least, yields about 3 gallons per minute per foot of drawdown, and both wells continued to yield ample water to low-capacity windmill pumps during the drought of 1940. Plate *3B* is a view across the alluvium-filled valley south of Bethlehem.

A test well (45a) was drilled within 100 feet of the well at Fair Plain discussed above. The log of this well shows that in addition to near-surface water occurring under water-table conditions, two strata of artesian water-bearing gravels and sands occur from 57 to 62 feet and from 70 to 73 feet below the surface, respectively. The near-surface water, which occurs in fine-to-coarse sand extending from the surface to a depth of 33 feet, stood at an elevation of 21 feet below the surface (about 2 feet above the level of the nearby stream), but the water from the deeper strata rose to within 17 feet of the surface.

A pumping test was made on well 45a after it had been fully developed. The results of this test are shown in figure 9 and may be briefly summarized as follows: Before pumping began the static water level was 16.83 feet below the top of the casing; at the end of 23½ hours of pumping at 61 gallons a minute, the water level was 30.02 feet below the top of the casing. The rate of pumping was increased to 70 gallons a minute, and pumping at this rate was continued for 24½ hours, at the end of which time the water level was 32.31 feet below the top of the casing. The rate of pumping was increased to 80 gallons a minute and continued at that rate for 2½ hours. The water level fell to 35.33 feet below the surface. The rate of pumping was decreased to 53 gallons a minute and maintained at that rate for 17½ hours, at the end of which time the water level was 26.39 feet below the surface.

The specific capacity of the well (gallons a minute per foot of drawdown) was indicated to be 5.09, 4.52, and 5.55, respectively, in the several pumping tests.

The chloride content of the water fell from 515 parts per million to 435 parts per million during the first 23½ hours of pumping. When the rate of pumping was increased to 70 gallons

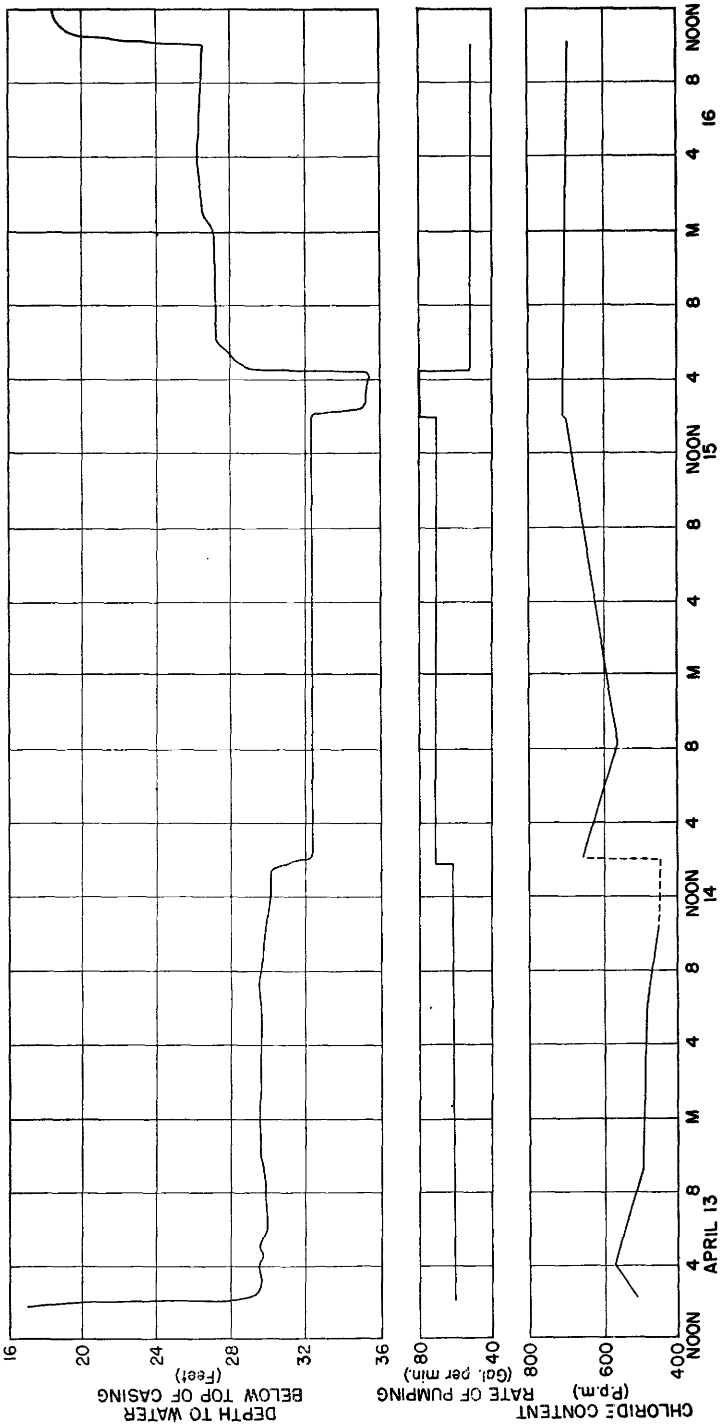


FIGURE 9.—Diagram showing results of pump test on the developed well at Fair Plain.

a minute the chloride content rose to 660 parts per million, declined to 565 parts per million, and then increased to 710 parts per million at the end of 48 hours of continuous pumping. The chloride content was still about 700 parts per million at the conclusion of the 70-hour test.

It seems likely that, as a cone of depression is created around the well, water from other sources, either from the limestones or from the near-surface alluvium, is brought into the well causing an increase in the chloride content of the water.

Analysis of a sample (table 10) collected in April 1940 shows that the water contained 500 parts per million of chloride at that time.

The dug well (32) at Manning Bay is 10 feet deep. According to a field test the water contained 685 parts of chloride on December 8, 1938. In 1939 Manning Bay was taken over by the United States Army. The well was used as a source of water supply, but it was found that when the withdrawal increased, the chloride content increased from 500 to 960 parts per million. It is stated that for several months, at least, the well was pumped at a rate of 30 gallons a minute, a remarkable yield for a dug well in St. Croix.

Very few wells are developed in the alluvial valley system discharging at Hope and Blessing. A well (50) at Lareine 42 feet deep supplies water to a wind-driven pump, as does a well 28½ feet deep at Hope (60). It is of interest to note that the chloride content of the water from the well at Hope was relatively low, about 110 parts per million.

The Castle Coakley well (63) was thought to be developed in limestone, but the low chloride content (79 parts per million) of the water suggests that it may be drawing water from the alluvium.

The drilled well at Anna's Hope (64) is 180 feet deep and may penetrate the weathered bedrock. However, it seems probable that the overlying alluvium is contributing a large part of the water available to the well and the well should be considered as being developed in Quaternary material. The well is said to yield ample water to a windmill pump even in times of protracted drought.

Several wells are located along the coast northwest of Christiansted. Two shallow wells at Little Princess are reported to yield small amounts of water at all times. In normal seasons water stands about 5 or 6 feet from the surface. One of the wells (69) yields water containing about 700 parts of chloride, but the other (70) yields water containing over 1,800 parts of chloride. The water from well 70 is used for drinking purposes occasionally by some of the native Cruzians and is described by them as "heavy" but quite palatable.

It seems established from the record of wells in the alluvium, particularly the Fair Plain developed well (45a), that there exists in St. Croix a potential supply of moderately large quantities of water which has hitherto been barely touched. It seems likely that the storage capacity of the alluvial sands and gravels may be relatively large and that with proper development several hundreds of gallons of water a minute might be easily obtained from the alluvial sands and gravels in the valley north and northeast of Fair Plain and in similar narrow alluvial valleys. Further, one or both of the deeper water-bearing strata may be present in relatively deep channels leading seaward from the mountain gorges across the alluvial lowland. Here the mineral content of ground water is lower than at localities nearer the sea. The location of these channels is not so apparent where the valleys are broad and in the general area north of Center Line road (pl. 3*A*), and it is not possible to predict their location, but their presence may be established by inexpensive test drilling with a light rotary or jetting rig.

GROUND WATER IN BEACH SAND

A well at Cane Bay (80) and another at Great Pond (105) obtain water from beach sand. Beach sand, including emergent beaches, is of limited extent in St. Croix except at Southwest Cape and cannot be counted on for more than a limited quantity of water. A well in beach sand generally yields a rather highly mineralized water, owing in large part to excessive salt spray and possible contamination by sea water resulting from overpumping.

At Cane Bay water stands 1½ feet above sea level. Although containing more than 1,000 parts of chloride the water is satisfactorily used in a cattle dip. At Great Pond water from beach sand contains over 5,000 parts of chloride but it said to be entirely satisfactory as a source of drinking water for cattle.

TEST-DRILLING PROGRAM

Through funds made available by the Public Works Administration, a program of test drilling on lands controlled by the Virgin Islands Co. was initiated in the fall of 1938 to determine the presence or absence of deep water-bearing strata in the area underlain by mid-Tertiary limestone. The wells were to be drilled on the property of the Virgin Islands Co., and a dependable supply of water for use at the Bethlehem sugar mill was to be obtained, if possible. The writer was assigned to the project and selected the sites for drilling. The drilling itself (pl. 6*B*) was done by the rotary clay seal method by the Layne Atlantic Co., of Norfolk, Va.

A study of the geology in the area north and northwest of Bethlehem Factory indicated that the marl and limestone of the Kingshill rested upon the older Mount Eagle volcanics, as had been described in the literature. The actual contact between the two formations was not displayed, and the dip of the surface of older rock plane was not known. However, it was thought that the plane probably sloped more or less gradually seaward in a manner analogous to the basement rock beneath the Atlantic Coastal Plain.

A site was selected for test drilling just east of Bethlehem Factory and slightly less than 1 mile south of the contact between the Kingshill and Mount Eagle rocks. It was hoped that information on the following points might be forthcoming upon the completion of the test well:

1. The presence or absence of water-bearing beds in the Tertiary limestones at greater depths than had been previously attained by wells in St. Croix.
2. The determination of the water-bearing characteristics of the basal conglomerate.
3. The presence or absence of water-bearing alluvial material or weathered bedrock beneath the basal conglomerate.

In the first test well (41, table 3, and pl. 1) 18 feet of soft yellow marl was first penetrated, beneath which lay 7 feet of sand and gravel. The next 83 feet of material consisted of soft (but probably indurated) yellow marl of the Kingshill exactly similar to that seen outcropping in many places on the island. However, at a depth of 108 feet a greenish-gray clay (blue when wet) was encountered, and at a depth of 1,508 feet from the surface the drill was still in this same material. Hard, thin layers of limestone, not more than 1 foot thick, occurred between 728 and 802 feet and between 1,291 and 1,448 feet, and a stratum of hard limestone conglomerate 16 feet thick was penetrated between 1,095 and 1,111 feet below the surface, a similar stratum occurring between 1,196 and 1,201 feet below the surface.

The near-surface sand and gravel was water-bearing and was being drawn upon by a nearby well, and hence no attempt was made to develop this stratum. The underlying limestone and clays were entirely barren of water-bearing beds.

It was apparent that the bedrock surface did not slope gradually seaward but plunged sharply downward from the contact near Jealousy, and, accordingly, to obtain the information sought in this program it was necessary to select a site nearer the foot of the mountains. The location for the second test was one-eighth of a mile west of estate Jealousy and 1,000 feet south of the contact of the Kingshill and Mount Eagle rocks.

In the second test well (39, table 3, and pl. 1) yellow marl extended from the surface to a depth of 91 feet. Hard layers of limestone, each one only a few inches in thickness, were encountered in the yellow marl. Below the marl gray clay of the Jealousy formation was penetrated which extended to a depth of 398 feet. The gray clay here contained much more detrital material than was found in the section at the first test well. A stratum containing boulders was encountered between 224 and 228 feet. Between 245 and 255 feet the clay contained many pebbles and small boulders, and from 255 to 398 feet below the surface the clay contained a variable but small amount of sand and pebbles. Cores of this material showed that the inclination of the bedding planes was not constant and the dip of individual strata ranged from 12° to 35° within a foot of core. The presence of thin cross-bedded sandy strata suggests that these are not true dips but are the result of cross bedding on a larger scale.

Hard limestone conglomerate extended from a depth of 398 to 459 feet below the surface. It is exactly similar to the rock seen cropping out in the stream bed a short distance northwest of the well. The conglomerate was well cemented and, as far as could be determined from cores, it was not characterized by solution cavities or fractures.

Weathered bedrock was encountered beneath the limestone conglomerate and cored for 11 feet, making the total depth of the test well 470 feet. The weathered bedrock was fractured but in the samples brought up the fractures were sealed by secondary deposits of calcite (lime).

Water was found only in the basal part of the limestone extending to a depth of 91 feet below the surface. The yield was less than 16 gallons a minute, and the water contained more than 1,600 parts per million of chloride. No water was yielded by the conglomerate or by the basement rock.

The information obtained by these test wells may be summarized as follows:

1. The limestones and marls of the Kingshill, which are seen at the surface in many places, are of limited thickness and

are underlain by a grayish clay of unknown maximum thickness. The limestones and marl rocks penetrated in these wells contained no stratum which under any conditions might be considered a particularly good water-bearing formation. The clay, as might be expected, yields no water.

2. The basal conglomerate, where not weathered, is a tight and impervious formation and will probably not yield water anywhere.
3. Bedrock lies at relatively great depths a short distance from the base of the northern range of mountains. Although fractured and open where weathered, it may become impermeable through the deposition of mineral matter by percolating ground waters.

The weathered bedrock has proven to be an excellent water-bearing formation in several places, as at Little Grange, Fobel (north of Jealousy), Hermon Hill, Longford, and Southgate. Whether fissures and cracks tend to be filled with secondary mineral matter at depth in most places or only in very few places is not known, but in any event the weathered bedrock, and possibly also the fresh harder rock beneath if encountered in wells at shallow depths, should be considered as possible sources of at least small supplies of water. This point has been previously discussed, but is repeated here to avoid the implication that the evidence gained in the second test well is applicable to all areas underlain by hard rocks in St. Croix.

It was decided to develop a well at a selected location where the alluvium would most likely be of maximum or nearly maximum thickness and subject to continuous and ample recharge. A site was selected (45a) near the existing drilled well (45b) at Fair Plain. In this place the surface and subsurface drainage of a wide area extending up into the mountains is concentrated in a narrow channel. The existing well demonstrated the presence of other than near-surface water-bearing formations. In addition it was felt that the location was far enough removed from the sea to avoid salt-water contamination.

In addition to near-surface water-bearing sands, water-bearing strata were encountered from 57 to 62 feet and from 70 to 73 feet below the surface. The relatively large yield of water obtained from these strata as compared to yields of other wells on the island has been discussed in a previous chapter. Yellow marl lay below the alluvial sands and clays and extended to a depth of 162 feet, and alternating harder limestones and soft marls extended to a depth of 208 feet below the surface, at which depth gray clay was encountered. The well was continued to a depth of 225 feet. No water-bearing strata were encountered in the limy rocks.

The test well was converted into a gravel-packed well and at present is supplying water to the Bethlehem Factory. It is reported to have furnished 18,000 gallons a day during the severe drought of 1940 and was pumped continuously at a rate of 40 (?) gallons a minute in 1943.

TABLE 3.—*Logs of test holes drilled in St. Croix, 1938–39*

Well 41, Virgin Islands Co. at Fredensborg

[Altitude, 90 feet]

	Thickness (feet)	Depth (feet)
Alluvium (Quaternary):		
Yellow marl	18	18
Coarse sand	4	22
Coarse gravel, water	3	25
Kingshill marl (Miocene-upper (?) Oligocene): Yellow marl	83	108
Jealousy formation (upper (?) Oligocene):		
Greenish-gray clay (thin, hard layers of limy rock at 728, 732, 762, 770, 778, and 802 feet)	987	1,095
Jealousy formation—Cont.		
Conglomerate—boulders of older hard rock cemented by lime. Clayey streaks present	16	1,111
Gray clay	85	1,196
Conglomerate	5	1,201
Gray clay with hard streaks at 1,291, 1,305 to 1,307, and 1,448 feet	305	1,506

Well 39, Virgin Islands Co. at Jealousy

[Altitude, 150 feet]

	Thickness (feet)	Depth (feet)
Kingshill marl (Miocene-upper (?) Oligocene):		
Yellow marl (contains hard, limy layers, each a few inches in thickness, at 81, 83, 84, 85, 88 feet); brackish water	91	91
Jealousy formation (upper (?) Oligocene):		
Gray clay	133	224
Clay and boulders	4	228
Gray clay	17	245
Gray and black clay con-		
Jealousy formation—Cont.		
taining a considerable amount of rounded pebbles and small boulders	10	255
Gray clay containing a variable but small amount of sand and pebbles	143	398
Hard limy conglomerate	61	459
Mount Eagle volcanics (Upper Cretaceous):		
Hard basement rock	11	470

Well 45a, Virgin Islands Co. at Fair Plain

[Altitude, 30 feet]

	Thickness (feet)	Depth (feet)
Alluvium (Quaternary):		
Fine sand gradually becoming a coarse gravel with depth, water	33	33
Clay—somewhat sandy or gravelly	24	57
Coarse sand and gravel, water	5	62
Clay	8	70
Sand and gravel, water	3	73
Kingshill marl (Miocene-upper (?) Oligocene):		
Yellowish marl	89	162
Limestone	5	167
Yellowish to white marl	8	185
Limestone and marl	10	195
Yellowish marl	13	208
Jealousy formation (upper (?) Oligocene): Blue clay	17	225

QUALITY OF WATER

COMPARISON OF SURFACE WATER WITH GROUND WATER

Samples of surface waters that were taken at Two Friends and at Jolly Hill may be characterized as moderately hard bicarbonate waters containing less than 400 parts per million of total dissolved solids, in which sulfate and chloride are low. So far as the two available analyses may be used as bases for characterization of St. Croix surface waters, the waters are rather simple chemically and about what would be expected from the solution of limestone rocks by percolating waters. Sodium and chloride may have originated in greater part as ocean spray carried over the islands by the constant winds.

The ground waters are in part derived from the infiltration of surface streams but are more highly mineralized than the surface waters. Most of the ground waters of St. Croix that were analyzed contained from 400 to 2,400 parts per million of total dissolved solids, and a few waters had more than 4,000 parts per million. The higher mineral content of the ground waters may be due to solution of some of the constituents of the materials through which the waters percolate. A brief study of the analyses of the ground waters shows, however, that the increase is not a simple proportionate increase of the elements found in a simple calcium and magnesium bicarbonate water, but, as shown graphically in figure 10, in proportions of constituents present, the ground waters generally contain a high, sometimes very high, content of sodium chloride and may also contain moderate amounts of sodium sulfate.

Analysis C in figure 10, a sample of surface water taken near the mouth of Salt River appears more like some of the ground waters analyzed than like either of the two other surface-water samples. Analyses from Castle Burke sump and Kobel well contain less sodium salts than most of the other ground waters analyzed because these waters have not traveled any considerable distance underground and have passed through relatively insoluble rock material only.

CONTAMINATION BY SEA WATER

One of the first questions which arises when the quality of the underground waters of an oceanic island is considered is the relation of the fresh water to the salt sea water. Therefore, this relation will be considered in detail.

It has been common knowledge for many years that fresh

water falling upon a sandy coast or upon a small sandy island will percolate into the sand and move laterally toward the shore to mingle ultimately with the sea. It might be supposed that in such places the salt water surrounding the island or adjoining the coast would penetrate the sand to mean sea level and immediately absorb all the fresh water that might percolate downward to its surface. For several physical reasons this does not happen. Such islands are found, in reality, to contain a dome-shaped lens of fresh water floating upon a concave surface of salt water, as shown in figure 11*A*. The fresh water is enabled to float upon the salt water because the fresh water has a considerably lower density.

This principle was first applied to the hydrology of seacoasts by Baden Ghyben[61] in 1887 as a result of investigations made in Holland and was also noted by Herzberg[62] of Berlin in 1900, and in more recent years has been applied in the United States.[63]

In figure 11, *A*, the weight of the higher column of fresh water, *H*, should be equal to the weight of the smaller column of salt water displaced, *h*. Thus it has been found that in places where the law is applicable, for every foot which fresh water extends above sea level it also extends approximately 40 feet below sea level.

Thus, in a well along the coast at St. Croix where the water level in wells stands 3 feet above sea level, salt water should be encountered in that well at 120 feet below sea level.

However, a corollary of this principle is that if the height of fresh water above sea level (*t*, in fig. 11, *A*) is reduced 1 foot, then the salt-water boundary moves upward 40 feet, as shown in figure 11, *B*. Consequently, if wells along the coast are heavily pumped, water levels in the immediate vicinity of the wells may be lowered to sea level or below sea level and cause an upward intrusion of salt water into the wells.

In most wells in St. Croix the water level stands more than a few feet above sea level and the danger of salt-water contamination appears to be negligible. There are a few places along the coast where ground waters have a high chloride con-

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[61] Baden Ghyben, W., Nota in verband met de voorgenomen put boring nabig Amsterdam: K. Inst. Ing. Tydschv., p. 21, 1888-1889, The Hague, 1889.

[62] Herzberg, Baurat, Die Wasserversooging einigir Nordseebader: Jour. Gasbelenchtung und Wasser versorging, Jahrg. 44, Munich, 1901.

[63] Stearns, H. T., Clark, W. O., and Meinzer, O. E., Geology and water resources of the Kau district, Hawaii: U. S. Geol. Survey Water-Supply Paper 616, pp. 10-21, 1930.

Stearns, H. T., and Vaksvik, K. N., Geology and ground-water resources of the Island of Oahu, Hawaii: Div. Hydrography, T. H., Bull. 1, pp. 346-364, 1935.

Barksdale, H. C., Sundstrom, R. W., and Brunstein, M. S., Supplementary report on the ground-water supplies of the Atlantic City region: New Jersey Water Policy Commission, Special Rept. No. 6, pp. 10-26, 1936.

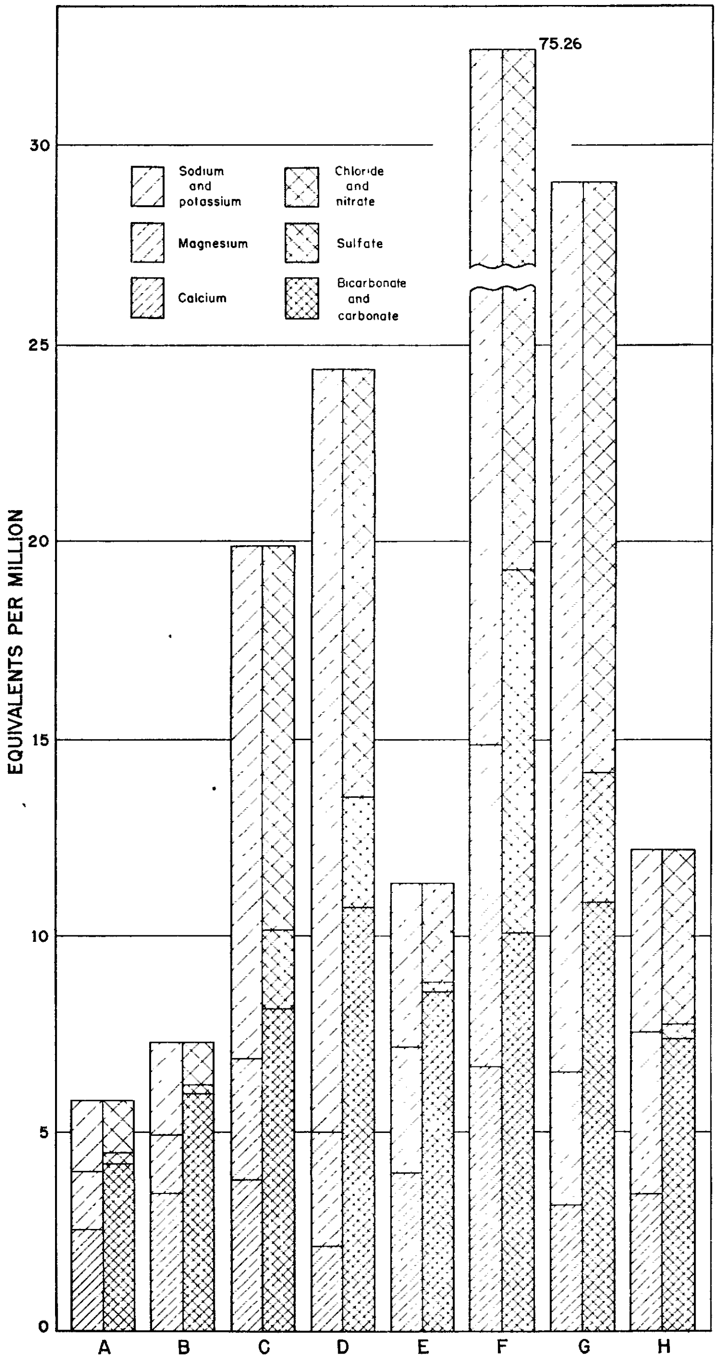

FIGURE 10.—Graphic representations of analyses of some St. Croix ground waters and surface waters.

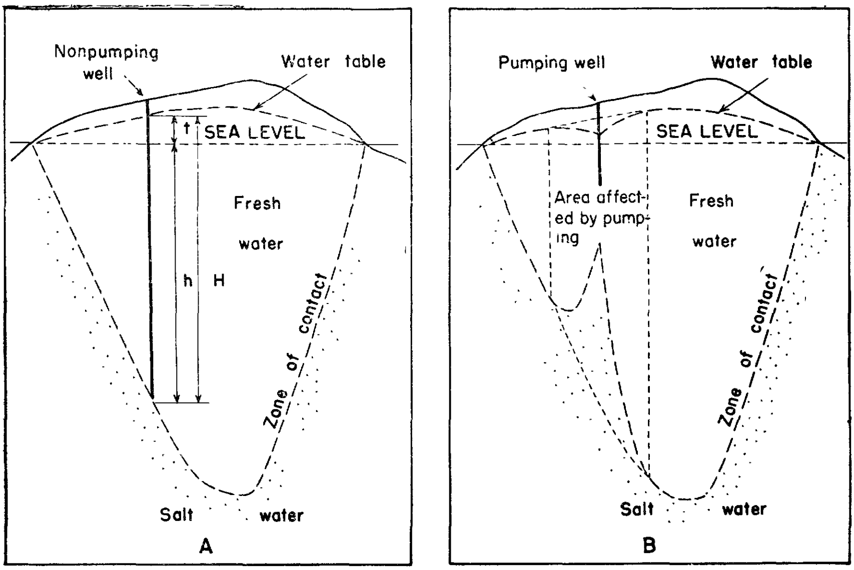

FIGURE 11.—Diagram showing relation between salt water and fresh water in homogeneous water-bearing sands making up a small island: *A*, Under nonpumping conditions; *B*, Where pumping is taking place.

tent; these places are (1) in the city of Frederiksted, and (2) along the coast northwest of Christiansted. A few wells elsewhere may also be contaminated by sea water.

TABLE 4.—*Analyses of ground waters in Leper Asylum well, St. Croix, showing chloride contamination and analyses of ocean water and of water from the Tertiary limestone area for comparison.*

[Results in parts per million]

	Range of composition of ground waters in Tertiary limestone area[1]	Leper Asylum[2]	Ocean water[3]
Silica (SiO_2)	21 to 49[4]	12	----------
Iron (Fe)	.3 to 1.7[4]	12	----------
Calcium (Ca)	10 to 133[4]	38	419
Magnesium (Mg)	6.9 to 101[4]	64	1,300
Sodium (Na)	287 to 1,391[5] (Na + K)	1,639	10,710
Potassium (K)		4.4	390
Carbonate (CO_3)	----------	20	----------
Bicarbonate (HCO_3)	615 to 971	712	150
Sulfate (SO_4)	62 to 500	638	2,690
Chloride (Cl)	84 to 1,985	1,895	19,350
Nitrate (NO_3)	Tr to 25	1.3	----------
Fluoride (F)	0 to 1.4[4]	1.0	----------
Total hardness as $CaCO_3$	48 to 747	357	6,380
Total dissolved solids	812 to 4,486[4]	4,708	35,000
Analyst	[6]	EWL[7]	----------
Date collected	[6]	July 7, 1936	----------

[1] Wells are Bethlehem, Bonne Esperance, Constitution Hill, Sion Farm, Profit, and spring at Envy. (See table 11.)
[2] Well 81a.
[3] Mean of 77 analyses of ocean water collected by Challenger Expedition.
[4] Not determined in some analyses of wells in Tertiary marl.
[5] Sodium and potassium content of waters from wells at Sion Farm and Bonne Esperance (1940 sample) were calculated.
[6] See table 8.
[7] EWL, E. W. Lohr.

In Table 4 ground water from the Leper Asylum well (81a), believed to be contaminated by sea water, is compared to ocean water and to water from wells in the Tertiary limestone area. In this water magnesium is high in relation to calcium, in addition to having a high chloride and fairly high sulfate content.

The analyses of water samples collected in 1919 from wells 77 and 80, located near the mouth of Salt River and at Cane Bay, respectively, suggest that little if any contamination by sea water had taken place at that time. However, field determinations made in 1939 (see table 11) show that the chloride content of the water from these wells is now much higher than it was in the samples collected for T. W. Vaughan in 1919. Well 77 yielded water containing 344 parts per million of chloride in 1919, but in December 1938 the chloride content was almost 2,000 parts per million. Likewise, the chloride content of well 80 at Cane Bay increased from 303 to over 1,300 parts per million. Well 77 discharged daily by a low-capacity gasoline pump. Well 80 supplies water to a cattle dip and is discharged somewhat less heavily by a hand pump. Both these wells are located at low elevations near the sea. As complete analyses of the waters yielded by these two wells in 1939 are lacking it is not possible to determine definitely the cause of the increased chloride content, but it is suggested that they may have been contaminated by sea water as a result of moderate discharge by pumping.

Wells 105 and 106 at Great Pond are located at low elevations near the sea and are pumped more or less continuously at a low rate. These wells yielded water containing 5,150 and 1,740 parts per million of chloride, respectively, in January 1939. It is suggested that here too the wells are probably somewhat contaminated by sea water.

The other ground waters of St. Croix for which analyses are at hand either show reasonably low chloride content or are of such chemical character or so located that contamination by sea water is most unlikely. Therefore, since it has been shown that probably only a few wells in St. Croix are contaminated by sea water, the source of the relatively high mineral content of waters from many wells calls for some other explanation.

CHLORIDE CONTAMINATION RESULTING FROM ORGANIC POLLUTION

The analysis of the water from well 9c (table 5) in Frederiksted shows a chloride content of 3,549 parts per million and, considering the location of the well near the coast, it might be thought that this represents mixing with sea water in part. However, the analysis also shows that the water has a very high nitrate content, generally an index of organic pollution, and it is probable that the very high chloride content has been derived from the same source. Further, the proportion of magnesium to calcium is lower than would be expected if sea-water contamination had taken place.

Well 9g at Frederiksted is located on higher ground some distance from the sea. When the analysis is examined, it is seen that the total mineralization is only about half that of the water from well 9c, near the shore, although it is still high. Chloride is less than half that in the water from well 9c, 1,609 parts per million. The nitrate content, 57 parts per million, is less, and it seems likely that here the high chloride content may be ascribed partly to organic pollution but the high ratio of magnesium to calcium and the very high sulphate content indicate sea water contamination.

It may be added that the water in well 90 at No. 1 Strand Street, Christiansted, which contains 507 parts per million of chloride as compared to 204 parts per million of chloride in well 91 in Water Gut, also shows high organic pollution since the analysis shows a nitrate content of 305 parts per million.

TABLE 5.—*Analyses of waters from wells showing organic pollution*

[Results in parts per million]

	Fredericksted		Christiansted Well 90
	Well 9c	Well 9g	
Silica (SiO_2)	26	23	25
Iron (Fe)	.50	.67	.17
Calcium (Ca)	401	86	86
Magnesium (Mg)	123	115	65
Sodium (Na) } Potassium (K)	2,119	1,099	552
Carbonate (CO_3)	0	0	0
Bicarbonate (HCO_3)	390	576	656
Sulfate (SO_4)	273	638	175
Chloride (Cl)	3,550	1,609	507
Nitrate (NO_3)	291	57	305
Total hardness as $CaCO_3$	1,507	687	482
Total dissolved solids	7,443	3,645	2,060
Analyst[1]	NF	NF	MDF
Date collected	June 6, 1919	June 6, 1919	June 4, 1919

[1] NF, Nathaniel Fuchs; MDF, M. D. Foster.

SALINE MINERALS ASSOCIATED WITH LIMESTONE OF TERTIARY AGE

It has been found in St. Croix that in the area near Jealousy and Bethlehem the limy rocks yield a salty water. An analysis (43, table 8) of water from the 245-foot well drilled near Bethlehem in 1934 (?), shows that the water had a total mineral content of 4,486 parts per million with 1,985 parts per million of chloride. A 105-foot well drilled one-fourth mile southwest of Jealousy yielded water containing over 2,400 parts per million of chloride. This water was obtained from a cased well in the marl (Tertiary) at a depth of 90 feet below the surface. Another water with high chloride content, 1,700 parts per million, was obtained from well 39 nearby at a comparable depth below the surface, and it seems evident that in this area the marl contains salt. Marly strata containing saline minerals may be responsible for the high mineral content of water obtained from wells at Bonne Esperance and Paradise and are undoubtedly a contributing factor to the generally high mineral content of water from wells in many other places in the limestone plain.

EFFECTS OF ALKALI SOILS

It is believed that the solution of alkali salts which have been concentrated at the surface in practically all low-lying parts of the island accounts in large part for the mineral content of many of the ground waters of St. Croix.

In the discussion of the occurrence of ground water it was noted that where the zone of saturation lies close to the surface, the capillary fringe may extend to the surface. Where this condition exists, ground water is continually being brought up to the surface and evaporated. Evaporation is undoubtedly high as cool ocean breezes are warmed in their passage across the sunny island, and their drying effect, coupled with periods of low rainfall, is evidenced by the type and degree of verdure of the vegetation. The mean evaporation at St. Croix from 1920 to 1935[64] was as follows:

TABLE 6.—*Mean monthly evaporation at St. Croix from 1920 to 1935*

Month	Inches	Month	Inches	Month	Inches
January	4.81	June	6.74	November	4.64
February	5.05	July	7.01	December	4.65
March	6.52	August	6.96		
April	7.09	September	6.12		
May	7.06	October	5.66	Total	72.31

As evaporation proceeds, the salts carried in solution by the ground waters are deposited at or near the surface and in time appreciable concentrations of mineral matter are built up. The concentration of salts at the surface varies inversely with the rainfall. As rain falls upon the surface and percolates into the

[64] Johnson, Arthur F., op. cit., p. 64.

ground it tends to dissolve these salts out of the earth and decrease their concentration at the surface, but in so doing the mineral content of the water in the zone of saturation is increased. Thus, under conditions of high evaporation and intermittent rainfall a process of concentration of salts at the surface and later transference of these salts to the zone of saturation may go on progressively where the ground-water levels are close to the surface.

In the evaporation of ground water the water itself passes off into the air, but the greatest part of the dissolved chemical content remains in the surface soil and is deposited in large part as less soluble calcium and magnesium carbonates and sulfates, and as highly soluble sodium carbonates, bicarbonates, sulfates, and chlorides. The concentration of these salts increases with time. During periods of heavy rain, the water percolating into the soil dissolves some of the salts deposited there and transports them downward into the zone of saturation in relatively concentrated solutions. The amount of calcium and magnesium corbonates and sulfates dissolved is probably not great and is limited by the amount of free carbon dioxide available. However, the sodium (and potassium) salts are freely soluble, and water passing through alkali soils containing these salts becomes heavily charged with them. By this process, the ground water maintains its calcium bicarbonate content relatively unchanged but becomes more highly mineralized in sodium (and potassium) sulfate and chloride.

In a reconnaissance soil map of St. Croix, Thorp[65] has delimited areas of alkali soils. Many alkali-soil areas are found at low elevations along the coast; for example, from Fredricksted to Spratt Hall on the west coast, many places along the south coast from Hope to Cotton Grove, along the north coast at Rustoptwist, and in patches from the mouth of Salt River to Cottongarden. The alkali soils are largely confined to areas below canyon mouths, or surrounding mouths of rivers, or small embayments of the sea. However, they are not entirely confined to the coast. Areas of alkali soils also border several streams and extend as much as 2 miles inland, as from Enfield Green to St. George, from Fair Plain to New Works, from the mouth of Salt River to Glynn, from Surlaine Point nearly to Catherine's Rest, and surrounding Great Pond and Southgate Pond and extending inland to Mount Washington and All-For-The-Better.

Other areas of alkali soil occur inland as isolated patches surrounded by unaffected or alkali-free soil. Those which have been

[65] Thorp, James, op. cit.

plotted are in the vicinity of the spring at Plessen, between Castle Burke and Lower Love, and along the streams west and north of Bethlehem.

EFFECTS OF SALT SPRAY

In a great many places the concentration of salts at the surface by evaporation of ground water will be augmented by salt spray blown for considerable distances inland. Evidence of the importance of salt spray is seen in the fact that cistern water, which had been collected from the roof at Central Factory near Christiansted, was found to contain 26 parts per million of chloride. Legget[66] states that "as evidence of what rainwater may contain may be mentioned the fact that for England the average chloride content is about 2.2 ppm . . ." and "rain falling at Land's End during strong southwest winds, blowing in from the sea, has been found to contain one hundred times this amount." Vaksvik[67] notes that on Oahu, Hawaii, all natural waters contain salt. "As no point on the island is more than 12 miles from the ocean, all of it is reached by fine ocean spray or minute particles of salt that remain suspended in the air when the spray evaporates. The material is blown over the land, and some of it is brought down by rains." A table is given showing the rainwater collected during showers at various points on Oahu contained from 6 to 42 parts per million of chloride.

Thorp[68] notes that white alkali, mostly sodium chloride and sodium sulfate, is "most concentrated near the numerous lagoons, and the salt concentration rapidly decreases toward the inland," whereas the black alkali, sodium carbonate, and bicarbonate, "was found affecting a few fairly large areas near Great Pond, the Leper Asylum, Southgate, Bethlehem, Castle Burke, and Jerusalem." This appears to indicate that along the coast the effect of salt spray upon the soil is dominant, whereas at more inland localities the salts in the soils have largely resulted from the evaporation of ground water.

BASE EXCHANGE

Inasmuch as some highly mineralized soft waters found in the Tertiary limestones are sodium bicarbonate waters rather than

66 Legget, Robert F., Geology and engineering: McGraw-Hill Book Co., New York, p. 459, 1939.

67 Stearns, H. T., and Vaksvik, K. N., op cit., p. 345.

68 Thorp, James, op. cit., p. 19.

sodium chloride waters, the sodium may best be explained as having resulted from base exchange.[69]

By the process of base exchange, hard bicarbonate waters which come into contact with certain materials bearing exchangeable sodium, exchange their calcium and magnesium for equivalent amounts of sodium. No change in the total amount of dissolved solids occurs. There seems to be no reason to believe that the marine marls forming the greater part of the Tertiary marl plain could not furnish exchangeable sodium to hard bicarbonate waters passing over them.

SUMMARY

The mineral content of most St. Croix ground waters is derived from (1) the solution of rock-forming minerals, (2) salt spray blown inland from the ocean and carried down into the zone of saturation by rainwater, and (3) concentration by evaporation at the ground surface of salts in ground water, originating from (1) or (2) above, and subsequent solution and addition of these concentrated salts to the zone of saturation below by rainwater. A very few wells have been contaminated by sea water, and a few owe a major part of their mineral content to organic pollution.

QUALITY OF WATER IN THE VARIOUS FORMATIONS

MOUNT EAGLE VOLCANICS

No analyses of waters from the few wells obtaining water from the Mount Eagle rocks are at hand. However, field tests for chloride were made of waters from a number of wells penetrating these rocks and a brief discussion may be based on these determinations.

In general, those wells which penetrate the Mount Eagle volcanics yield water with a moderate to high chloride content. The lowest chloride content, 172 to 250 parts per million, was found in water from wells located at high elevations at Orange Grove (83), Hermon Hill (85), and Catherine's Rest (117), whereas wells encountering bedrock beneath alluvium at lower elevations generally have a somewhat higher chloride content. Drilled wells at Longford (114) and Nugent (112) yield water containing more than 600 parts per million of chloride, and the dug well at Hartman (111), likewise entering the zone of weath-

[69] Renick, B. C., Geology and ground-water resources of central and southern Rosebud County, Mont.: U. S. Geol. Survey Water-Supply Paper 600, pp. 41-42, 1929. Foster, Margaret D., The chemical character of the ground waters of the South Atlantic Coastal Plain: Washington Acad. Sci. Jour., vol. 27, No. 10, pp. 405-411, 1937.

ered rock, yields a water containing 1,275 parts per million of chloride. In these wells at Longford, Nugent, and Hartman, however, it is believed that the source of mineral content is in the overlying alkaline soils. A dug well on the mountainside at Barons Bluff (79) yields water containing 340 parts of chloride. Inasmuch as these cliffs lie in the path of the prevailing winds they are in a position to receive much salt spray, and the ground water here may be high in sodium chloride and relatively low in other constituents.

DIORITIC ROCKS

Only two wells in St. Croix are known to be developed in the dioritic rock. Water from the Kobel well (38), north of Jealousy estate, contains 647 parts of total dissolved solids, as shown in the following analysis made in the spring of 1940:

TABLE 7.—*Analyses of water from well at Kobel in dioritic rock*

[Results in parts per million]

Silica (SiO_2)	57	Sulfate (SO_4)	18
Iron (Fe)	2.9	Chloride (Cl)	148
Calcium (Ca)	69	Nitrate (NO_3)	.05
Magnesium (Mg)	50	Fluoride (F)	.4
Sodium (Na)	104	Total hardness as $CaCO_3$	378
Potassium (K)	3.0	Total dissolved solids	647
Bicarbonate (HCO_3)	398	Date collected	May 10, 1940
Carbonate (CO_3)	26		

It is a hard bicarbonate water in which the magnesium content in only slightly less than the calcium. Sodium and chloride are farly low as compared to most other St. Croix ground waters. In a pumping test made on this well on February 3, 1939, the chloride content had increased from 160 to 278 parts per million after pumping 20 gallons a minute for 6 hours. This increase may be due to the flow of more highly mineralized water from near the surface into the well, induced by the pumping.

The well (100) at Southgate in eastern St. Croïx also penetrates dioritic rock and yields water containing 280 parts per million of chloride. As the well is located in a "slightly alkaline" soil area, it would seem that the water did not enter the well through the immediately overlying soil.

KINGSHILL MARL

The following table contains analyses of waters from wells developed in the Tertiary limestones of the plain extending from Frederiksted to Christiansted. An analysis of water from one spring issuing from the limestones is also included. These wells, with the exception of the well at Castle Coakley, are located in

TABLE 8.—*Analyses of waters from wells in the Kingshill marl*

[Results in parts per million]

	Envy[1]	Bethlehem[2]	Anguilla[3]	Profit[4]	Bonne Esperance[5]	Bonne Esperance[5]	Castle Coakley[6]	Constitution Hill[7]	Sion Farm[8]
Silica (SiO_2)	42	21	27	23	49	------	------	23	------
Iron (Fe)	1.6	1.7	.12	1.0	.3	------	------	75.75	------
Calcium (Ca)	42	133	61	26	10	------	------	21	------
Magnesium (Mg)	35	101	39	8.9	10	------	------	6.9	------
Sodium amd Potassium (Na+K)	442	1,385	426	478	673	[9]1,391	------	287	[9]510
Carbonate (CO_3)	0	0	0	0	0	------	------	0	------
Bicarbonate (HCO_3)	655	615	551	812	971	890	755	622	658
Sulfate (SO_4)	130	442	139	89	189	[10]500	180	62	[10]170
Chloride (Cl)	375	1,985	428	269	364	1,400	79	84	275
Nitrate (NO_3)	9.3	.4	45	Tr	25	20	21	14	5.1
Fluoride (F)	------	1.4	------	------	------	1.6	.8	------	0
Total hardness as $CaCO_3$	229	747	312	101	66	[11]216	[11]26	81	[11]48
Total dissolved solids	1,421	4,486	1,472	1,320	1,842	------	------	812	------
Analyst[12]	MDF	EWL	MDF	MDF	MDF	MDF, WMN, LWM	MDF, WMN, LWM	MDF	MDF, WMN, LWM
Date collected	June 4, 1919	July 7, 1936	June 4, 1919	June 4, 1919	June 4, 1919	April 15, 1940	April 15, 1940	June 3, 1919	April 15, 1940

[1] Spring. [2] Well 43. [3] Well 46. [4] Well 47. [5] Well 53. [6] Well 63. [7] Well 67. [8] Well 68. [9] Calculated. [10] By turbidity. [11] Determined.
[12] MDF, M. D. Foster; WMN, W. M. Noble; LWM, L. W. Miller; EWL, E. W. Lohr.

places where seepage of water to the wells from Quaternary alluvial deposits seems unlikely, and hence the analyses are considered as truly representative of water from the Tertiary limestones.

Brief inspection of the analyses (table 8) shows that two rather well defined types of water are yielded by the Tertiary rocks.

One type of water, yielded by a spring at Envy and by wells at Anguilla, Bethlehem, and Bonne Esperance (1940 sample), is a hard water in which the total hardness ranges from 216 to 747 parts per million and in which sodium is present in large part as sodium chloride and sodium bicarbonate. The bicarbonate content falls within about the same range as that of the softer waters from the Kingshill, however. It is interesting to note that the sample taken from Bonne Esperance well in 1940 is much harder than the water yielded in 1919, but in the 1940 sample the bicarbonate content is less and the additional hardness appears to be present as carbonate hardness. There is also much more sodium chloride.

The other type of water is yielded by wells at Proft, Bonne Esperance (1919 sample), Castle Coakley, Constitution Hill, and Sion Farm. It is relatively soft and contains generally less than 100 parts per million of total hardness and from 551 to 970 parts per million of bicarbonate. The Castle Coakley sample, containing only 26 parts per million of total hardness, is soft by almost any standard but may not be representative. This type may be classed, therefore, as soft to slightly hard sodium bicarbonate water.

The sample from the Bethlehem "salt well" and the 1940 sample from Bonne Esperance are high in chloride—1,985 and 1,400 parts per million, respectively—but the chloride content of other samples analyzed ranges from relatively low to moderate. The sulfate ranges from 62 to 500 parts per million and is highest in those samples containing a high chloride content. Both sulfates and chlorides are thought to have their source in soluble salts in the limestone which were deposited syngenetically.

The difference in mineral content of the samples collected from the Bonne Esperance well in 1919 and 1940 is believed due to the lack of recharge in a period of low rainfall and consequent inflow of highly mineralized water, induced by more or less continuous pumping at a low rate, from limestone areas containing high concentrations of soluble salts.

ALLUVIUM

WELLS FROM ALLUVIUM WITHIN AREAS OF MOUNT EAGLE VOLCANICS

Analyses (table 9) indicate that the mineral content of waters from wells located in Quaternary alluvial deposits within areas of Mount Eagle rocks differs widely, those analyzed ranging from 659 to 2,329 parts per million total dissolved solids. It is thought that the difference in total mineral content may generally be ascribed to the location of wells with respect to drainage channels along which relatively large underflow takes place. It seems apparent from the analyses at hand and from field determinations of chloride content that in wells located along main drainage lines the waters are less highly mineralized than those from wells in other locations. It is believed that the relatively greater amount of water moving along such channels, both on the surface or underground, tends to reduce the concentrations of salts in the alluvium along those channels, or that wells in such locations receive larger accretions of less highly mineralized surface waters than wells located elsewhere, or both. Wells at Anna's Hope (64) and Christiansted (91) are located along drainage lines. These wells have a mineral content of 659 and 896 parts per million total dissolved solids, respectively. Conversely, water from the Longford well, located in the more arid eastern part of the island and not along a main line of drainage, is more highly mineralized and contains 2,329 parts per million of total dissolved solids. Well 90 at Christiansted is located a short distance away from the minor drainage channel in which well 91 is situated. Water from the former well contains more than twice the amount of total dissolved solids found in water from the latter.

The waters from these wells are quite hard with the exception of the water from the Orange Grove well, which has a hardness of 87 parts per million. The hardness ranges from 173 to 519 parts per million. The waters may be classed as hard calcium and magnesium bicarbonate waters containing variable amounts of sodium salts. In a few waters sulfate is present as calcium sulfate.

The chloride content of the waters mentioned above ranges from 56 to 794 parts per million. A field determination of chloride content shows that the water yielded by the well at Salt River may be more highly mineralized at times than is indicated by the analysis in table 8. The increase in dissolved constituents may be due to contamination by sea water as the well is pumped, but the greater part of the mineral content is thought to be derived locally from the adjacent "salt pan" or alkali-soil areas.

TABLE 9.—*Analyses of waters from wells in the alluvium within areas of Mount Eagle volcanics*

[Results in parts per million]

	Anna's Hope[1]	Anna's Hope[2]	Salt River[3]	Cane Bay[4]	Orange Grove[5]	Christiansted[6]	Christiansted[7]	Green Cay[8]	Cottongrove[9]	Longford[10]
Silica (SiO_2)	65	35	35	28	----------	25	24	57	34	32
Iron (Fe)	.10	.93	.13	.25	----------	.17	.11	.62	.76	.23
Calcium (Ca)	40	30	82	106	----------	86	82	54	93	53
Magnesium (Mg)	37	24	48	62	----------	65	39	41	46	43
Sodium (Na)	134	814	234	253	[11]369	552	188	319	410	786
Potassium (K)		10								
Bicarbonate (HCO_3)	502	828	449	672	698	656	489	606	499	868
Carbonate (CO_3)	0	0	0	----------	0	----------	----------	----------	----------	----------
Sulfate (SO_4)	20	351	50	77	80	175	71	77	108	151
Chloride (Cl)	56	625	344	303	165	507	204	283	544	794
Nitrate (NO_3)	38	17	4.3	11	2.1	305	12	24	27	33
Fluoride (F)	----------	1.6	----------	----------	----------	----------	----------	----------	----------	----------
Total hardness as $CaCO_3$	252	173	402	519	[12]87	482	365	303	421	309
Total dissolved solids	659	2,300	1,040	1,218	----------	2,060	896	1,176	1,520	2,329
Analyst[13]	MDF	WMN	NF	NF	WLL	MDF	MDF	NF	MDF	MDF
Date collected	June 4, 1919	April 15, 1940	June 3, 1919	June 3, 1919	March, 1933	June 4, 1919	June 4, 1919	June 3, 1919	June 3, 1919	June 3, 1919

[1] Well 64. [2] Well 65. [3] Well 77. [4] Well 80. [5] Well 82 or 83. [6] Well 90. [7] Well 91. [8] Well 101. [9] Well 104. [10] Well 115. [11] Calculated.
[12] Determined. [13] MDF, M. D. Foster; WMN, W. M. Noble; NF, Nathaniel Fuchs; WLL, W. L. Lamar.

TABLE 10.—*Analyses of waters from wells in the alluvium within Tertiary limestone areas*

[Results in parts per million]

	Plessen[1]	Golden Grove[2]	Castle Burke[3]	Castle Burke[3]	Fredensborg[4]	New Works[5]	Fair Plain[6]	Fair Plain[7]	Lareine[8]
Silica (SiO_2)	----	47	46	----	----	50	36	40	----
Iron (Fe)	----	.13	.18	----	----	.04	.22	[10]2.3	----
Calcium (Ca)	----	50	80	----	----	21	42	64	----
Magnesium (Mg)	----	33	39	----	----	17	29	41	----
Sodium (Na)	} ----	286	95	----	----	528	435	{ 514	----
Potassium (K)	}							{ 3.2	
Bicarbonate (HCO_3)	362	709	526	530	771	748	714	662	688
Carbonate (CO_3)	----	0	.6	----	----	28	----	0	----
Sulfate (SO_4)	20	74	10	3	[9]60	132	123	157	[9]300
Chloride (Cl)	200	152	86	92	390	335	318	500	510
Nitrate (NO_3)	1.6	9.6	.16	.75	1.0	8.8	12	12	15
Fluoride (F)	.8	----	1.2	.8	1.2	1.6	.04	1.0	.4
Total hardness as $CaCO_3$	[11]195	260	360	207	[11]273	122	224	328	[11]105
Total dissolved solids	----	1,031	595	----	----	1,497	1,175	1,631	----
Analyst[12]	MDF, WMN, LWM	MDF, WMN, LWM	EWL	----	MDF, WMN, LWM	EWL	EWL	WMN	MDF, WMN, LWM
Date collected	April 15, 1940	June, 1919	July, 1936	April 13, 1940	April 15, 1940	July 7, 1936	July 7, 1936	April 15, 1940	April 15, 1940.

[1] Spring 28b. [2] Well 33. [3] Sump 34b. [4] Well 42. [5] Well 44. [6] Well 45b. [7] Well 45a. [8] Well 50. [9] By turbidity. [10] In sediment.
[11] Determined. [12] EWL, E. W. Lohr; MDF, M. D. Foster; WMN, W. M. Noble; LWM, L. W. Miller.

WELLS FROM ALLUVIUM WITHIN TERTIARY LIMESTONE AREAS

The waters from wells and springs in the alluvium within the areas of Tertiary marls, for which analyses are shown below (table 10), generally contain more than 1,000 parts per million of total dissolved solids. The least highly mineralized water is obtained from springs in which water has traveled a relatively short distance underground through surficial gravels, whereas water obtained from somewhat deeper wells a greater distance from the foot of the northern range of mountains may contain a considerably greater amount of total dissolved solids.

The analyses indicate that the waters are moderately hard or hard bicarbonate waters generally containing fairly high sodium bicarbonate, chlorides, and sulfates.

The sample from the Castle Burke sump had a carbonate hardness of 360 parts per million and no noncarbonate hardness. The nonhardness-forming constituents are relatively low, and the total dissolved solids are only 595 parts per million. The mineral content of this water may be derived in large part through simple solution of the surficial sediments free of excessive alkali or other salts through which this water passed.

The water from the spring at Plessen also has a relatively low mineral content; more than half the bicarbonate is present as calcium and magnesium bicarbonate, and the remainder is present as sodium bicarbonate. The chloride content is fairly high—200 parts per million. Inasmuch as the spring is located in an alkali-soil area, as noted by Thorp[70] it is believed that much of the mineral content of the water is derived from the solution of those salts from the soil.

The samples from New Works and Lareine have a relatively high content of total dissolved solids, yet the hardness is relatively low, only 122 and 105 parts per million, respectively. It is suggested that here too base exchange may have been an important process in creating a fairly soft high sodium bicarbonate water. However, the moderately high chloride and sulfate content of these waters suggests that there has been some solution of alkali salts from the soil.

The proportions of sulfate and chloride in samples from the wells at New Works, Golden Grove, Fredensborg, Fair Plain, and Lareine suggests that the solution of salts from the alkali soil may have been effective.

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[70] Thorp, James, op cit., p. 19.

BEACH SAND

Water from well 105 at Great Pond contained over 5,000 parts per million of chloride when visited by the writer. It is thought that this well is overpumped and has been contaminated by sea water. (See fig. 11, *B*.) At Canebay a field determination indicated that the water from well 80 contained more than 1,000 parts of chloride, although an analysis of a sample collected in 1919 (included in table 9 with waters from wells in the alluvium, for convenience) contained only about 300 parts of chloride. The increase may also be due to sea-water contamination.

SUITABILITY OF WATER FOR VARIOUS USES

HUMAN CONSUMPTION

Vaksvik[71] has pointed out that,

> although most people can detect the presence of salt when the chloride content exceeds 200 parts per million, water containing considerably higher quantities of chloride can be consumed by human beings without harmful effect. People who are accustomed to drinking water containing as high as 350 parts per million of chloride have stated that they prefer their own water to that of the Honolulu municipal supply (chloride content from 45 to 72 parts per million), which they consider tasteless. Several families of Japanese living on the west side of the entrance to Pearl Harbor use waters from a spring and several shallow dug wells that have a chloride content of 950 to 1,100 parts per million.

In several places in Tidewater Virginia water containing from 200 to 400 parts per million is used for drinking purposes by municipalities or military posts. Water from one well near Norfolk contains 1,080 parts per million of chloride and is said to be used from time to time by some individuals.

In St. Croix one individual stated that water from well 69 at Little Princess was occasionally used as drinking water. This water contains more than 1,800 parts per million of chloride.

It seems probable that the water from many wells in St. Croix would be quite satisfactory as drinking waters. In a great many wells the chloride content is moderate, and these waters would probably not be unpalatable.

It may be pointed out, however, that many wells may be polluted, as the nitrate content, which is derived from the decomposition of organic matter, is high in waters from many wells. Waters containing 1 or 2 to 45 parts per million of nitrate are generally from wells where cattle are watered, but nitrates in excess of 200 parts per million are found only in wells in the towns. Conversely, it is interesting to note that nitrate is ex-

[71] Stearns, H. T., and Vaksvik, K. N., op. cit., p. 345.

tremely low in waters from wells located in cane-field areas, namely, Fredensborg, the sump north of Castle Burke, and the spring at Plessen. Only 0.05 part per million of nitrate was found in the water from the well at Kobel.

CATTLE

Well No. 105, developed in beach sand adjacent to the ocean at Great Pond, yields water containing more than 5,100 parts per million of chloride. This water is the sole source of drinking water for a herd of cattle. According to the owner of the cattle, this water is of excellent quality for this purpose and has been used successfully for many years.

IRRIGATION

The question of suitability of ground waters in St. Croix for irrigation is a pertinent one. Large volumes of water are not available for the purpose, but on the other hand smaller volumes which might be used to irrigate small tracts of sugar cane, particularly in seasons of severe drought, may be obtained in some places.

Scofield[72] has discussed the limits of permissible sulfate and chloride content in irrigation waters and has stated that 480 or more parts per million of sulfate or 355 or more parts per million of chloride in irrigation water are unsafe.

In regard to sulfate content the water from only a few wells exceeds 480 parts per million, notably at Cottongrove and Longford in the East End area and at Bonne Esperance (1940 sample). However, with respect to chloride the water from many wells is not considered desirable, notably Cottongrove, Longford, Bonne Esperance (1919 and 1940 samples), Lareine, Fredensborg, Fair Plain (developed well), Enfield Green, Paradise, Castle Burke, and others in various parts of the island.

In Hawaii[73] water containing more than the permissible 355 parts per million set by Scofield is used to advantage

> although excessive chloride content of water has a bad effect on sugar cane, the amount that it will tolerate varies with the type of soil, the terrane, and the quantity of water applied to the fields. Several plantation officials have mentioned figures ranging from 700 to 900 parts per million of chloride as the maximum permissible without impairing the yield of sugar. On one plantation it was found that best results were obtained when the water discharged from a group of wells containing as high as 850 parts per million of chloride was mixed with high-level spring and tunnel water very low in

[72] Scofield, C. S., Quality of irrigation waters: California Dept. Public Works, Div. Water Resources, Bull. 40, 1933.

[73] Stearns, H. T., and Vaksvik, K. N., op. cit., p. 345

chloride. On another plantation brackish water from spring-fed sea-level ponds is used for the reason that for certain fields it is the only water available.

Most of the waters from wells in the central plain, the sugar-producing area, contain less than 900 parts per million of chloride.

Scofield has further given the limits of a permissible sodium to calcium and magnesium ratio. In terms of equivalents per million (not parts per million) it may be expressed as follows:

$$\frac{\text{Na} \times 100}{\text{Ca} + \text{Mg} + \text{Na}} = \text{percent sodium}$$

When the percentage of sodium is 60 percent or more, the water is considered unsafe for irrigation.

When the ratios for typical waters obtained from wells in central St. Croix are calculated, it is evident that nearly all waters must be classed as poor or harmful if used for irrigation. The percentage of sodium, according to the formula given above, for waters from the well at Anguilla is about 75 percent; from the spring at Envy and the Bethlehem "salt well," about 80 percent; from the Bonne Esperance well, 96 percent and 92 percent (1940 and 1919 samples, respectively); and from Sion Farm well, 96 percent. Thus, it seems improbable that the Tertiary limestone will anywhere yield a good irrigation water.

Wells drawing from deeper strata in the alluvium yield water within the same range. Both the developed well and the older drilled well at Fair Plain yield water containing about 81 percent sodium, and water from the New Works well has about 91 percent sodium. Water from the drilled well at Anna's Hope contains about 90 percent sodium.

Shallow wells and springs in the central part of the island yield water containing smaller proportions of sodium. The water from the Golden Grove dug well yields water containing more than 70 percent sodium in the Scofield formula, but water from the sump north of Castle Burke contains only about 38 percent sodium, an amount within the permissible limits by a wide margin. Water from the spring at Plessen is probably only slightly less favorable, as is water from the shallow well at Fredensborg.

Water from the Kobel well north of Jealousy in the dioritic-rock area has a sodium content of about 38 percent in the Scofield formula and may be classed as a good water for irrigation.

In summary then, it would appear that most ground waters of St. Croix are very poorly adapted to use as irrigation waters. Most of them contain excessive sodium in relation to total calcium and magnesium. Some waters also contain excessive quantities of chlorides and sulfates, and a few may be classed as poor on the basis of total dissolved solids alone.

Although this paper is primarily concerned with the ground-water supply, it may be pointed out that samples of water taken from streams at Two Friends, Jolly Hill, and Salt River at Concordia show that the sodium content according to the Scofield formula is about 33 percent, 23 percent, and 32 percent, respectively. These waters may, therefore, be classed as good irrigation waters if the proportion of sodium to calcium and magnesium does not greatly increase in some seasons. It seems logical that if irrigation is ever to be carried out on a large scale in St. Croix, an effort should be made to impound surface water for the purpose rather than to develop ground water. However, it is reported that in times of severe drought very little surface water is available, and at such times only ground water could be used.

As practically all ground waters in St. Croix contain a moderately large amount of dissolved salts, which are harmful where concentrated in the soil, irrigation should be carried out by methods insuring adequate natural or artificial drainage of the irrigated tracts.

Thorp[74] has emphasized this point in discussing proper methods of irrigating certain acreage in St. Croix:

> In case a water supply of considerable volume is found, it will be necessary to take precautions to use the water carefully and to dispose of the waste water in such a manner as to prevent the excessive accumulations of alkali and soluble salts. Alkali salts in small quantities were noted in many places. Most of these areas, except those close to the sea or to lagoons, contain only enough alkali at present to slightly affect the soil. Irrigation would tend to concentrate the salts in low places where subdrainage is poor and along areas where there is a change in slope from comparatively steep to more gentle.

Thorp has further pointed out that

> soils affected by black alkali become puddled and impervious to water. Their naturally good granular structure breaks down, the soil runs together and it is impossible to make them productive without expensive chemical treatment combined with copious irrigation and carefully planned drainage.

SUGAR AND RUM PRODUCTION

It is probable that no ground water obtained on St. Croix should be used for boiler feed without treatment. Few of the waters can be made suitable for use merely by reduction of the hardness. Most of the waters contain undesirable amounts of sodium as bicarbonate and chloride, which would probably necessitate expensive treatment to reduce corrosiveness, foaming, or other deleterious action.

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[74] Thorp, James, op. cit., p. 19.

Moderately mineralized ground waters are used as maceration waters. In the production of sugar the very small amount of salts which are precipitated with the sugar are not objectionable. In the production of rum practically all the salts are left after fermentation, and waters of high mineral content can be used. The water from well 81a containing about 1,900 parts per million of chloride and having a total dissolved solid content of 4,700 parts per million has been used successfully at Central Factory.

SUMMARY OF GROUND-WATER RESOURCES

WATER-BEARING FORMATIONS

The existing wells on the island of St. Croix obtain water from the Mount Eagle volcanics, the diorite, the Kingshill marl, and the alluvium.

The alluvium is the best water-bearing formation, and properly constructed drilled wells located in the larger alluvial valleys can supply moderate amounts of water. A modern gravel-packed well constructed during this investigation in such an alluvial valley produced from 50 to 80 gallons a minute in a 68-hour pumping test. Smaller amounts of water are also obtained by other wells developed in this formation. Wells in the alluvial valleys appear to be more dependable in times of drought than wells that obtain water from rocks.

A smaller number of wells obtain water from the Kingshill marl. These wells are more likely to fail in times of drought and generally yield only a few gallons a minute under conditions of continuous pumping. Deep test drilling indicated that Tertiary Kingshill strata are probably not underlain by water-bearing formations at depth.

A few wells obtain water from the Mount Eagle rocks, and some of the areas underlain by these rocks are worthy of further exploration. There are two drilled wells in dioritic rock, both of which furnish ample water to wind-powered pumps in times of drought. One of the wells yielded 20 gallons a minute with less than 15 feet of drawdown in a 7½-hour pumping test.

Springs yield water in a few places. Small amounts of water are obtained from springs that issue from the alluvium not far from the base of the mountains in the central part of the island, and a somewhat stronger spring issues from the Kingshill marl near the seacoast.

ADEQUACY OF PRESENT SUPPLY

The existing wells, springs, streams, and cisterns on St. Croix are sufficient to supply most of the island's needs in periods of normal rainfall. During periods of drought, however, streams go dry, cisterns become depleted, many wells that are poorly located or improperly constructed fail, and the lack of water may become acute.

QUALITY OF WATER

The quality of water obtained from wells varies within wide limits, but in general it may be said that the ground waters are hard and contain a moderate to high content of dissolved salts, which are present largely as sodium and calcium bicarbonates and chlorides and lesser amounts of sulfates. The water from Mount Eagle rocks may have only a moderate mineral content and, as far as is known, waters from the diorite contain a very moderate amount of dissolved solids. The Kingshill marl generally yields water containing a moderately high to high mineral content, and the mineral content of waters from the alluvium varies from moderate to high.

The mineral content of well water is thought to be derived from rock-forming minerals, from alkali in the soil, and from salt spray. In a few places contamination by sea water has apparently taken place. The water from only a few wells may be suitable for irrigation, but most well water is suitable for domestic uses and for cattle. Most ground waters would need treatment before they could be used for boiler feed, but existing supplies can and are used as maceration waters and in further diluting molasses prior to fermentation in rum manufacture.

RECORDS OF WELLS AND SPRINGS

Wells and springs in St. Croix which are listed in table 11 were visited by the writer in 1938-39 with the exception of wells 47 and 64. These are listed by Vaughan[75] in an unpublished manuscript and are included here because chemical analyses were made of their waters.

RECOMMENDATIONS

Although water is present in all the rocks of the island, the deposits that will yield water to wells are not as widely distributed. It has been found from a study of old wells drilled by the islanders and from more recent drilling by Government agencies that moderately large quantities of water may be obtained from sandy beds filling old alluvial valleys. Several of these valleys may yield several hundreds of gallons of water a minute, in the aggre-

[75] Vaughan, T. W., Ground waters of St. Croix, V. I.: Unpublished manuscript, U. S. Geol. Survey, 1919.

gate, to properly constructed and located wells. Probably enough water to care for a large part of the needs of the island could be developed in these valleys. Discussion of whether the costs of construction of efficient modern wells, installation of pumps, pipe line to points of use, and maintainence can be met or justified by either private citizens or governmental agencies does not fall within the scope or purpose of this report. It is merely pointed out that in certain areas water in reasonable quantity can be obtained from wells that are properly located with respect to geologic conditions and constructed by an experienced driller using modern equipment.

The locations favorable for the development of a few hundreds of gallons of water a minute are in the lower courses of larger streams in the western and southern parts of the island, as follows: (a) North of Frederiksted, (b) from Fair Plair northward and northwestward, (c) north of Hope and Blessing, (d) north of Jerusalem, and (e) northeast of Jerusalem.

Other valleys, wholly or partly filled with alluvium, may be productive of lesser quantities of water. These are: (f) Valleys west of Spratt Hall, (g) Salt River Valley, (h) the upper reaches of the valleys mentioned in the preceding paragraph, (i) the short valleys near Rustoptwist and LaValle on the North Side, and (j) the short valleys in the East End area.

At areas (a) to (e) the largest yields will be obtained, but less mineralized water will be obtained from areas (f) to (j) and particularly (h), the upper reaches of the major valleys.

In almost all these favorable areas exploratory drilling may have to be done before the optimum sites for wells are known. Most of the exploratory holes will be less than 100 feet deep and need be only very small in diameter. They need not cost much to drill, and drilling them would be good insurance against the possibility of installing expensive equipment and obtaining less than a maximum amount of water. Further, by exploring several areas it may be possible to make savings in pipe line or to get a better quality of water than if only one or two areas were explored.

The maximum amount of water obtainable from wells drilled into the dioritic rock or into the Mount Eagle volcanics is not known. The diorite appears promising as a source of moderate amounts of water, but only a few shallow holes have been drilled in it and confirmatory data are lacking. Further, this rock is limited in areal extent.

It is thought that streams in the areas of the Mount Eagle volcanics may be localized along fracture or fault zones, and hence along stream valleys wells that have been drilled from 100 to 200 feet in these rocks may strike crevices which will yield more than the minimum quantities now pumped from shallow wells developed in these rocks. This is problematical, however, but might be most worth while to determine where there is a possibility of intercepting a fairly large underflow of only slightly mineralized water, as in the valleys above Spratt Hall, Little Grange, Grove Place, and Little Fountain.

The Tertiary limestones, by and large, are poor water-bearing strata. Only one well, at Paradise, is known to yield more than an extremely meager supply.

In St. Croix, as in many other places, it is difficult to construct wells by hand that will yield water in times of drought. St. Croix is subject to severe and frequent droughts, and many inhabitants who depend upon shallow wells find themselves greatly inconvenienced at times. This recurrent situation cannot, except by chance, be eliminated by digging more shallow wells or even by constructing drilled wells unless they are properly located and finished. It must be emphasized that accumulated data on St. Croix ground-water conditions show that reasonable quantities of water from wells may be obtained in relatively few places; wells must be located in these relatively limited favorable areas in order to provide an ample supply of water for the island in times of severe drought.

All wells proposed to furnish a maximum amount of water should be located by a trained ground-water geologist. Selection of each well site is an individual geologic problem on St. Croix; the location and interpretation of results of test holes, the location and details of construction of wells, and testing of wells, carried out with an understanding of the quantity and quality of water needed or sought, cannot be performed with maximum efficiency by an engineer or geologist lacking ground-water experience.

TABLE 11.—*Records of wells and springs in St. Croix*

No.	Estate or location	Topographic situation	Approximate altitude above sea level (feet)	Type of well[1]	Depth of well (feet)	Principal water-bearing material: Character of material	Principal water-bearing material: Geologic horizon	Water level: Feet below surface	Water level: Date of measurement	Method of lift[2]	Use of water[3]	Chloride content (parts per million)[4]	Remarks
1	¼ mile north of Butlers Bay	Seacoast	26	Dg	24	Weathered volcanics	Upper Cretaceous	13¼		M	DS	98	
2	Butlers Bay	do	26	Dg	40	do	do	26	Dec. 21, 1938	M	DS	280	
3	Sprat Hall	Valley	35	Dg	35	do	do	15	do	W	S	110	
4	William	Coastal terrace	12	Dg	12	Alluvium	Pleistocene	3¾	do	W	S	112	
5	Prosperity	do	25	Dg	25	do	do	23 (?)	do	W[5]	S	548	
6	Jolly Hill	Narrow valley		Dr		Weathered volcanics	Upper Cretaceous			G	S		
7	LaGrange	Coastal terrace	40	Dg		Alluvium	Pleistocene			G	Ind.		According to owner, well yields 50 gallons a minute for limited periods. Goes dry in severe drought.
8	¼ mile south of LaGrange	do	40	Dg	15	do	do	8½	Jan. 11, 1939	G[6]	Ind.	218	According to owner, well yields 200 gallons a minute for limited periods.
9a	Hill and Strand Streets, Frederiksted	Seacoast	10	Dg	12	Limestone	Mid-Tertiary	9	Dec. 20, 1938	B	PS	1,800	
9b	King Cross and Strand Streets, Frederiksted	do	10	Dg	11	do	do	9	do	B	PS	2,220	
9c	King and King Cross Streets, Frederiksted	Slope toward sea	18	Dg	15	do	do	13	do	B	PS	1,690	
9d	Queen and King Cross Streets, Frederiksted	do	15	Dg	16	do	do	15	do	B	PS	2,740	
9e	Hill and Princess Streets, Frederiksted	do	21	Dg	18	do	do	17½	do	B	PS	2,470	
9f	New and Queen Cross Streets, Frederiksted	do	46	Dg	43	do	do	41½	do	B	PS	1,270	
9g	30 Hospital Street, Frederiksted	do	25 (?)	Dg	26	Alluvium	Pleistocene	[7]24	June 6, 1919	B	DS		
10	Wheel of Fortune	Broad valley	30	Dg	12	do	do	3¾	Jan. 12, 1939	W	S	410	Water level varies from 1½ to 9½ feet from surface. Yields an "ample" supply.
11	Stony Ground	Rolling plain	40	Dr	90	Limestone	Mid-Tertiary	21½	Dec. 20, 1938		Obs.	206	
12	Camphorico	do	55	Dg		do	do	48	do	W	S	710	
13	Concordia	do	125	Dg	15	do	do	4½	do	W	S	168	
14	Whim	do	95	Dg	16	do	do	5	do	W	S	240	Water level 2 feet below surface June 5, 1919.[7]
15	Hope	Coastal terrace	14	Dg	7	Marly alluvium	Pleistocene	0	do	W	S	470	
16	Robe Hill	Mountain valley	240	Dr	62	Weathered volcanics	Upper Cretaceous	25½	Dec. 19, 1938	W	S	138	Water level about 7 feet below immediately adjacent stream bed.

17	Cane Valley	do	260	Dg	14	do	do	1½	do	M	SD	96	Height of cement curb subtracted from depth of well and depth to water.
18	Valbygaard	do	220	Dg	32	do	do	24	Dec. 9, 1938	W	SD	124	Water level about 18 feet below immediately adjacent stream bed.
19	Hogensborg	Rolling plain	120	Dg	9	Alluvium (?)	Pleistocene	4½	Dec. 19, 1938	G[6]	S	184	
21	Near highway at Hogensborg	do	120	Dg	11½	Limestone (?)	Mid-Tertiary	5½	do	W	S	216	
22	Cain	Shallow valley	90	Dr	42	Alluvium (?)	Pleistocene	2	do	W	S	254	
23	Enfield Green	do	40	Dr	71	Limestone (?)	Mid-Tertiary	31	do	W	S	458	
24	Diamond	do	85	Dr	90	do	do	32	do	W	SInd.		Furnishes water for 100 head of cattle, a small cane mill, and distillery.
25	St. George	do	150	Dg	16	Alluvium	Pleistocene	5	do	W	S	214	
26	Grove Place	Mountain valley	195	Dg	14	Weathered volcanics	Upper Cretaceous	4½	do		D	250	Goes entirely dry in drought.
27	¼ mile southeast of Grove Place	Alluvial plain	155	Dg	24	Alluvium	Pleistocene	3	do	W	D	104	Do.
28	Plessen	do	120	Dg	8	do	do	2¾		W	DS	440	Sometimes goes dry.
28b	do	do				do	do			W	DS	316	Never goes dry.
29	Paradise	Rolling plain	95	Dg	37	Limestone	Mid-Tertiary	34¼	Dec. 8, 1938	W	S	945	
30	Betty's Hope	Shallow valley	20	Dg		Alluvium	Pleistocene	4	Dec. 14, 1938	W	S	390	
31	Envy	Coastal terrace				Limestone	Mid-Tertiary				S	542	Flow estimated at 30 or 40 gallons a minute.
82	Manning Bay	do	20	Dg	10	do	do	5¼	Dec. 8, 1938	W	DS	685	Water level 3 feet below surface June 4, 1919.[7]
33	Golden Grove	Valley	50	Dg	28	do	do	14½	Dec. 9, 1938	W[6]	DS	242	Water level fell to 18½ feet below surface by March 25, 1939. Water level 10 feet below surface June 4, 1919.[7]
34	Castle Burke	Alluvial plain	95	Dr	260	do	do				D	600	Sand 12 to 15 feet, white marl 15 to 90 feet, blue clay 90 to 260 feet.
34b	do	do				Alluvium	Pleistocene			G	D		Yields a maximum of 5 gallons a minute. See analysis.
35	Upper Love	do	130	Dg	10	do	do	5	Dec. 1938	W	S	498	
36	River	Mountain valley	175	Dr	28	Alluvium	do			W	S		
37	Hermitage	do	275	Dr	55	Weathered volcanics	Upper Cretaceous			W	S	266	Supplied water for 600 cattle in drought period, according to B. Nelthropp.
38	½ mile north of Jealousy	do	200	Dr	63	Weathered granitic rock	Eocene (?)	10	Feb. 3, 1939	W	S	278	Drawdown 15 feet after pumping 19½ gallons a minute for 6 hours.
39	¼ mile west of Jealousy	Rolling plain	150	Dr	470	Limestone and clay	Mid-Tertiary	15½	Feb. 27, 1939		T	1,700±	Test well No. 2. Yield less than 16 gallons a minute.
40	¼ mile south of Jealousy	Stream bank	140	Dr	105	do	do	10½	Dec. 12, 1938		Obs.	2,480	
41	Fredensborg	Shallow valley	90	Dr	1508	Limestone and clay	Mid-Tertiary			T			Test well No. 1.
42	do	do	90	Dg	21	Alluvium	Pleistocene	6	Dec. 8, 1938	G	D	152	Yields about 3 gallons a minute 8 hours a day in normal seasons. In drought yield limited to 3 hours pumping per day.

TABLE 11.—*Records of wells and springs in St. Croix*—Continued

No.	Estate or location	Topographic situation	Approximate altitude above sea level (feet)	Type of well[1]	Depth of well (feet)	Principal water-bearing material		Water level		Method of lift[2]	Use of water[3]	Chloride content (parts per million)[4]	Remarks
						Character of material	Geologic horizon	Feet below surface	Date of measurement				
43	Bethlehem Factory	Rolling plain	100	Dr	245	Marl and clay	Mid-Tertiary				Obs.		Yield small. Water highly mineralized.
44	New Works	Broad valley	55	Dr	58	Alluvium	Pleistocene	28	1936	W	D	340	Reported to yield more than 20 gallons a minute.
45a	Fair Plain	do	30	Dr	225	do	do	17	Mar. 23, 1939	G	Ind.	700	Yields 70 gallons a minute with 15¼ feet of drawdown after pumping 52 hours.
45b	do	do	30	Dr	58	do	do	14½	Mar. 2, 1939	W	S	384	Yields about 10 gallons a minute with 5 feet of drawdown.
46	Anguilla	Coastal terrace	20	Dg	11	Alluvium	do	9	Dec. 8, 1938	W[5]	S	585	Water level 9½ feet below surface June 4, 1919.[7]
47	Profit	Hilltop	150	Dg	170	Limestone	Mid-Tertiary	110	June 4, 1919	W	S		
48	Spanish Town	Rolling plain	100	Dg	90	do	do	89	Dec. 8, 1938	W	S	235	Supply does not fail in driest seasons.
49	Clifton Hill	do	100	Dg	67	do	do	[7]40	June 5, 1919	W[5]	DS	830	
50	Lareine	Broad valley	105	Dg	42	Alluvium	Pleistocene	36⅓	Dec. 9, 1938	W[5]	S	418	
51	Slob	Rolling plain	150	Dg	145	Limestone	Mid-Tertiary	53½	Dec. 8, 1938		Obs.		Water reported to be highly mineralized. Water level 55 feet below surface June 4, 1919.[7]
52	Lebanon	Valley	200	Dg	25	Weathered volcanics	Upper Cretaceous			W[6]	DS	380	Chloride content increased slightly after pumping 2 hours. Yield estimated to be about 7 gallons a minute.
53	Bonne Esperance	Hilltop	275	Dg	145	Limestone	Mid-Tertiary	[7]60	June 4, 1919	W[5]	DS	904	
54	Marys Fancy	Valley	340	Dg	150	do	do	93¼	Dec. 9, 1938		Obs.	600±	
55	Limestone	do	190	Dg	106	do	do	93½	do		Obs.		
56	Strawberry	Broad valley	150	Dg	94	do	do	83¾	do	W[6]	DS	254	Water level 56 feet below surface June 3, 1919.[7]
57	Ruby	Rolling plain	200	Dg	99	do	do	94½	Dec. 8, 1938	W[6]	S	145	Yields from 3 to 5 gallons a minute.
58	Diamond	do	140	Dg	135	do	do	115½	do	W	DS	214	Supplied 50 people and 50 animals with water in severe drought. Water level 74 feet below surface June 4, 1919.[7]
59	Barren Spot	do	100	Dg		do	do			W	SD	250	Water level 49 feet below surface June 3, 1919.[7]

60	Hope	Edge of coasta terrace	35	Dg	28½	do	do	26½	do	W	D	100	Water level 20 feet below surface June 3, 1919.[7]
61	Jerusalem	Hilltop	110	Dg	86	do	do	82½	do	W[5]	DS	590	Yielded about 4 gallons a minute in dry season. Water level 75 feet below surface June 3, 1919.[7]
62	Cane Garden	do	64	Dg	47	do	do	45½	Jan. 24, 1939	W	S	2,340	Water level 42 feet below surface June 3, 1919.[7]
63	Castle Coakley	Broad valley	100	Dg	99	do	do	55g	June 3, 1919	W	DS	150	
64	Anna's Hope	Valley	140	Dr		Limestone (?)	Mid-Tertiary			W	SD	690	
65	do	do		Dg	11	Alluvium	Pleistocene	71	June 4, 1919	M	SD		
66	Peter's Rest School	Broad valley	200	Dr	200	Limestone	Mid-Tertiary	156	Sept. 1930	W[6]	D		Water level reported by B. Nelthropp.
67	Constitution Hill	Hillside	300	Dg	225	do	do	225+	Dec. 9, 1938		Obs.		Water level 190 feet below surface June 3, 1919.[7]
68	Sion Farm	Rolling plain	200	Dg	148	do	do	128	1937	W	DS	254	Water level reported by Jensen yields about 1,000 gallons a day in dry season. Water level 100 feet below surface June 3, 1919.[7]
69	¼ mile southeast of Little Princess	Coastal terrace	20	Dg	12	Alluvium	Pleistocene	5¼	Dec. 22, 1938	W[5]	S	690	
70	Little Princess	do	25	Dg	13	do	do	6	do	W[6]	DS	1,840	
71	LaGrande Princess	do	40	Dr		do	do			W[5]	S	2,910	
72	do	Hillside	55	Dg	33	Limestone	Mid-Tertiary	28	Dec. 22, 1938	W[6]	S	1,180	Well has not been pumped in 3 months.
73	Rattan	do	325	Dg		do	do	132¼	do		Obs.	180	
74	St. John	Coastal terrace	80	Dg	34½	do	do	32½	do		Obs.	230	Water level 23 feet below surface June 3, 1919.[7]
75	do	Valley	75	Dr	42	Weathered volcanics	Upper Cretaceous	22	do	W[5]	DS	740	Always yielded ample since 1931.
76	Judith's Fancy	Gentle slope	50	Dg	33	do	do	26¾	do	W[5]	DS	1,520	
77	South of Greig Hill	Marsh	5	Dg	7	Alluvium	Pleistocene	1	Dec. 16, 1938	G[6]	S	1,930	Pump has capacity of 5 gallons a minute.
78	¼ mile northwest of Greig Hill	Seacoast	4½	Dg	12	do	do	3½	do	W	S	378	
79	Baron Bluff	Side of mountain	150	Dg	10½	Weathered volcanics	Upper Cretaceous	6½	Dec. 19, 1938		S	340	
80	Cane Bay	Seacoast	7	Dg	16	Beach sand	Recent	5¾	Dec. 16, 1938	M	DS	1,310	
81	Leper Asylum	Coastal terrace	20	Dr		Alluvium	Pleistocene			W[5]	Ind.	4,780	Furnishes about 3,500 gallons a day.
81b	Central Factory	do	20	Dr		do	do			W	Ind.		Do.
82	¼ mile north of Orange Grove	do	60	Dr		do	do			W[5]	S	310	
83	⅓ mile southwest of Orange Grove	Valley	150	Dg	41	Weathered volcanics	Upper Cretaceous	36	Jan. 24, 1939	W	S	204	
84	Jail	Coastal terrace	20	Dg		Alluvium	Pleistocene	9	do	W	D	715	
85	North side of Hermon Hill	Valley	160	Dr	90	Volcanics	Upper Cretaceous	56	do	G[5]	Ind.	178	Yields about 1,200 gallons a day in the dry season.
86	¼ mile south of Hermon Hill	Valley head	170	Dr	72	Weathered volcanics	do	61	do	W[5]	DS	452	Water level 20 feet from surface in wet season, according to owner.
87	½ mile south of Hermon Hill	Valley	140	Dg	29	do	do			W	S		Water level fluctuates widely according to seasons.

TABLE 11.—*Records of wells and springs in St. Croix*—Continued

No.	Estate or location	Topographic situation	Approximate altitude above sea level (feet)	Type of well[1]	Depth of well (feet)	Principal water-bearing material		Water level		Method of lift[2]	Use of water[3]	Chloride content (parts per million)[4]	Remarks
						Character of material	Geologic horizon	Feet below surface	Date of measurement				
88	Water Gut and West Streets, Christiansted	do	60	Dg		do	do			W[5]	D	340	
89	Water Gut and Market Streets, Christiansted	do	20 (?)	Dg	14	do	do	4		B	D	375	
90	No. 1, Strand Street, Christiansted	Seacoast	10 (?)	Dg	7½	do	do	[7]5	June 4, 1919	B	D		
91	King and Princess Streets, Christiansted	Coastal terrace	20	Dg	9	do	do	2½		B	D	950	
92	Mount Welcome	do	30	Dr	82	do	do			W	S	508	
93	St. Peter	do	30	Dr	80	do	do	10	1927	W	S	270	Water level reported by B. Nelthropp.
94	Butzberg	Hillside	75	Dg	33	do	do	19¼		W[6]	S	275	
95	do		9	Dg	18	Alluvium	Pleistocene	7		W[6]	S	250	
96	do	Salt marsh	12	Dg	12	do	do	4½		W[6]	S	225	
97	do	Filled lagoon	8	Dg	10	do	do	3¾		W[5]	S	950	
98	Darby Hill	Valley	35	Dg		do	do	15¼	Jan. 25, 1939	W[5]	S	1,020	
99	All-For-The-Better	Head of valley	90	Dg		do	do	29½		W[5]	S	320	Well may also develop weathered granitic bedrock. In nearby abandoned well more nearly in axial part of valley water level is 20 feet from surface.
100	Southgate	Broad valley	45	Dr	80	Weathered granitic rock?	Eocene (?)			W	DS	280	
101	Green Cay	Edge of coastal terrace	9	Dg	10	Alluvium	Pleistocene	6¼	Jan. 25, 1939	W[5]	S	336	Furnished water to 300 cattle during a period of drought. Water level 5 feet below surface June 3, 1919.
102	Cotton Valley	Valley	11	Dg	10	do	do	3¾	do	W[5]	S	870	
103	Tague Bay	Coastal terrace	25	Dg	12	do	do	7½			Obs.	500	
104	Cottongrove	do	30	Dg	30	do	do	[7]16	June 3, 1919	W	DS		
105	½ mile east of Great Pond	Beach	10	Dg	10	Sand	Recent			W	S	5,150	Supplies 2,500 gallons a day.
106	Great Pond	Seacoast	20	Dg	24	Weathered volcanics	Upper Cretaceous	19¼	Jan. 25, 1939	W[5]	S	1,740	
107	½ mile north of Great Pond	Broad lowland	30	Dg	40	Alluvium	Pleistocene	6⅓	do		S	538	Yield is small.
108	Mount Washington	do	60	Dr	76	do	do			W[5]	S	320	Yields about 2 gallons a minute.
109	¾ mile south of Sight	do	50	Dg	35	do	do	17	Jan. 25, 1939	W[5]	S	544	Dried up in drought of 1924–25.

110	Petronella	do	80	Dr		Weathered granitic rock	Eocene (?)			W	S	455	
111	Hartman	do	45	Dg	47	do	do	39 1/3	Jan. 24, 1939	W[5]	S	1,280	
112	Nugent	Coastal terrace	40	Dr	45	Weathered volcanics	do			W[5]	S	645	
113	1 mile southwest of Nugent	do	5	Dg	10	Alluvium	Pleistocene	4 3/4	Jan. 24, 1939	M[6]	S	830	
114	Longford	do	50	Dr	83	do	do	38	do	G[6]	S	608	Well reported to have flowed when drilled in dry season in 1930.
115	do	do		Dg	38	do	do	[7]23	June 3, 1919	W	S		
116	Granard	do	50	Dr	82	Weathered volcanics	Upper Cretaceous			W	DS	780	
117	Catherine's Rest	Valley	190	Dr	28	do	do			W	S	250	

[1] Dg, dug, Dr, drilled.
[2] M, pump operated manually; W, windmill; G, pump powered by gasoline engine; B, bucket.
[3] D, domestic; S, stock; Ind., industrial; PS, public supply; Obs., obsolete; T, test well.
[4] As determined by field tests.
[5] Well being pumped when visited.
[6] Well not being pumped when visited.
[7] Data from unpublished manuscript "Ground waters of St. Croix, Virgin Islands," by T. W. Vaughan.

APPENDIX

NATIONAL PARK SERVICE DRILLING PROJECT

INTRODUCTION

A well-drilling project for the Virgin Islands was undertaken in the period December 1940 to July 1941 by the Civilian Conservation Corps in response to a request made by Governor Lawrence W. Cramer, of the Virgin Islands, to Mr. Conrad L. Wirth, CCC and ERA Coordinator, National Park Service, United States Department of Interior. This request was prompted by severe local shortages of water that occurred as the result of drought condition in 1941, during which many existing wells and Creque Dam Reservoir went dry.

It was subsequently arranged that the CCC would furnish a geologist to investigate the project, recommend the most favorable drilling sites, and send its drilling crew and equipment to the islands to develop water supplies on Federal-owned or controlled land for Federal or Federal-sponsored projects. Benefiting agencies were required to furnish the well casing, screens, and production equipment.

The project was carried out under the supervision of Donald C. Hazlett, a geologist of the National Park Service, working under Mr. H. E. Rothrock, of the same organization. The writer advised both Mr. Rothrock and Mr. Hazlett in detail on ground-water conditions in St. Croix before the project was initiated, recommended many sites for drilling, and made available copies of his geologic map and basic well data. The writer was not associated with the project, however, while it was being carried out. Subsequently, largely through the efforts of Mr. Brent S. Drane, of the National Resources Planning Board, the basic data gained in the

CCC drilling project were made available to the writer and submitted with the request that they be incorporated with the results of the writer's own studies and interpreted accordingly.

The following section has been prepared mostly from a series of typewritten memoranda written by Donald C. Hazlett. Much of the data is particularly valuable in bringing out new geologic information. However, the lack of background detail concerning the various wells that were drilled, lack of data on quality of water obtained, and lack of information on the performance of wells after completion are keenly felt. For some wells basic data are incomplete. This report on the CCC project is not intended to be a full account of the various drilling or water-supply activities engaged in by the CCC while in the Virgin Islands, but rather a discussion of drilling on St. Croix only.

SELECTION OF WELL AND TEST-HOLE SITES

Wells were drilled in the Whim homesteads area southeast of Frederiksted, in the Colquhoun homesteads area at the south foot of Blue Mountain, and in various other locations in the central part of the limestone plain, particularly at Fair Plain and in the St. John—Princess homesteads area northwest of Christiansted. A few wells were also drilled in the eastern part of the island. With few exceptions the location of well sites was restricted to the limited areas in which water was to be used; much drilling was done in areas known to be unfavorable, and the low yields obtained from many wells and failure of others were to be expected. By and large, however, the light rotary rig used seemed to be adapted to the drilling conditions encountered, and the small-yield wells that were developed in these areas seem to have filled a real need. Wells of somewhat larger yield, which were sunk in a few places, were very worth while and confirmed the writer's conclusions regarding the occurrence of ground water in the island. A few of the "dry" wells or test holes showing negative results require attention because it is believed that some of these were not properly located, or, although located at a logical spot from a consideration of the geology and existing records, drilling showed that that particular location was unfavorable and that exploration for probable water-bearing strata should have been carried on elsewhere, in some instances only a few hundred feet away.

SUMMARY OF RESULTS

Of the wells discussed in this report on the CCC drilling project, five wells provided 3 gallons per minute or less, two others yielded respectively 4 and 5 gallons a minute, two yielded 8 gallons a minute, two yielded 15 gallons a minute, and two yielded 40 gallons a minute. Six wells were "dry" and two provided very small quantities of brackish water.

The two wells of highest yield were developed in the alluvium-filled valley near Fair Plain. Fifteen gallons a minute was obtained from wells in alluvial fill at Golden Grove and near Christiansted. A well that obtains water from the Tertiary limestones at Paradise yields 15 gallons a minute. A well at Whim that yielded 8 gallons a minute may obtain water from Tertiary limestones, and a well of similar capacity at St. John may also obtain water from these limestones.

The data on the successful wells, together with information on wells of low yield and the dry holes, confirm the conclusions previously drawn by the writer; namely, the alluvial-filled channels yield fairly good supplies to properly constructed wells, and in places the Tertiary limestones yield moderate amounts of water. In many places where the alluvium is reasonably thick, as northwest of Christiansted, permeable water-bearing formations such as coarse clean sands are lacking. Apparently good water-bearing strata in the alluvium are confined to restricted channels leading back to well-defined gorges in the mountains or hills. Where broad areas are overlain by a mantle of alluvium, as in the vicinity of Bethlehem and Colquhoun, the present streams do not necessarily mark the course of the deep alluvium-filled valleys and a number of shallow test holes may have to be drilled before the ancient valleys are located. It is also shown conclusively that solution cavities in limestone, in St. Croix as elsewhere, are very irregular in occurrence, and in some places these rocks yield a reasonable amount of water but at other nearby localities the same strata may yield very little or no water to wells.

DESCRIPTION OF WELLS AND TEST HOLES

WHIM HOMESTEADS

Four wells were drilled on Federal homestead lands north of Hope, about 2½ miles southeast of Frederiksted, for domestic consumption and livestock. Their locations, C-1, C-2, C-3, and C-4, are shown on the map (pl. 1). These wells are 114, 136, 123, and 90 feet deep, respectively, and presumably they penetrated the Kingshill marl. C-1 and C-2 each yielded 1 gallon a minute of brackish water, C-4 yielded 2 gallons a minute of water, and C-3, 8 gallons a minute. Water from C-3 and C-4 was probably fresh. The available data are so meager that no comments or discussions of the results can be made.

PARADISE

Well C-5 was drilled to supply livestock at Paradise, in the narrow valley just east of well 29. The Kingshill marl was struck at 34 feet, and strata of "very porous" white limestone were present from 40 to 45 and from 60 to 71 feet. Perforated 6-inch casing was set from 45 to 71 feet; upon bailing, the well yielded 15 gallons a minute. The length of the test or draw-down are not known.

This well is presumably considerably better than well 29, at Paradise, which is dug to a depth of 37 feet and which is reported to yield about 100 gallons per hour. It is at a slightly higher elevation than well C-5 and obviously does not reach the porous limestone strata encountered in C-5.

Further, water from well 29 contains 945 parts per million of chloride, according to the field test, whereas water from C-5 is reported to contain only 210 parts of chloride. It would appear that well 29 obtains water seeping in from the immediate surrounding area through material highly loaded with salts originating as salt spray or otherwise, whereas C-5 reaches a stratum through which ground water has been moving relatively rapidly, perhaps fed from the alluvium to the north or east, in which the dissolved salt content is low.

In connection with the relatively high yield of well C-5, attention may be called to the limestone spring at Envy, about 1 mile to the southeast. This spring may issue from the strata encountered in well C-5, or from similar strata.

PROPOSED UNDERFLOW DAM AT FAIR PLAIN

Tests were made at Fair Plain to determine the feasibility of creating an underground dam by grouting the water-bearing strata with cement through 2-inch wells.

Test hole No. 1 (C-6), on the east side of the valley near the contact of alluvium with the Tertiary limestones, encountered clayey fill to a depth of 79 feet (see log, table 12). This area was considered undesirable for a grouting test.

Test hole No. 2 (C-7), on the east bank of the present stream, struck permeable sands and gravels at 22 to 29 feet, at 48 to 51 feet, and at 72 to 78 feet. Two hundred gallons of cement grout was poured in the hole through 2-inch pipe, which was perforated opposite the water-bearing horizons. After 24 days a hole was drilled 2.6 feet north of the grouted hole in an effort to determine the effectiveness of the grout. Sands proved to be still open, and drilling mud was lost constantly and attempts to secure cores were unsuccessful. When cuttings were examined it was found that even in the most gravelly beds "evidence of penetration of the grout was so slight as to be negligible. It was estimated that the particles of grout found in these cuttings would constitute less than a teaspoonful. No grout was found adhering to the pebbles." It was concluded therefore that an underground dam could not be created by this method.

The writer is of the opinion that an underground dam at this point, even if it were possible to build one, might be of doubtful value. It is thought that the largest amount of underflow passing Fair Plain and other restricted alluvial channels (at Hope, Blessing, Jerusalem, and other places) could be captured by pumping wells heavily enough to create a cone of depression in the channel-mouth area. Such pumping could be controlled to prevent back-flow from the sea, yet be great enough to withdraw from the ground most of the normal seaward underflow.

FAIR PLAIN

At the request of United States Army officials, test holes and wells were drilled to supply water to the airdrome located in the Manning Bay area. Test holes were drilled in the deep alluvial-filled valley 1/4 to 1/2 mile northwest of the Fair Plain well (45a). The results of drilling were about what would be expected from the record of the Fair Plain well; in two test wells (C-8 and C-9) three water-bearing sands were penetrated (see logs, table 13). The second test hole was converted into a 10-inch gravel-pack well, and when pumped with air it furnished about 45 gallons a minute. The chloride content is said to have decreased from 450 parts per million to 245 parts per million after several months' pumping.

To avoid overdraft on one well, two other wells (C-10 and C-11) were drilled, 100 and 200 feet west of C-9, respectively. Data on these are not available except a statement that they yield about as much water as the first well. It was planned to pump the three wells by suction from a central point using only one pump. It was further anticipated that 30 gallons a minute would be the normal total draft on these wells.

GOLDEN GROVE

A well was drilled on property of the Virgin Islands Co. at Golden Grove to provide fresh water for Adventure village. The record of this well (C-12) is particularly interesting in that it shows the presence of an excellent water-bearing stratum in the alluvium-filled valley about a mile upstream from Fair Plain. Below 27 feet of clayey fill, 21 feet of gravel and boulders were

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encountered. (See log, table 12.) A screen (possibly perforated casing) was set from 38 to 50 feet.

The well was bailed for 3½ hours at a rate of 15 gallons a minute with very slight draw-down below the static level at 29 feet. It is apparent, therefore, that much more water than 15 gallons a minute could be made available by increasing the draw-down. The well was equipped with a wind-powered pump and in November 1943 was reported to be giving excellent service. The water contained 295 parts per million of chlorides.

Ground-water conditions here are comparable to those found at Fair Plain. It is of interest to note that the alluvium is 48 feet thick at this place as compared to 80 feet at Fair Plain. It is suggested that the 48 feet of alluvium encountered here is not the maximum thickness present in this area and that a somewhat greater thickness of alluvium may be present 50 or 100 feet to the east or west of this well.

FREDENSBORG

Results of drilling on the Virgin Islands Co. property for water for the village at Fredensborg provides a good example of the difficulty of locating the axis of the buried alluvial valley leading back to the mountains, where the present valley is very wide. A hole (C-13) was drilled just east of Bethlehem on the east bank of the present stream. Only 13 feet of fill was penetrated before reaching a limestone of Tertiary age. A second hole (C-14), about 100 feet east of the first hole, struck the limestone at 15 feet.

As the alluvial cover was very thin, it appeared that developed wells would produce very small quantities of water, and the test holes were not converted into wells.

COLQUHOUN—MOUNT PLEASANT HOMESTEADS

Wells and test holes were drilled in the vicinity of Colquhoun—Mount Pleasant to obtain water for the homesteads in that area. The first hole (C-15) was drilled in the southeast corner of the homesteads area along the course of an intermittent stream leading from Little Fountain to Fredensborg. The scant data available indicates that 77 feet of alluvium (clay?) was encountered, below which blue clay of the Jealousy formation was penetrated to 91 feet. The strata were not water bearing.

The second hole (C-16) was drilled about 700 feet north of the first test hole at Colquhoun. No data on this well are at hand except that it yielded only 1 gallon a minute.

A third hole (C-17) was drilled about half a mile west of the first hole. No data on this test hole are available except that the hole was drilled to 85 feet and that the results were negative.

It is difficult to interpret the results of drilling these three holes when so few data are available for study. Certainly the area should be a reasonably favorable one, as it is in this area that much of the run-off from the mountains seeps into the alluvium. In the first test hole 77 feet of alluvium were penetrated, about as great a thickness as was found in wells at and near Fair Plain. It seems that here the alluvium may have been clayey, there may have been other factors that prevented the completion of a successful well at that site, or the data at hand may be incorrect.

The fourth hole at Colquhoun—Mount Pleasant (C-18) was drilled in or along the gut east of the village. Again data are meager, but it appears that the hole was drilled to a depth of 55 feet and yielded 4 gallons a minute. Whether this well obtains water from the underlying diorite or is drawing water from the surface alluvium is not known.

RATTAN

A well (C-19) 226 feet deep was drilled at Rattan about ¾ mile east-southeast of the old estate in a low valley about 300 feet above sea level. The water level was 108 feet below the surface. No other data are available except that the well apparently obtains some "fresh" water.

ST. JOHN—PRINCESS HOMESTEADS

A number of wells were drilled in the St. John—Princess Homesteads area northwest of Christiansted. Data on these wells are meager, but certain facts are definite and of interest.

Well C-20 is located near the head of a small valley south of St. John. This well penetrated alluvium from the surface to a depth of 26 feet, Tertiary limestones from 26 to 87 feet, and blue clay from 87 to 100 feet. It is not known whether the limestone or the alluvium furnished the water, but in any event the well is reported to yield 8 gallons a minute.

It is of geologic interest to note the thickness of the Tertiary limestones, which extend to about 13 feet above sea level, and the underlying blue clay here, close to the inner edge of the basin in which the Kingshill marl and Jealousy formation were deposited. Geologic conditions here may be similar to or identical with those at the location at which the second test well was drilled in 1939 at Jealousy (39, table 3). It may also be recalled that

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well 75, in a small valley immediately north of St. John, went through a cover of marl of Tertiary age and encountered weathered Mount Eagle volcanics at 21 feet (about 55 feet above sea level).

Several wells were drilled in the area fronting the Caribbean Sea between St. John and Little Princess. One well south of St. John (C-20) yielded 8 gallons a minute but another (C-21), just east of the road leading to Judith's Fancy, was dry. The third well (C-22) was about a quarter mile southeast of the second and is reported to yield 3 gallons a minute. It is a minimum of 46 feet deep, but it is not known whether water is obtained from the alluvium or the underlying limestone. A fourth well (C-23), just southeast of La Grande Princess, was dry, and a fifth well (C-24), near Little Princess, obtained 3 gallons a minute.

A well (C-25) 80 feet deep was also drilled at the head of a small valley below Bellevue at an elevation of about 150 feet. This well probably penetrated Tertiary limestone beneath a thin alluvial cover, but it is not known from which stratum water is obtained. Depth to water is reported to be 45 feet and the yield 5 gallons a minute.

CENTRAL FACTORY

A test hole (C-26) was sunk at Central Factory to determine conclusively whether a supply of fresh water could be obtained by drilling. Yellow clayey material containing minor sand and gravel was encountered down to a depth of 99 feet (about 60 feet below sea level), below which 7 feet of blue clay was found. A screen was set from 98½ to 101½ feet, but the well proved to have a yield of less than ½ gallon a minute.

It might be expected that the older bedrock would be encountered here about sea level. As bedrock is not present it might be concluded that beneath a veneer of alluvium the material penetrated was Kingshill marl underlain by blue clay of the Jealousy formation and that at this place the surface of the pre-Jealousy formation drops off sharply in a manner similar to that noted along the north edge of the basin. However, the yellow clay and boulders reported are more likely alluvium than Kingshill marl, and it is concluded that a filled post-Miocene valley is indicated. The depth below sea level to which this valley has been eroded is noteworthy. At Fair Plain, 1 mile from the south coast, fill extended to about 50 feet below sea level. At Central Factory, on the north coast, a post-Miocene valley was apparently eroded to more than 70 feet below sea level.

CHRISTIANSTED

A well (C-27) was constructed at the Parade Ground, 1/4 mile east of Christiansted, to provide additional water for the Christiansted Hospital. The well, near well 92 but seemingly better located with respect to the axis of the valley heading up into Mount Welcome, encountered sand and gravel lying upon weathered bedrock at 35 to 47 feet below the surface. (See log, table 13.) The well was continued to a depth of 59 feet. Perforated 6-inch casing was set from 41 to 59 feet, and, upon bailing, the well yielded 15 gallons a minute with very slight drawdown.

This well is one of those encountering strata in which water moves freely to the sea. The water level (44 feet below the surface) is 3½ feet above sea level; pumping this well continuously at 40 or 50 gallons a minute might lower the head to such an extent that sea water would move up the dip and enter the well.

COTTON VALLEY

A well (C-28) was drilled at Cotton Valley, East End, to provide water for picnickers to the area. The well is near the head of the valley and slightly west of its axis. Much coarse detrital material was encountered, but most of it is described as clayey. Weathered bedrock extended from 69 to 92 feet below the surface; the hole was continued in the unweathered bedrock to 93 feet.

Ten feet of perforated casing was set from 70 to 80 feet. Upon bailing, the well yielded about 2 gallons a minute.

The writer believes that for optimum results the well should have been located a little nearer the sea and more nearly along the axis of the valley, where detrital material would probably be better sorted and graded. However, for the purpose in view, ample water was obtained. It is interesting to note that here, as in the Christiansted Hospital well, water stood only a little above sea level. Static level in the Cotton Valley well was 51.2 feet below the surface, or 3.6 feet above sea level.

COTTONGARDEN

A test hole (C-29) was drilled in Cottongarden Valley near the easternmost end of St. Croix. The well was located in the axis of the valley about 200 yards from the sea. Alluvial fill was penetrated to a depth of 83 feet (about 50 feet below sea level). The alluvium was very coarse, and gravel and boulders are reported at various depths (see log, table 12), but most of the strata were clayey. Drilling was continued into the weathered bedrock to a depth of 111 feet. Although the well was not cased and tested it was suggested that a completed well might yield 1 or 2 gallons a minute.

RÉSUMÉ OF NATIONAL PARK SERVICE DRILLING PROJECT

Invaluable data have resulted from the CCC drilling project on St. Croix. Wells and test holes in various types of formations furnish a clearer picture of conditions than that which was available to the writer in 1939 based on only a few test holes and on fragmentary data.

The ancient alluvium-filled valleys are the best sites for wells in many parts of the island, in the area underlain by the old rock as well as in the area underlain by Kingshill marl. The fill is now known to extend 50 feet or more below sea level in several places other than Fair Plain, and it appears safe to assume that favorable thicknesses of fill may be found at widely scattered localities near the sea, not only at the mouths of large streams but underlying the beds of many smaller streams as well.

The necessity of shallow exploratory drilling in order to locate the axes of buried valleys is well shown; in places holes were drilled which encountered the underlying older rocks at very shallow depths, as at Fredensborg. Elsewhere, although reasonable thicknesses of fill were located, predominantly sandy strata free of clay were not present, as at Central Factory and Colquhoun.

The limestone of Tertiary age was a good water-bearing formation in a few places but in general it may not be relied upon to furnish much water. The weathered surface of the Mount Eagle volcanics is much more reliable as a source of small quantities of water.

TABLE 12.—*Logs of wells and test holes drilled by the National Park Service in 1940-41*

Well C-5, Virgin Islands Co. at Paradise

[Altitude, 80 feet]

	Thickness (feet)	Depth (feet)
Alluvium (Pleistocene):		
Brown and yellow clay	2	2
White limy clay	13	15
Yellow clay	8	23
Yellow clay and gravel	11	34
Kingshill marl (Miocene-Oligocene):		
White limestone	6	40
Kingshill marl (Miocene-Oligocene) Continued:		
White (very porous) limestone, water	5	45
White limestone	15	60
White (porous) limestone, water	11	71

Well C-6, Virgin Islands Co. at Fair Plain

[Altitude, 20½ feet]

Alluvium (Pleistocene):			Kingshill marl (Miocene-Oligocene):		
Brown clay	8	8	White clay and soft limestone	3	82
Brownish-yellow clay with gravel throughout	26	34	White limestone	5	87
Yellow clay with large gravels	39	73	White limestone and clay	5	92
Brownish-yellow clay with gravel	6	79			

Well C-7, Virgin Islands Co. at Fair Plain

[Altitude, 21½ feet]

Alluvium (Pleistocene):			Alluvium (Pleistocene)—Con.		
Brown clay	8	8	Gravel	3	51
Clay and sand	4	12	Yellow clay	21	72
Brown sandy clay	10	22	Clay and gravel	6	78
Gravel with some clay	7	29	Kingshill marl (Miocene-Oligocene): White clay and limestone	2	80
Brown sandy clay	3	32			
Yellow clay	4	36			
Clay and gravel	12	48			

Well C-8, U. S. Army at Fair Plain

[Altitude, 32 feet]

Alluvium (Pleistocene):			Alluvium (Pleistocene)—Con.		
Top soil	3	3	Yellow sandy clay	3	75
Yellow sandy clay	12	15	Yellow clay	3	78
Sand, gravel, and boulders	5	20	Sand, water	5	83
Yellow clay	35	55	Kingshill marl (Miocene-Oligocene): Yellow and white clay and marl	19	102
Sand and gravel, water	5	60			
Yellow clay	9	69			
Sand and gravel, water	3	72			

Well C-9, U. S. Army at Fair Plain

[Altitude, 31 feet]

Alluvium (Pleistocene):			Alluvium (Pleistocene):—Con.		
Top soil	3	3	Gravel, water	1	60
Yellow clay	8	11	Yellow clay	1	61
Sand and gravel	3	14	Clay with gravel	7	68
Yellow clay and boulders	8	22	Yellow clay	11	79
Sand and gravel, clay seams	9	31	Sand and gravel, water	2	81
Yellow clay	11	42	Kingshill marl (Miocene-Oligocene): Yellow clay and white limestone	4	85
Sand and gravel, water	8	50			
Yellow clay	9	59			

Well C-12, Virgin Islands Co. at Golden Grove

[Altitude, 55 feet]

Alluvium (Pleistocene):			Kingshill marl (Miocene-Oligocene): White limestone	64	112
Brownish-yellow clay	6	6			
Yellow clay and gravel	8	14			
Yellow clay, gravel, and boulders	13	27			
Gravel and boulders, water	21	48			

Well C-13, Virgin Islands Co. at Bethlehem

[Altitude, 80 feet]

Alluvium (Pleistocene):			Kingshill marl (Miocene-Oligocene):		
Brown sandy soil	4	4	White marl	11	24
Sandy clay and gravel	9	13	Yellow and white clay and limestone	12	36

Well C-14, Virgin Islands Co. at Bethlehem

[Altitude, 80 feet]

Alluvium (Pleistocene):			Kingshill marl (Miocene-Oligocene): White clay and limestone	38	53
Brown sandy clay	3	3			
Clay, sand, and gravel	5	8			
Clay, gravel, and boulders	7	15			

Well C-15, Homesteads at Colquhoun-Mount Pleasant

[Altitude, 135 feet]

Alluvium (Pleistocene): Alluvium	77	77	Jealousy formation (Oligocene): Blue marl	14	91

Well C-20, Homesteads at St. John-Princess

[Altitude, 100 feet]

Alluvium (Pleistocene): Alluvium	26	26	Jealousy formation (Oligocene): Blue clay	13	100
Kingshill marl (Miocene-Oligocene): Limestone	61	87			

Well C-26, Virgin Islands Co. at Central Factory

[Altitude, 30 feet]

Alluvium (Pleistocene):			Alluvium (Pleistocene):—Con.		
Yellow clay with sand and gravel	8	8	Yellow clay with some sand and gravel	42	99
Yellow clay with small boulders	23	31			
Yellow clay with boulders Sandy clay	26	57	Jealousy (?) formation (Oligocene): Blue clay	7	106

Well C-27, Christiansted Hospital at Parade Ground, Christiansted

[Altitude, 47½ feet]

Alluvium (Pleistocene):			Mount Eagle volcanics (Upper Cretaceous): Weathered rock	12	59
Yellow clay with gravel	3	3			
Yellow clay, boulders	32	35			
Gravel and sand with a few clay seams	12	47			

Well C-28, Municipality of St. Croix at Cotton Valley

[Altitude, 53¾ feet]

Alluvium (Pleistocene):			Mount Eagle volcanics (Upper Cretaceous):		
Brown clay and gravel	8	8	Gray weathered rock, water	23	92
Yellow clay and gravel	18	26	Unweathered rock	1	93
Yellow clay, boulders	40	66			
Sandy clay and gravels	3	69			

Well C-29, Municipality of St. Croix at Cottongarden

[Altitude, 30 feet]

Alluvium (Pleistocene):			Mount Eagle volcanics (Upper Cretaceous):		
Red clay and gravel	15	15	Weathered dark-gray clay	21	104
Red clay	2	17	Black clay	1	105
Clay and boulders	3	20	Weathered dark-gray rock, streaks of black clay	6	111
Red clay	13	33	Hard gray rock	1	112
Yellow clay	4	37			
Large boulders	2	39			
Sandy clay, boulders	9	48			
Yellow clay with boulders	35	83			

Table 13.—*Records of wells and test holes drilled by the National Park Service in 1904–41*

Well No.	Location	Owner	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Principal water-bearing material		Depth to which well is cased	Water level (feet below surface)	Yield (gallons a minute)	Use of water[1]	Reported quality[2]	Remarks
							Character of material	Geologic horizon						
C-1	One-fourth mile west of Goodhope	Whim homesteads	Plain	25	114	8 (?)		Kingshill marl			1	Ab	Brackish	
C-2	Goodhope	do	do	25	136	8 (?)		do			1	Ab	do	
C-3	One-fourth mile east of Goodhope	do	do	30	123	8 (?)		do			8	D	Fresh	
C-4	One-half mile northeast of Goodhope	do	do	50	90	8 (?)		do			2	D	do	
C-5	Paradise	VICO	Shallow valley	80	71	8–6	Porous limestone	do	71		15	S	[2]Cl, 210	Perforated 6-inch casing set from 45 to 71 feet. See log.
C-6	Fair Plain	do	Narrow valley	20½	92	8 (?)						T		Test hole in connection with proposed ground-water dam. See log.
C-7	do	do	do	21½	80	8 (?)	Gravel	Alluvium				T		See log.
C-8	do	U. S. Army	do	32	102	8 (?)	Sand and gravel	do				T		First test hole. See log.
C-9	do	do	do	31	85	10	do	do	82	21	45	T D	[2]Cl, 245	Second test hole and first well. See log. Perforated casing acts as strainer.
C-10	do	do	do	31 (?)		10	do	do			45 (?)	D		Second well, 100 feet west of first well.
C-11	do	do	do	31 (?)		10	do	do			45 (?)	D		Third well 100 feet west of second well. C-9, C-10, and C-11 to be pumped as a unit at 30 gallons a minute.
C-12	Golden Grove	VICO	do	55	112	6	do	do	38	29	15	D	[2]Cl, 295	Screen set from 38 to 50 feet. See log.
C-13	One-fourth mile east of Bethlehem	do	Broad valley	80	36	8	Clayey gravel	do	0		1	Ab		See log.

C-14	One-fourth mile east of Bethlehem		do	80	53	8	do	do	0		1	Ab		Located 100 feet east of C-13. See log.
C-15	Three-fifths mile southeast of Colquhoun	Colquhoun-homesteads	Alluvial plain	135	91		Marl	do (?)			Dry	Ab		Blue clay of Jealousy formation encountered at 77 feet.
C-16	One-half mile southeast of Colquhoun	do	do	140							1	D		
C-17	One-half mile south of Colquhoun	do	do	155	85						Dry	Ab		
C-18	Colquhoun—Mt. Pleasant	do	Valley	190	55		Diorite (?)	Mount Eagle volcanics			4	D		
C-19	Rattan	Homestead	do	300			Limestone	Kingshill marl		108		D		
C-20	One-fifth mile south of St. John	St. John-Princess homesteads	Valley head	100	100		do	do			8	D		See log.
C-21	One-half mile east of St. John	do	Coastal plain	50							Dry	Ab		
C-22	One mile east of St. John	do	do	25	46						3	D		
C-23	One-fourth mile southeast of La Grande Princess	do	do	55							Dry	Ab		
C-24	Little Princess	do	do	65	44		Limestone	Kingshill marl			3	D		
C-25	Bellevue	do	Valley head	150	80		do	do		45	5			
C-26	Central Factory	VICO	Coastal terrace	30	106	6	Marly sand	Alluvium	89		½			Strainer set at 89 to 101 feet 6-inch casing and strainer replaced by 3-inch casing. Lower end perforated.
C-27	One-half mile east of Christiansted	Hospital	Valley	47½	59	6	Sand and gravel	do	60	44	15	D		Draw-down during pump test "slight." Casing perforated from 41 to 59 feet.
C-28	Cotton Valley		do	54.8	93	8	Weathered rock	Mount Eagle volcanics	80	51.2	2	D		Casing perforated from 70 to 80 feet. See log.
C-29	Cottongarden		do	111	30		do	do	0	28		T		See log.

[1] Ab, abandoned; D, domestic; S, stock; T, test well.
[2] Chloride content in parts per million.

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EXPLANATION

QUATERNARY

Recent

Beach deposits
(Largely calcareous sand. Small areas of fossil reef included. Yields small amounts of rather highly mineralized water to a few wells)

Alluvium
(Clayey and sandy fill of local origin. Arkosic areas underlain by dioritic rocks and marly areas underlain by Tertiary rocks. Maximum thickness known is 80 feet. Yields ample water to dug and drilled wells pumped by wind power. Several developed wells obtain more than 40 gallons a minute from the alluvium. Mineralization of water variable)

TERTIARY

Miocene

Kingshill marl
(Relatively soft white to buff homogeneous marl, thin-bedded white limestones, and limy rocks of coral-reef origin in which stratification is lacking. In a few places small pebbles included in marly or limestone rocks. Maximum thickness greater than 600 feet. Supplies many wells with small quantities of water. Generally a poor water-bearing formation. Mineralization of the water moderate to high)

Oligocene

Jealousy formation
(Gray clay of maximum thickness greater than 1400 feet. Contains detrital material in places. Basal limestone conglomerate and other minor conglomeratic beds are included. Basal conglomerate makes the only known outcrop of this formation. Not a water-bearing formation)

Early Tertiary or late Cretaceous

Diorite intruded into Mount Eagle volcanics
(Gray coarse-grained rock with granitic texture. Black fine-grained selvage included. Weathered portion appears to be a very good water bearer. Mineral content moderate)

CRETACEOUS

Upper Cretaceous

Mount Eagle volcanics
(Water-sorted volcanic tuffs, dark marine limestones, volcanic breccias, and minor (?) volcanic flows. Supplies small quantities of water to many wells. Somewhat larger supplies may be available. Mineral content moderate)

Known fault

Inferred fault

Axis of syncline

Axis of anticline

Strike and dip of beds

Strike of vertical beds

Observed outcrop

Well
(Number referred to in table of well records)

Spring