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A PRELIMINARY STUDY OF NATURAL CONSTRUCTION MATERIALS ON ST. CROIX U. S. VIRGIN ISLANDS

by

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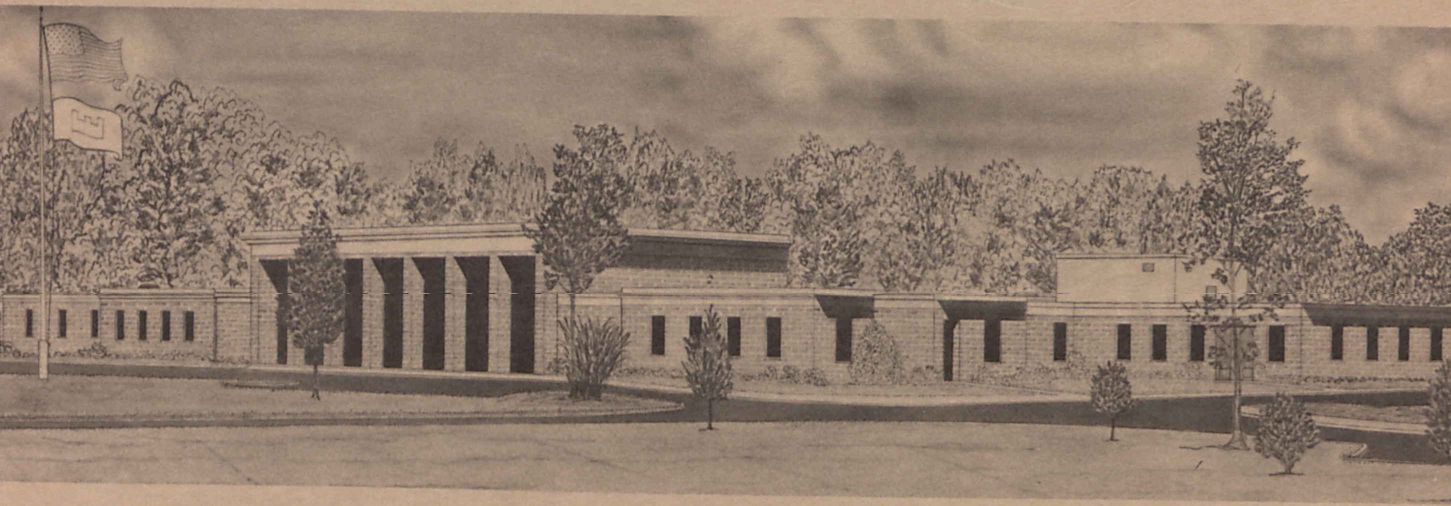

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This study consisted of a preliminary geological and engineering evaluation of natural brick and cement materials on St. Croix, U. S. Virgin Islands. The analyses of geological literature, maps, and aerial photographs revealed that the Kingshill Marl (Miocene) should be investigated as a source for cement and that the Jealousy formation (Oligocene) and Quaternary alluvium be investigated as possible source material for bricks. Geological field work and sampling were conducted at selected sites where these geologic units were exposed. The

classification tests conducted on the collected samples included mechanical analyses, Atterberg limits, chemical, and mineralogical. The tests used to determine suitability as brick material included extrudability, shrinkage, and green and dry strengths. The constraints to commercial manufacture of brick and cement were studied in terms of material properties, volume and variability, and land use. The Kingshill Marl was found to be highly calcareous material totally lacking deleterious constituents and possessing a composition suitable for the manufacture of cement. The Quaternary alluvium and the Jealousy formation are plastic clays containing predominantly smectite and calcite. These clays, particularly the Quaternary alluvium, were found to be highly suitable for brick manufacture in terms of extrudability and fired strength. Shrinkage and lime hydration are manageable constraints to the use of these clays in brickmaking. The volume of potential cement and brick materials is believed to be sufficient for commercial operations. The vertical and horizontal variability is not known and must be determined. The studied brick and cement materials occur in areas that have been zoned for agriculture or are on public land. Zoning is not considered a serious restraint.

PREFACE

This project, entitled "Engineering and Economic Evaluation of a Natural Construction Material Found on St. Croix, Virgin Islands - Phase I," was conducted in the Soils and Pavements Laboratory (S&PL), U. S. Army Engineer Waterways Experiment Station (WES), under interagency agreement H-49-76 with the U. S. Department of Housing and Urban Development (HUD). Mr. Conrad Arnolts was the HUD contract monitor.

The work was performed in the Engineering Geology and Rock Mechanics Division, S&PL, by Mr. John H. Shamburger, Chief, Terrestrial Sciences Branch (TSB) and SP5 David M. Hyman of the TSB and Dr. David M. Patrick of the Engineering Geology Research Facility.

Brickmaking tests and their evaluation were performed by Dr. William B. Hall of Mississippi State University. Chemical and mineralogical tests and evaluation were conducted by Messrs. Tony B. Husbands and Alan D. Buck, respectively, under the supervision of Mrs. K. Mather, Chief, Engineering Sciences Division, Concrete Laboratory. Soil classification was performed in the Soil Testing Branch, Soil Mechanics Division, S&PL.

The invaluable assistance of Messrs. Nicasio Nico and Anthony Baschulte of the Virgin Islands Housing Authority and Mr. Norman F. Bibby of Martin-Marietta Alumina Co. is gratefully acknowledged.

Directors of WES during this investigation were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Mr. F. R. Brown was the Technical Director.

CONTENTS

A PRELIMINARY STUDY OF NATURAL CONSTRUCTION MATERIALS ON ST. CROIX, U. S. VIRGIN ISLANDS

PART I: INTRODUCTION

Purpose

1. The lack of available, local, low-cost building materials such as brick and cement in the U. S. Virgin Islands has resulted in the need to import these materials either from the U. S. mainland, Puerto Rico, or elsewhere at substantial cost. Therefore, the U. S. Department of Housing and Urban Development (HUD) devised a plan to investigate sources of natural construction materials on St. Croix, U. S. Virgin Islands. This plan called for a preliminary investigation, to be followed by a comprehensive survey if warranted. The purpose of this report is to describe the findings of the preliminary investigation and to provide recommendations for subsequent studies.

Scope

2. The study reported herein consisted of three interrelated tasks. Task 1 consisted of reviewing and studying literature, maps, and imagery related to land use, geology, and availability of certain natural materials, contacting local agencies, and collecting and classifying samples. Task 2 involved examining and testing of collected samples, relating manufacturing processes, economics, and specification restraints to the test results, and identifying constraints imposed by the geology of these materials. Task 3 was the formulation of recommendations and a work plan for future studies based upon Tasks 1 and 2.

3. The manufactured products considered in this report are brick and cement. Brick materials, however, were identified early in the study as showing the most promise and are therefore given the most consideration.

4. Although samples from St. Thomas were also collected and tested, the major emphasis of these studies was on the natural construction materials on St. Croix.

PART II: SITE INVESTIGATIONS

General

5. On the basis of field reports, HUD had identified a triangular shaped area on St. Croix (Fig. 1) which appeared to exhibit the most promise for containing construction materials. Although HUD did not limit this investigation to the triangular area, preliminary study of images and maps revealed that this approximate area did appear to be the most likely area in terms of geology and land use for the development of natural construction materials.

6. This section deals with the results of map and imagery interpretation conducted in the office, visits to Virgin Islands government agencies, and the field work conducted in the triangular area.

Site Geology

7. Current knowledge of the general geology of St. Croix is based upon the work of Cedarstrom (1950)[1] and Whetten (1962)[2], both of whom have prepared geologic maps of the island. These geologic maps were used to select particular areas for sampling and to identify specific geologic units which appeared to possess properties suitable for making either brick or cement. However, the studies conducted by Whetten and Cedarstrom provided little detailed information on the mineralogical, petrological, or other physical characteristics of the geologic units in the triangular area. Also, the interpretations of contacts or boundaries between geologic units are not, in all cases, the same on Whetten's and Cedarstrom's maps. The general geology, including controversial aspects, is given below. A generalized geologic map and geologic cross section are shown in Figs. 1 and 2, respectively.

Mount Eagle volcanics

8. St. Croix is essentially a volcanic island consisting of a "backbone" of volcanic rocks and volcanoclastic sediments extruded and deposited during Cretaceous time. This sequence of rocks is called the

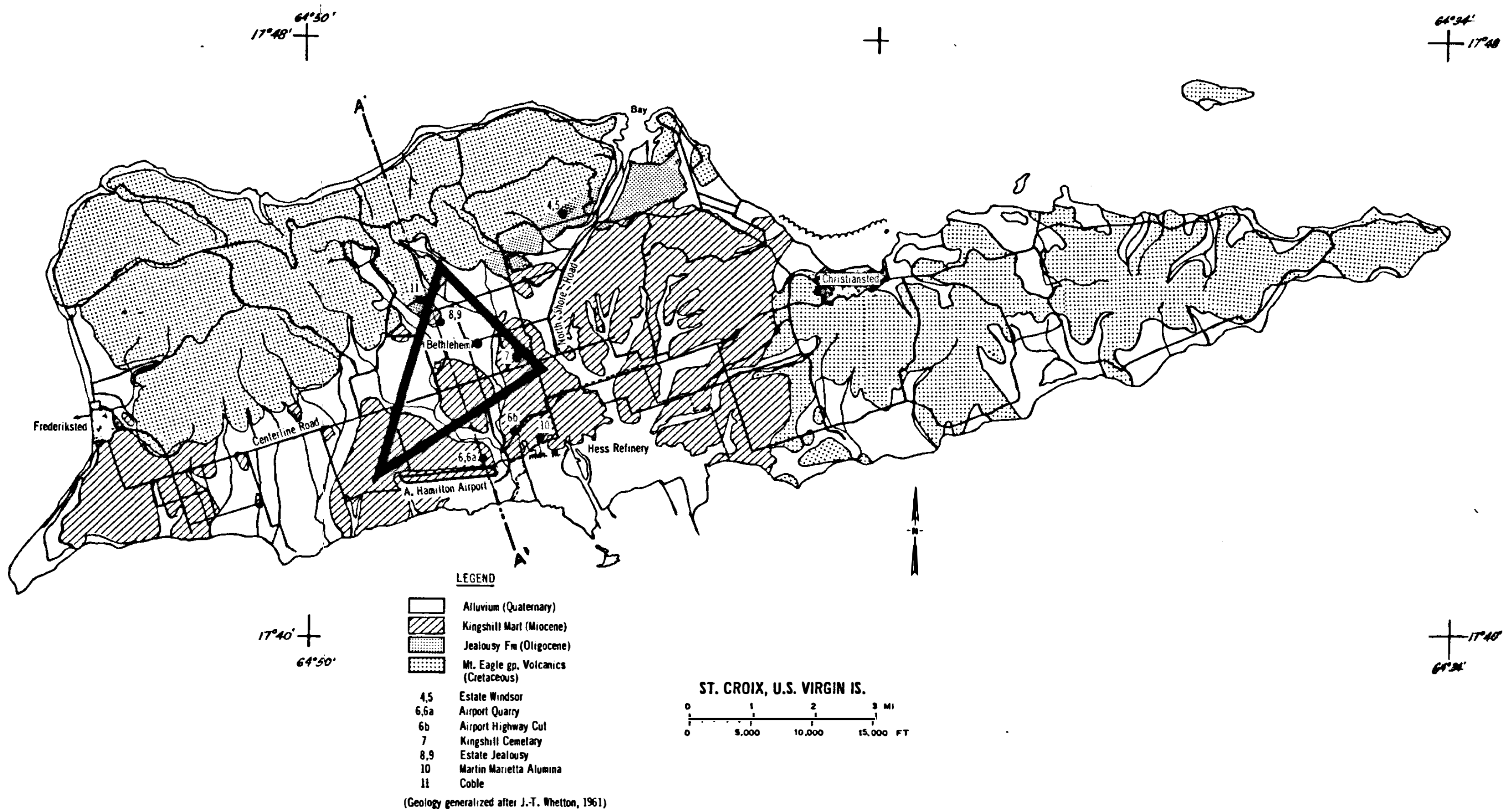

Figure 1. Geological map of St. Croix

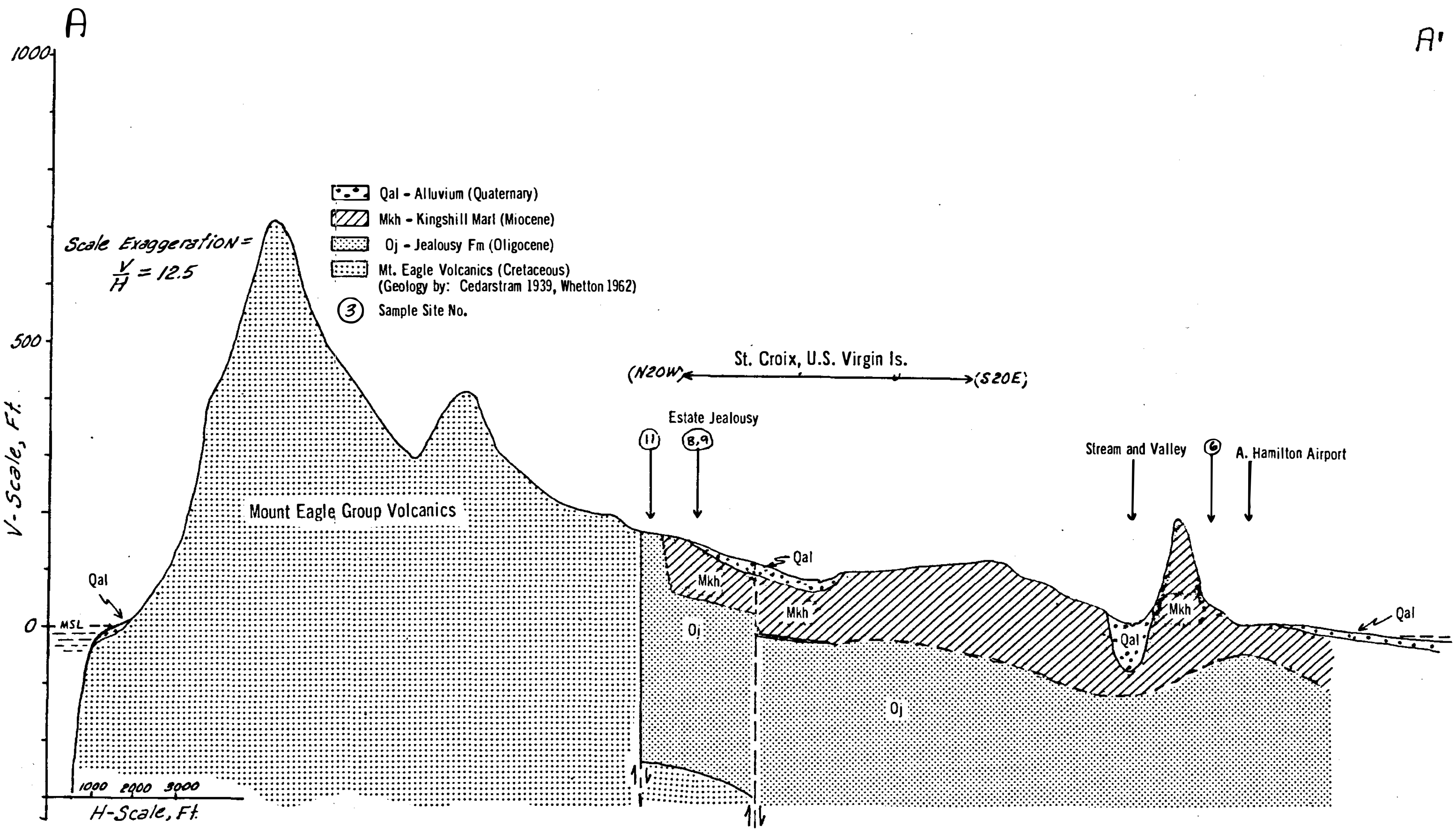

Figure 2. Geological cross section A-A

7

Mount Eagle Group and is exposed in the mountainous band extending across the northern one-half of the western half and more or less throughout the eastern half of the island. The rocks themselves consist of extrusive basalts, tuffs, and some sedimentary rocks containing volcanically derived material (volcanoclastic). The Mount Eagle Group has been subjected to folding, faulting, and localized contact metamorphism by the intrusion of gabbro and diorite. On the southern half of the western portion of the island the Mount Eagle Group is covered by a relatively thick sequence of Tertiary and Quaternary sediments. Whetten found evidence that these sediments lie in a graben and that a fault contact occurs between the Tertiary sediments to the south and the Mount Eagle Group to the north.

Tertiary sediments

9. Overlying the Mount Eagle Group on the southern half of the western portion of St. Croix are approximately 1600 ft of Tertiary sediments. These deposits consist of two geologic units, the older and underlying Jealousy formation (Oligocene) and the younger Kingshill Marl (Miocene). The Jealousy formation, although purported to be approximately 1400 ft thick, does not exhibit a wide outcrop area nor is it well exposed within its outcrop area, apparently due to a cover of Quaternary alluvial material. The outcrop area of the Jealousy formation extends north-northeast and roughly parallels the southern limit of the Mount Eagle Group. The Tertiary sediments, generally, were deposited in a marine basin which was receiving sediments from the volcanic highlands to the north.

10. Cedarstrom's description of the Jealousy formation in a boring near Bethlehem (see Fig. 1) is presented below:

Material	Thickness, ft
Greenish-gray clay	987
Calcareous conglomerate	16
Gray clay	85
A conglomerate of Mount Eagle rocks cemented by calcareous material	5
Gray clay with a few limestone streaks	305
TOTAL	1398

11. Whetten interpreted that the Jealousy formation is a montmorillonitic mudstone which has evolved from the alteration of volcanic ash deposited under marine conditions.

12. Stratigraphically, the Kingshill Marl overlies the Jealousy formation and is exposed over wide areas of the western half of the island. The Kingshill formation exhibits a maximum thickness greater than 600 ft and consists of homogeneous marl, thin-bedded white limestones, and fossiliferous limestone reef-rocks (Cedarstrom, 1950).

Quaternary alluvium

13. The Jealousy formation, the Kingshill Marl, and to a certain extent, the Mount Eagle Group have been locally covered by a veneer of Quaternary sediments which may be classified as alluvium, or in some instances, colluvium. These sediments were deposited along present and perhaps former stream valleys and consist primarily of material derived from the weathering of the Mount Eagle Group in the highlands and also material derived from the weathering of the Tertiary sediments.

14. The maximum thickness of the Quaternary alluvium is believed to be approximately 81 ft. The composition of the alluvium is dependent upon the composition of the source rocks. Thus, the alluvium consists of sand and clay at sites near the Mount Eagle Group and clay and calcium carbonate at sites on and around the Tertiary sediments (Cedarstrom, 1950).

15. The compositional similarity between the alluvium and the Tertiary sediments has resulted in difficulty in distinguishing between the alluvium and the Jealousy formation. Thus, the outcrop area of the Jealousy formation increases or decreases with respect to the alluvium outcrop area depending upon the respective interpretation of Whetten or Cedarstrom.

16. The preliminary review of the site geology and what was known of material properties suggested that the Jealousy formation and the Quaternary alluvium exhibited potential for brickmaking and the Kingshill Marl should be considered as a source of cement. Further study of site geology as well as land-use patterns was accomplished by analyses of aerial photographs; these studies are discussed in the next section.

Airphoto Interpretation

17. Color and panchromatic (black and white) aerial photographic coverage of the island was studied for the purpose of identifying geologic units, determining pertinent land-use patterns, and designing the field sampling program. These studies were supplemented and accomplished in conjunction with topographic maps.

18. Generally, the image analysis did not contribute materially to the elucidation of the areal extent of the Quaternary alluvium, particularly in and around areas underlain by the Jealousy formation. There were no discernible differences in photographic signatures between areas of known Jealousy and areas of known alluvium. Areas of higher elevation could be identified as Kingshill Marl but the determination of the contact between the Kingshill Marl and the adjacent alluvium was highly subjective.

19. The aerial photographs were also used to examine the land-use and cultural patterns in the triangular area. The photographs were studied in conjunction with U. S. Department of Agriculture (USDA) soils and land-use maps[3,4]. Figure 3 illustrates the land-use map of St. Croix prepared by the USDA. This map reveals that most of the land within the triangular area is agricultural or public land.

20. Field sampling sites or areas were chosen based on geologic and soils maps, aerial photographs, and the land-use map.

Field Investigations

21. Field studies were conducted on St. Croix, and to a lesser extent, on St. Thomas for the purpose of examining the field relationships of the geologic units identified as potential sources of construction materials and to collect samples of these materials for laboratory testing. Soil samples were collected by means of shallow hand-auger borings and trenching, and rock samples were collected at outcrops. Sample locations on St. Croix are shown on Fig. 1 and classification data are shown on Table 1.

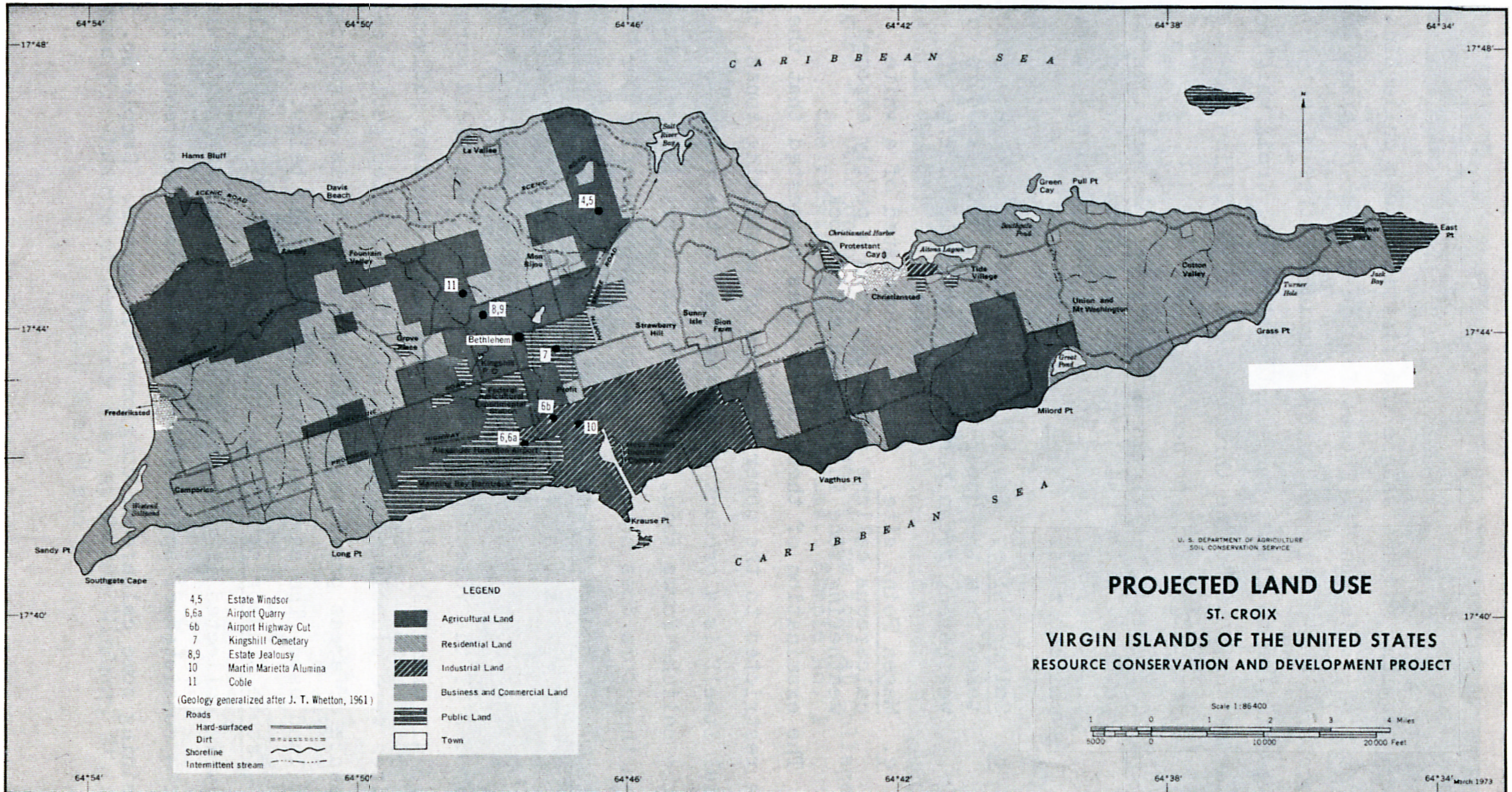

Figure 3. Land-use map

St. Thomas

22. Geological reconnaissance and limited sample collecting were conducted at three sites on St. Thomas for the purpose of examining the reported occurrence of caliche and to determine whether or not this material was similar to clayey-marly material on St. Croix which also had been termed "caliche." The three sites are identified and a brief description of the material is presented below:

a. College of the Virgin Islands site. Sample 1 is a powdery, white calcareous caliche from the upper 4 ft of a weathering zone in volcanic rock. Figure 4 shows the caliche zone.

b. Solberg site. Sample 2 is a white calcareous caliche taken from the upper portion of an 8-ft exposure of weathered, green porphyritic volcanic rock.

c. Magen Point site. Sample 3 consisted of a white calcareous caliche collected from a poorly exposed weathering zone in volcanoclastic rock.

23. The examination of these three sites suggested that the caliche is restricted to the upper portions of weathering zones, that the material itself is a product of weathering of the volcanic rocks, and that the caliche forms thin, discontinuous layers in the soil profile and therefore does not exist in sufficient quantity for further consideration as a source for making lime.

St. Croix

24. Having established some indication of the soils and weathering characteristics of the volcanic rock on St. Thomas, the field work on St. Croix dealt primarily with the Tertiary and Quaternary sediments. Sampled sites were pinpointed in the field after limited geological reconnaissance of areas previously selected on the basis of geology, soils, and land use. The sampled sites are discussed below.

25. Estate Windsor site. Two composite samples of the Jealousy formation were collected in trenches near a farm pond at Estate Windsor. Sample No. 4 consisted of approximately 2 ft of tan calcareous silty clay containing some calcareous conglomeratic matter. Sample No. 5 was

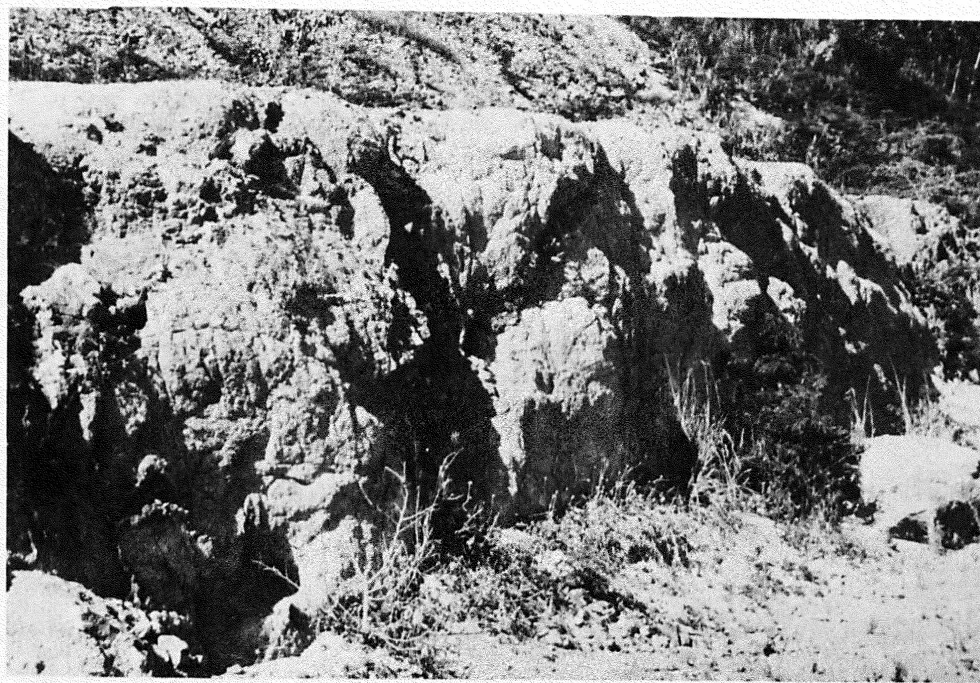

Figure 4. Outcrop of caliche in weathering zone at College of the Virgin Islands, St. Thomas. Sample No. 1

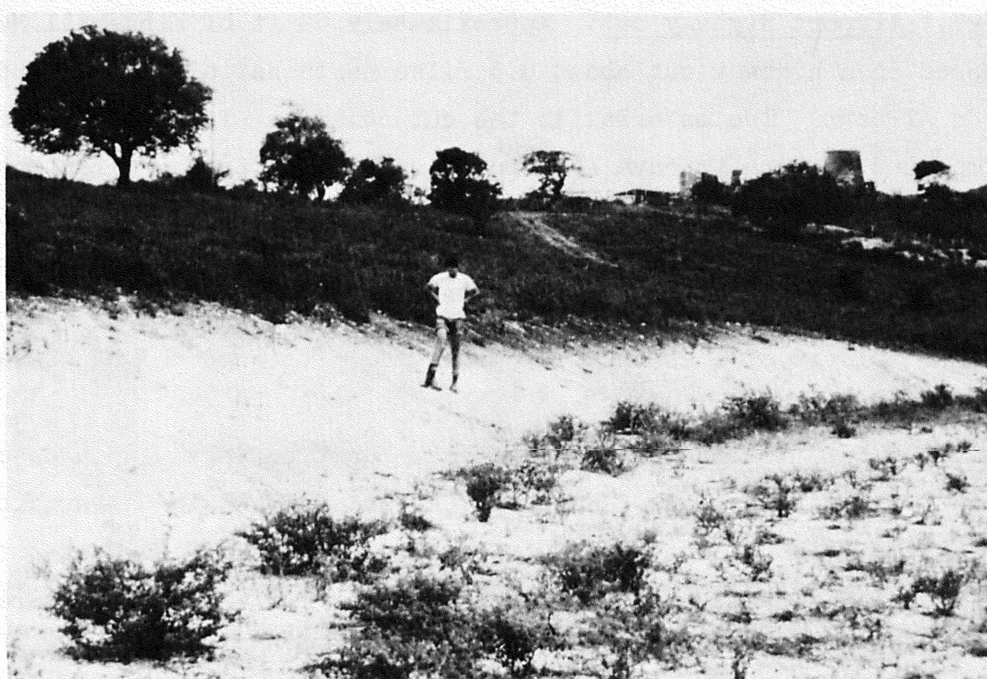

Figure 5. Outcrop of Jealousy clay at Estate Windsor, St. Croix. Sample Nos. 4 and 5

taken 10 ft south of sample No. 4 and consisted of approximately a 2-ft composite of calcareous tan silty clay with white mottles. Figure 5 illustrates the sampled sites. This site is zoned for agriculture.

26. Airport Quarry site. This site is a quarried hillside of the Kingshill Marl and is located at the eastern edge of a ridge that lies just north of the Alexander Hamilton Airport on St. Croix. This quarry shows a 50- to 60-ft-thick section of the gently folded marl. This location and another similar exposure at the Airport Highway cut present the best views of Kingshill lithology. The top 6 ft of the quarry exposure is a fairly dense, fossiliferous limestone. The limestone becomes less dense and more of a marl downwards from the top. Near the base there is a seam of tan plastic clay about 2 in. thick. (The exposure at the highway cut showed a fairly dense limestone, marly with fossils (especially colonial corals) throughout.) Sample No. 6 was a stratigraphic composite taken at the quarry and sample No. 6a was taken from a recent quarry stockpile. Figure 6 shows a view of the quarry face. The quarry is on public land; adjacent land is zoned for industry.

27. Airport Highway cut. Approximately 50 ft of Kingshill Marl is exposed in a highway cut about 0.5 miles northeast of the Alexander Hamilton Airport. The material in the cut consists of dense fossiliferous limestone and appears to have a composition similar to the limestone at the airport quarry. No samples were taken at the road cut.

28. "Kingshill" Cemetery site. Sample No. 7 consisted of Kingshill Marl that was collected in an exposure at an excavation. The material consisted of fossiliferous limestone with sand and clay seams. The land is public.

29. Estate Jealousy site. Two hand-auger borings were made at the ruins of Estate Jealousy. These sites are on what is believed to be Quaternary alluvium. Sample No. 8 was taken along the road south of a farm building and consisted of approximately 64 in. of gray, calcareous clay becoming somewhat reddish below 27 in. Sample No. 9 was taken approximately 200 ft southeast of sample No. 8 and consisted of 97 in. of tan to cream colored, silty plastic clay. The site is zoned for agriculture.

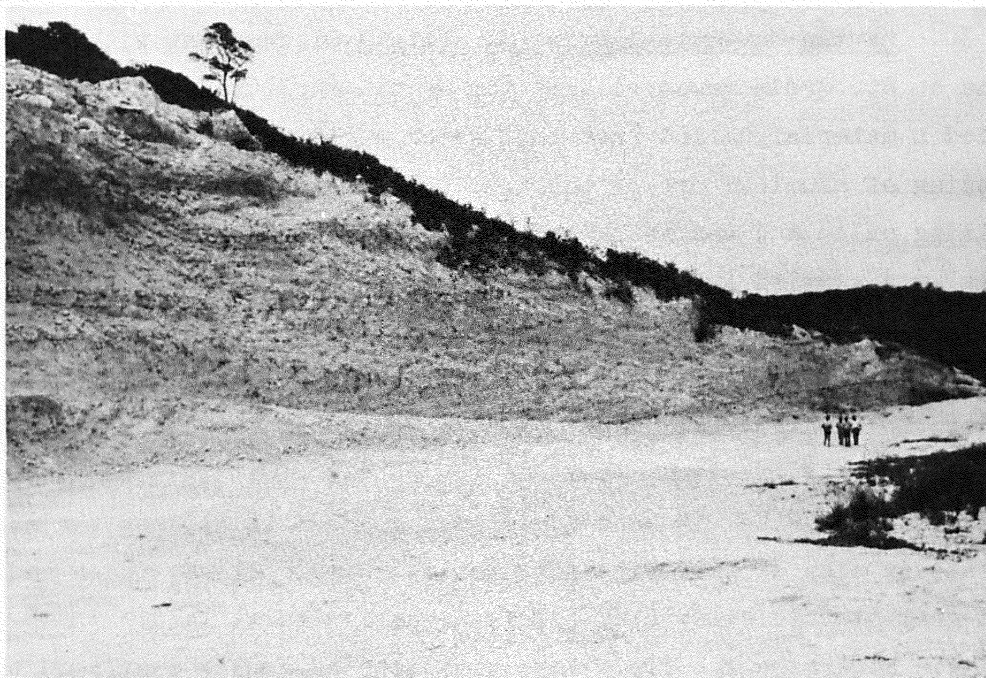

Figure 6. Kingshill marl exposed in quarry near Alexander Hamilton Airport, St. Croix. Sample No. 6

Figure 7. Tailing pile of red mud from Martin Marietta Alumina Co., St. Croix. Sample No. 10

30. Martin-Marietta Alumina Co. site. Discussions with various persons on St. Croix revealed that the Martin-Marietta Alumina Company produced a material called "red mud" which was a waste product from the processing of aluminum ore or bauxite. The red mud was being discarded in tailing piles and was not known to have any commercial value. This material was sampled (sample No. 10) (through the courtesy of Martin-Marietta Alumina Co.) for the purpose of determining its potential as an admixture in brickmaking. The red mud was red, fine-grained, hard, and purported to be highly alkaline. Figure 7 illustrates the material in stockpile.

31. Coble site. A hand-auger boring about 11 ft deep was made in the Jealousy clay at this site near Coble. Sample 11 was taken and is a tan to gray plastic silty clay. This is agricultural land.

32. Remarks. The field investigations generally confirmed the observation that the contacts between the Jealousy formation and the alluvium were extremely difficult to detect and that there did not appear to be significant differences in the materials collected at the Jealousy sites and the alluvium sites.

PART III: MATERIAL TESTING AND EVALUATION

General

33. The laboratory tests performed during this investigation consisted of two general types: (a) classification tests used to measure general physical properties and to identify the constituents, and (b) specific tests for evaluating a particular product, such as bricks. The selection of types of tests to be run and the number of samples to be tested was based upon the field relationships, field classification, and cost restraints.

Material Tests

Physical tests

34. Atterberg limits. The Atterberg limits are a measure of the plasticity of a fine-grained material and are used to determine the engineering classification of soils. Atterberg limits were determined for selected samples of alluvium, Jealousy clay, and the red mud. The data are shown in Table 1. The alluvium is classified as plastic clay (CH), the Jealousy classified as sandy clay (CH to CL), and the red mud is a nonplastic sandy silt (ML).

35. The plasticity indexes of the Jealousy samples varied from 24 to 53 and those of the alluvium varied from 40 to 167 indicating that both materials exhibit a reasonably high degree of plasticity or workability through a range of water contents. Also, it appears that the clay mineral content is sufficiently high that the presence of sand in the sandy clays does not appreciably lower the plasticity values.

36. Mechanical analyses. The grain-size distributions (Table 1) were determined by sieving and by hydrometer for selected samples of alluvium, Jealousy clay, and the red mud. The main difference between the alluvium and Jealousy clay was in the relative amounts of sand versus clay. The alluvium averaged 64 percent clay and 5 percent sand whereas the Jealousy clay averaged 42 percent clay and 23 percent sand.

Table 1

CLASSIFICATION DATA

Sample No.		Site	Geologic Unit	Field Class.	Depth	MA (%) Sd Si Cl	Plastic Limit	Plasticity Index	Laboratory Classification	Specific Gravity
1	St. Thomas	College of V. I.	Soil*	Caliche	24" - 48"	NT	NT	NT	NT	NT
2		Solberg	Soil*	Caliche	36" - 60"	NT	NT	NT	NT	NT
3		Magen Point	Soil*	Caliche	48" - 60"	NT	NT	NT	NT	NT
4	St. Croix	Estate Windsor	Jealousy formation	Sandy clay	0 - 24"	NT	NT	NT	NT	NT
5		Estate Windsor	Jealousy formation	Sandy clay	0 - 24"	28-32-40	20	24	Sandy clay (CL)	2.67
6		Airport Quarry	Kingshill marl	Limestone	Composite of 40'	NT	NT	NT	NT	NT
6a		Airport Quarry	Kingshill marl	Limestone (stockpile)	Composite of 40'	NT	NT	NT	NT	NT
7		Kingshill Cemetary	Kingshill marl	Limestone, sandy	36" - 48"	NT	NT	NT	NT	NT
8a		Estate Jealousy	Alluvium	Silty clay	29" - 64"	4-33-63	31	60	Plastic Clay (CH)	2.70
8b		Estate Jealousy	Alluvium	Silty clay	0 - 29"	NT	NT	NT	NT	NT
9c		Estate Jealousy	Alluvium	Silty clay	0 - 41"	NT	NT	NT	NT	NT
9b		Estate Jealousy	Alluvium	Silty clay	41" - 71"	8-24-68	24	167	Plastic Clay (CH)	2.70
9a		Estate Jealousy	Alluvium	Silty clay	71" - 97"	4-34-62	27	40	Plastic Clay (CH)	2.70
10		Martin-Marietta Aluminum processing plant	NA	Sandy silt	Surface of Tailing pile	25-27-38	27	13	Sandy silt (ML)	NT
11c		Coble	Jealousy		0 - 5'1"	NT	NT	NT	NT	NT
11b		Coble	Jealousy		5'1" - 8'6"	NT	NT	NT	NT	NT
11a		Coble	Jealousy		8'6" - 11'	19-35-44	34	53	Sandy clay (CH)	2.70

NT - Not Tested
* Weathered zone in volcanic rock

The silt content of the alluvium averaged 30 percent and that of the Jealousy clay averaged 33 percent. The red mud consisted of 25 percent sand, 27 percent silt, and 38 percent clay. The low plasticity and the fairly high clay-size content of the red mud suggest that the clay-size grade does not contain appreciable clay minerals. Generally, the grain-size distributions of the alluvium and Jealousy clays indicate sufficient fines for brickmaking.

Chemical tests

37. Chemical analyses were performed on samples of Jealousy (No. 11a), alluvium (No. 9c), Kingshill Marl (No. 6a), and the red mud (No. 10) from the Martin-Marietta plant. These data are shown in Table 2. The purposes of these analyses were to identify chemical restraints relative to either brick or cement manufacture, to provide compositional data which could be correlative with mineralogical and classificational input, and to learn something of the natural variability of the material.

38. Kingshill Marl. Chemical analysis revealed that this material contains somewhat less than 84 percent calcium carbonate. The silica (12.19 percent) and alumina (2.56 percent) contents suggest that this material contains minor amounts of clay minerals and therefore could not be considered as a brick material without additives. The mineral content of the marl makes it a good source for cement. The low concentrations of ferric iron (1.22 percent), magnesia (1.01 percent), and alkalis (less than 1.0 percent) indicate that the material contains insignificant amounts of substances which would be deleterious to either bricks or cements.

39. Jealousy clay. The chemical analysis of this material revealed approximately 15 percent lime (CaO). If one assumes that most of the lime represents calcium carbonate, the calcium carbonate content is computed to be approximately 26 percent of the total sample. Actually, some of the total lime may be in the clay minerals and feldspars. Significantly, the alkalis, magnesia, and trivalent iron are not present in sufficient quantity to pose problems in bricks, nor would they be

Table 2

CHEMICAL ANALYSES OF SELECTED SAMPLES

	Kingshill No. 6a	Alluvium No. 9a	Jealousy No. 11a	Red Mud No. 10
SiO_2	12.19	41.06	49.35	6.68
Al_2O_3	2.56	11.52	11.70	33.30
Fe_2O_3	1.22	5.31	5.78	23.00
CaO	47.10	19.24	14.64	2.25
MgO	1.01	2.22	2.29	0.13
Na_2O	0.49	1.41	1.41	3.87
K_2O	0.45	1.26	1.27	0.49
TiO_2	---	---	---	17.17
LOI @ $900^\circ C$	36.02	17.99	14.28	11.92
	101.04	100.01	100.72	98.81

deleterious if the material were used as an admixture in cement. Excessive amounts of calcium carbonate, however, may be deleterious in bricks depending upon the grain size and distribution of this component in the material.

40. Alluvium. The chemical analysis of the alluvium is quite similar to that of the Jealousy clay, the main difference being in the relative amounts of silica and lime. The computed calcium carbonate content of the alluvium sample is approximately 34 percent.

41. Red mud. The chemical analysis of the tailing material at the Martin-Marietta plant was performed to provide some information on the suitability of this material in brickmaking. The results of this analysis were not conclusive although there appears to be excessive alkalis and trivalent iron present. The low silica content indicates minor quantities of clay minerals present as surmised from the Atterberg limit data.

Mineralogical tests

42. Qualitative mineralogical analyses were performed by X-ray diffraction (XRD) on selected samples for the purpose of identifying mineral constituents and their variability among samples, and to determine the presence or absence of mineral components which could be deleterious to bricks or cements. The analyses consisted of the examination of the bulk sample and a more detailed analysis of the minus-two-micrometer* size fraction containing the clay mineral suite. The results of these tests are given in the Petrographic Report, Appendix A, and are summarized below.

43. Kingshill Marl. As indicated by the chemistry, this material contains mainly calcite (calcium carbonate) accompanied by minor amounts of quartz and feldspar. The minus-two-micrometer size fraction contained small amounts of smectite. No deleterious mineral constituents were detected.

44. Jealousy and alluvial clays. Generally, these clays consisted of clay minerals (mainly smectite), calcite, quartz, and feldspars. Smectite and calcite were the primary constituents. The variability

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* One micrometer = 0.001 mm.

between sample sites and with depth was only moderate. Detectable differences in composition and concentration could be seen but basically the various samples represented one suite of minerals.

45. Red mud. This material contained no clay minerals. The principal constituents were iron, aluminum, and titanium minerals.

46. Caliche from St. Thomas. Sample No. 1 consisted of abundant calcite, some quartz, and minor amounts of feldspars and clay minerals. The clay minerals, although not as abundant, showed some similarity to the clay mineral suite in the Jealousy samples.

Material Evaluation

Brick

47. An initial acceptance/rejection test was run on all ten samples. This test consisted of dry pressing the material into bars and firing the bars at 1850 deg, 1950 deg, and 2050 deg F. The weight loss and shrinkage of the bars were measured after firing and the general nature of the bar was observed. This initial test indicates whether or not the material will vitrify and develop strength upon firing and gives some indication of shrinkage and the presence of deleterious substances in the material.

48. Before proceeding with a discussion of the testing, it would be well to discuss brickmaking material and describe the desirable characteristics of bricks and brick materials. Satisfactory common bricks may be made from materials having a wide range of composition. This results from the large number of factors which affect the brickmaking process. Often these factors are interrelated or dependent. The wide range of acceptable compositions therefore precludes acceptance or rejection criteria based upon composition alone. The determination of acceptability must be based upon physical tests which more or less model the various stages of manufacture and which include the preparation of samples which are subjected to conditions similar to those during actual production. These tests are empirical in nature and relate to plasticity, extrudability, shrinkage, strength (green and fired), weatherability, and firing properties.

49. The material must be plastic or workable, meaning that it will absorb water and can be molded and extruded through a die. The strength of the molded and extruded material must be sufficient for the green or unfired bricks to be stacked one upon the other in the kiln. The composition must not permit excessive shrinkage or volume reduction to occur after extruding (air drying) or during firing. The attainment of strength after firing is dependent upon the development of glassy bonds throughout the brick which occur because of vitrification in the clay minerals and which hold the brick together. Aside from appearance, but somewhat related to it, is the weatherability of the brick. This last factor involves the presence of chemical constituents in the material which break down or alter with time. Weatherability also includes the permeability of the brick and whether water can be drawn into the brick causing failure if freezing occurs.

50. Standard tests used to determine the suitability of materials for brick were performed on ten samples. These tests were conducted by Dr. William B. Hall at Mississippi State University. The report describing the results of these tests is included in Appendix B. The samples tested include Jealousy clay (Nos. 4, 11a, 11b, and 11c), alluvial clay (Nos. 8, 9a, and 9b), Martin-Marietta red mud (No. 10), the Kingshill Marl (No. 6), and a sample of caliche from St. Thomas (No. 1). The following paragraphs describe the nature and results of these tests.

51. On the basis of this test three samples were rejected. These were Nos. 1 (St. Thomas), 4 (Windsor), and 6 (Kingshill Marl). Sample No. 11 (Coble) was marginal. The reason for failure of these materials is most likely due to the calcium carbonate (calcite) present in the clay. The calcium carbonate converts to lime (CaO) during firing, and then, after firing, takes on water (forming $Ca(OH)_2$). This results in an expansion which may disintegrate the brick depending upon the concentration and apparently the grain size of the calcium carbonate in the unfired material.

52. The samples which were not rejected and a sample prepared by mixing the Martin-Marietta sample with material from 9c in the initial test were mixed with water, molded, and were extruded through a die.

After drying, the weight loss and shrinkage were measured and the extruded bars were fired at 2050 deg F. The weight loss, shrinkage, and strength of the bars were measured after firing. These data are given in Appendix B, Tables III and IV.

53. The samples of alluvial clays Nos. 8, 9b, and 9a were found to possess satisfactory characteristics in terms of extrudability and fired strengths[5]. Photographs of the extruded and fired samples are shown in Figs. 8-11. The shrinkage, however, was somewhat high. The red mud may be used with satisfactory results as an additive to effect coloration. The Jealousy clays appear to contain considerable calcium carbonate, which may require that these clays be treated in order to minimize the effects of this component.

Cement

54. The analysis of the feasibility of utilizing the Kingshill Marl as well as the various clays as components in portland cement was based on the classificational and compositional data previously described. Empirical testing was not conducted. The relatively high degree of purity in terms of calcium carbonate content and the total absence of deleterious constituents in the Kingshill Marl suggest that this material is a potential source of cement. The detailed results of the analyses are given in the Petrographic Report, Appendix A.

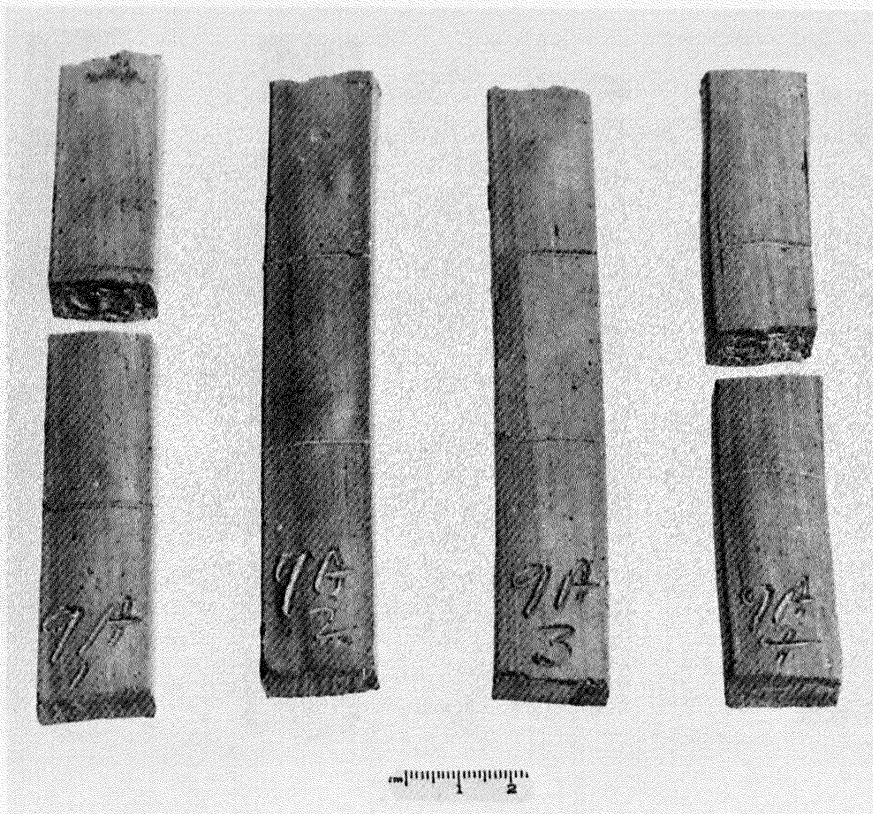

Figure 8. Sample 9a (alluvium), extruded and fired bars

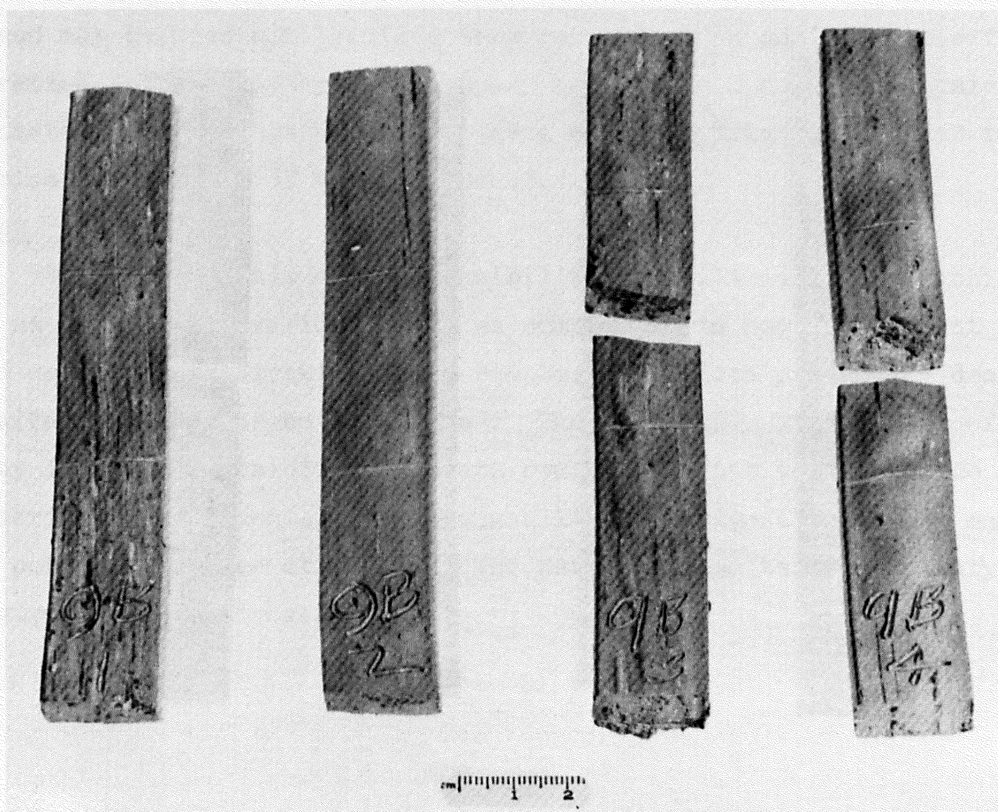

Figure 9. Sample 9b (alluvium), extruded and fired bars

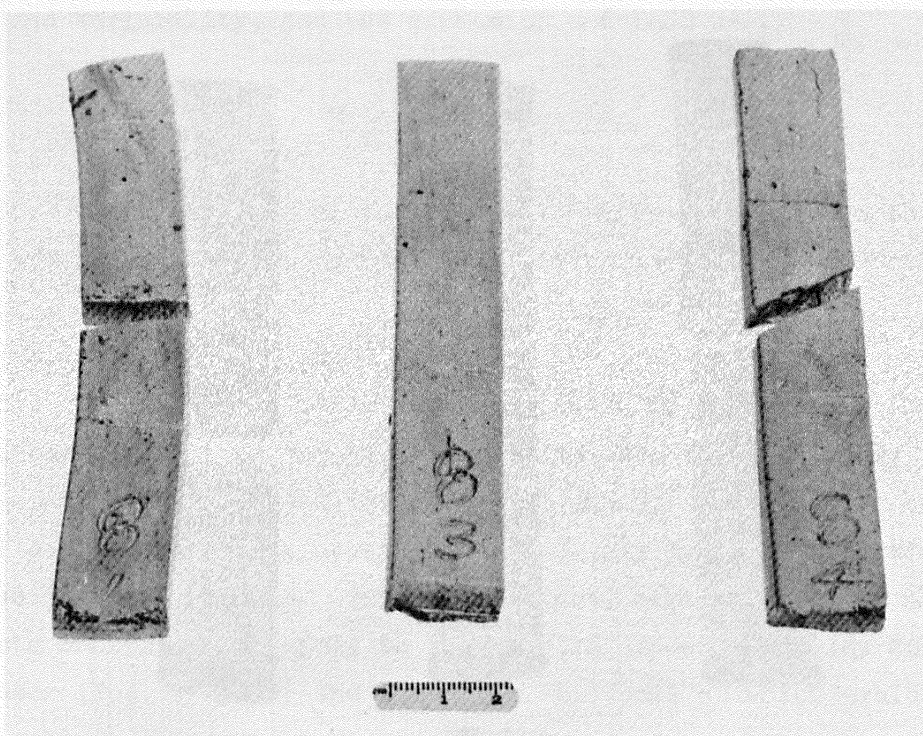

Figure 10. Sample 8 (alluvium), extruded
and fired bars

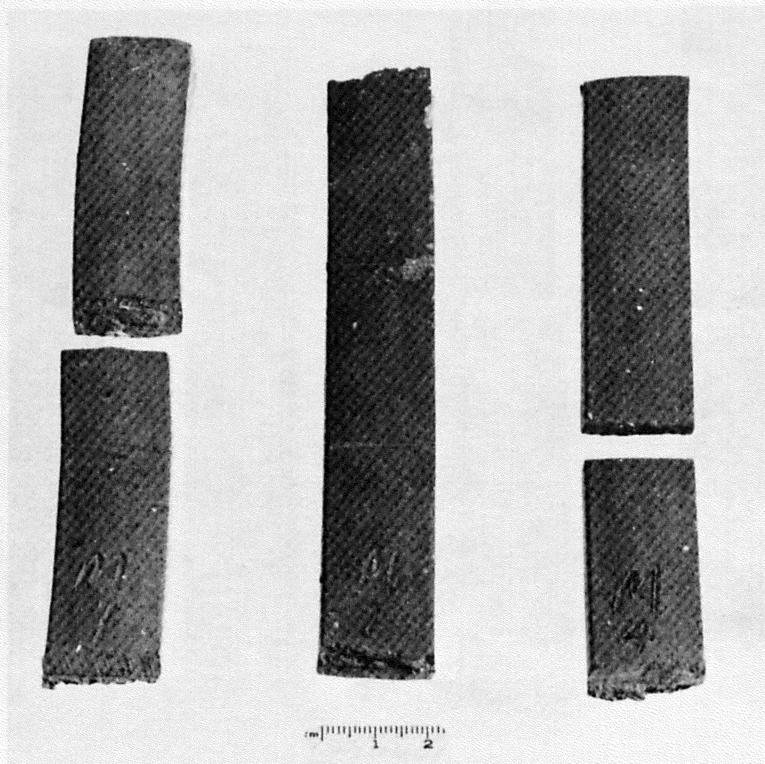

Figure 11. Mixture containing 33% alluvium (9a) and 67% red mud (10) extruded and fired bars

PART IV: CONSTRAINTS

General

55. This portion of the report addresses those factors which would influence or control the production and manufacture of structural products utilizing the natural materials previously described. Generally, the constraints may be categorized as to (a) material properties, (b) volume and variability, and (c) economics and land use.

Material Properties

56. The properties of the materials which are believed to significantly affect utilization include composition and the results of empirical tests.

Bricks

57. The materials which have been shown to be suitable for bricks, based mainly on the empirical tests, are represented by the samples collected in the alluvium (Nos. 8 and 9). The calcium carbonate content and the shrinkage appear to be the only material restraints detected in these samples. These restraints, particularly the calcium carbonate content, also apply to the samples of Jealousy clay collected at Windsor (Nos. 4 and 5) and Coble (No. 11), all of which exhibited considerable calcium carbonate.

58. The calcium carbonate content and the shrinkage are not believed to be prohibitive restrictions. The detrimental effects of calcium carbonate can be lessened considerably by chemical additives such as sodium chloride or by fine grinding. Shrinkage can be reduced by carefully controlling firing and drying rates or by prefiring a portion of the batch.[6]

Cement products

59. Sources of cement materials are from the Kingshill Marl. Compositionally this geologic unit appears to possess the approximate composition of a natural cement rock. Deleterious constituents are

absent. Some admixed clay may be required, however. The testing has not revealed any compositional restrictions to using the Kingshill Marl with either the Jealousy or alluvial material.

Volume and Variability

60. The constraints considered in this category include primarily the areal and vertical distribution, the uniformity, and the depth of cover over the materials in question. At this stage in the investigation, this category of constraints is the least understood. The understanding of the distribution of the materials must be based upon geologic maps, field observations, and the limited number of hand-auger borings made. As previously mentioned, the data given on the geologic map are, in some cases, open to interpretation.

Bricks

61. The general conclusion is that possible brickmaking materials are confined to those areas underlain by the Jealousy formation and certain areas of Quaternary alluvium and that the alluvial material exhibited superior properties. The Jealousy clay, although quite thick, does not have a particularly large outcrop area in the zone of interest. The usable area of exposure is estimated to be approximately 553 acres. The Jealousy outcrop area is considerably larger to the northeast but this area is more built up. The Quaternary alluvial deposits exhibit a large outcrop area in the zone of interest, having an estimated areal extent of 755 acres; however, the thickness of the alluvium is variable and may be quite thin in some places. The alluvium in a general sense, however, is not as restricted in terms of available material as is the Jealousy formation.

62. The lateral and vertical variability of both the alluvium and the Jealousy formation is not known with a high degree of certainty, and less is known about the Jealousy formation than the alluvium. The examination of geologic sections and boring logs (Cedarstrom, 1950) suggests that the alluvium is not particularly uniform. On the other hand, the compositional tests run on, albeit shallow, samples of

Jealousy and alluvial material revealed a degree of similarity between and among both units, the main difference being in the relative amounts of calcite versus clay minerals.

Cement products

63. The Kingshill Marl is believed to be available in sufficient quantity (2268 acres) that volume is not considered to be restrictive. The variability of this material is not completely understood although the examination of this unit at several sites indicated an apparent uniformity from site to site.

Remarks

64. The preliminary field work and the study of the literature indicate that sufficient volumes of alluvium, Jealousy, and Kingshill material are present for commercial extraction. However, the volume of available material and its variability can only be reliably determined after the conduction of a more elaborate drilling and sampling program.

Economics and Land Use

65. The restrictions imposed by economics and land-use considerations have been subjected to limited study during this preliminary investigation. The salient variables which must be addressed in order to determine the economics and land-use restrictions are given below.

Market

66. The availability of local markets on the Virgin Islands as well as neighboring islands would be the basis for determining the need for either brick or cement plants on St. Croix. The market situation would also dictate the type plant to be constructed.

Type of plant

67. Consideration of the type of plant to be constructed is primarily based upon the anticipated market. The construction of a large, fully automated brick plant, for example, would be based upon anticipation of a rather large regional as opposed to local market. A predominantly local market may be better served by a smaller, less sophisticated operation. These considerations also apply to cement plants.

Costs

68. The costs related to the manufacture of construction materials include those of land acquisition, plant construction, labor, taxes, transportation of products to markets, land reclamation, and energy. A detailed study of costs has not been undertaken. The incentives offered by the Virgin Islands Government appear to be liberal and should provide encouragement. A summarization of Virgin Islands government incentives is given in Appendix C.[7]

Available land

69. The areas of interest containing alluvium and Jealousy clay are in regions zoned for agriculture. The Kingshill Marl areas are either zoned for industry or are public land. The preliminary study of land use including visits with Virgin Islands Government agencies suggests that the land within the zone of interest could be made available for plant operations.

Environmental

70. The environmental consequences of open-pit mining and the manufacture of bricks or cements may be a severe constraint. There are several considerations included under this category. The impact of mining and manufacturing upon the natural, scenic beauty of the island would require that special consideration be given to choice of site and that land reclamation be initiated as soon as possible after a mining area has been worked out. Groundwater shortages, locally, could present a problem on St. Croix, and may require stringent control of water use and effluent discharge. Surface water pollution, including the effects on beaches, must also be considered. Another possible concern is that of air pollution. This could result, in both brick and cement production, from the dusts derived from grinding the raw materials and from the burning of fuels used to heat the kilns. Air pollution associated with the manufacture of cement is considered to be a serious restraint.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

71. The examination of samples of caliche from St. Thomas indicated that this material does not possess the material properties nor the volume necessary for commercial brick or cement manufacture.

72. Classification and empirical tests of selected samples of Quaternary alluvium and Jealousy clay revealed that these materials possess properties suitable for the manufacture of bricks. These materials were found to have excellent extrudability, drying properties, and green and dry strengths.

73. On the basis of chemical and mineralogical analyses the Kingshill Marl is believed to possess the material properties necessary for the manufacture of cement.

74. The Quaternary alluvium, Jealousy clay, and Kingshill Marl are believed to be present in sufficient quantity for commercial extraction but this must be proven.

75. Significant but resolvable restraints to exploitation are: (a) calcium carbonate content and shrinkage exhibited by the alluvium and Jealousy clay, (b) material variability of the alluvium, Jealousy clay, and Kingshill Marl; (c) marketing and economic considerations; and (d) environmental impact.

Recommendations

76. The questions of material volume and variability can only be answered after examining data collected from a detailed sampling program. Therefore, it is recommended that such a program be implemented in the general vicinity of Coble, Estate Jealousy, and the Airport Quarry. The borings should extend approximately 40-50 ft in depth and should be appropriately spaced.

77. The tests previously described should be run on individual and composite samples collected in this detailed boring program. Further testing should include the following:

a. Determine specific processing techniques for minimizing shrinkage and the effects of calcium carbonate for the alluvial and Jealousy material.

b. Examine the suitability of the Jealousy and alluvial clays for bloating and lightweight aggregate production.

c. Conduct firing and other detailed tests of the Kingshill Marl to determine ultimate suitability for cement making.

REFERENCES

1. Cedarstrom, D. J., "Geology and Groundwater Resources of St. Croix, Virgin Islands," U. S. Geological Survey, Water Supply Paper 1067, Washington, D.C., 1950.

2. Whetten, J. T., "Geology of St. Croix, U. S. Virgin Islands," Ph.D. Thesis, Princeton University, Trenton, New Jersey, 1962.

3. U. S. Department of Agriculture - Soil Conservation Service, "Soil Survey - Virgin Islands of the United States,", Government Printing Office, Washington, D.C., 1970.

4. U. S. Department of Agriculture, Soil Conservation Service, "Virgin Islands of the United States - Resource Conservation and Development Project," Government Printing Office, Washington, D.C., 1973.

5. American Society for Testing and Materials, "ASTM Standard Specifications for Building Brick (Solid Masonry Units made from clay or shale)," Philadelphia, Pennsylvania, C-62-75a, 1975.

6. Grimshaw, R. W., The Chemistry and Physics of Clays, 4th ed., Wiley Interscience, New York, 1971.

7. Eleventh Legislature of the Virgin Islands of the United States, "Industrial Development Law," Bill No. 6643, St. Thomas, U. S. Virgin Islands, 1975.

APPENDIX A: PETROGRAPHIC REPORT

by

Alan D. Buck

Samples

1. Ten powder samples in plastic bags were received 17 June 1976 from the Soils and Pavements Laboratory of the Waterways Experiment Station for examination by X-ray diffraction to identify their mineral constituents. One of the samples was a red mud by-product of processing aluminum from bauxite ore; one came from a stockpile of marl; one was described as a caliche soil; the remaining seven samples were from an Oligocene clay formation (Jealousy) and Quaternary alluvium from St. Croix, Virgin Islands. The samples are identified in Table A1 as listed by the Soils and Pavements Laboratory, Engineering Geology and Rock Mechanics Division.

2. The results of the X-ray work were to be used as a basis, insofar as possible, for predicting the suitability of the marl as raw material for the manufacture of portland cement. Chemical analyses of four samples including the limestone were made by the Chemistry and Plastics Branch, Concrete Laboratory, WES.

3. About 5 g of each sample were ground to pass a 45 µm (No. 325) sieve. These materials were then back-packed to minimize preferred orientation and were X-rayed.

4. Other representative portions of each sample weighing about 25 g each were used to prepare oriented clay slides by settlement in water, decantation, and sedimentation onto glass slides of clay-sized material ($<$ 2 µm). A sedimented slide of each sample was then X-rayed in the air-dry condition and after saturation with glycerol. Companion slides from selected samples were X-rayed air-dry and again after heating for 1 hr at 350 deg C. The glycerol treatment is used to identify smectite* and the heat treatment is intended to differentiate between vermiculite and chlorite.

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* A general term for any form of swelling montmorillonitic clay.

TABLE A1

Concrete Laboratory Serial No.	Field Data Sample No.	Field Data Description
CL-12 Ss-1	1	Caliche, Virgin Islands College site, St. Thomas
CL-12 Ss-2	4	Jealousy clay, Windsor, St. Croix
CL-12 G-1	6A	Alexander Hamilton Airport Quarry (stockpile sample of limestone)
CL-12 Ss-3	8	Alluvial clay (29 to 64 in.)
CL-12 Ss-4	9A	Alluvial clay (71 to 97 in.)
CL-12 Ss-5	9B	Alluvial clay (0 to 41 in.)
CL-12 Ss-6	10	Martin-Marietta red mud from processing African bauxite
CL-12 Ss-7	11A	Jealousy (8-1/2 to 11 ft)
CL-12 Ss-8	11B	Jealousy (5+ to 8-1/2 ft)
CL-12 Ss-9	11C	Jealousy (0 to 5+ ft)

5. A portion of the limestone sample (No. 6A) was weighed, allowed to react completely in dilute hydrochloric acid, washed, dried, and weighed again to determine the amount of acid-insoluble residue. A small portion of acid-insoluble residue was X-rayed.

6. A small amount of an opaque brown material was obtained from the red mud (No. 10) by hand-picking. This material was mixed with water and the slurry was allowed to dry on a small aluminum plate; the dried slurry was then X-rayed.

7. A magnet was used to verify that each sample contained small amounts of magnetite.

8. All of the X-ray patterns were made with an X-ray diffractometer using nickel-filtered copper radiation.

Results

9. The mineralogical composition of each sample and an estimate of the amounts of these minerals are shown in Table A2.

10. The red mud is largely composed of the aluminum mineral boehmite, hematite, and the hydrous iron compounds, goethite, lepidocrocite, amorphous material, and the titanium minerals anatase and rutile. While no clay minerals were detectable, small amounts of calcite and feldspar were present. There was also a small amount of unidentified material with an X-ray diffraction peak at about 2.40 to 2.41 angstroms.

11. The marl from the stockpile (No. 6A) was largely calcite with small amounts of smectite, kaolinite, quartz, and feldspars. Treatment with HCl indicated that approximately 83 percent of the rock is carbonate and 17 percent is acid-insoluble clay, quartz, and feldspars. Since no carbonate other than calcite was detected it can be said that 83 percent of the rock is calcite.

12. Bogue[1] comments that limestone or other calcareous deposits which are high in magnesium carbonate, gypsum, or pyrite may be unsuitable as raw materials for the production of portland cement. While there is no exact composition that a raw material must have to be suitable for cement, Lea[2] shows a typical raw mix composition for making portland cement (Table A3). Consideration of its chemical analysis (reported

Table A2

Mineralogical Composition of Ten Samples from the Virgin Islands

	Sample Identification by Groups									
					Jealousy Soil			Alluvium		
					Coble, St. Croix			Estate Jealousy, St. Croix		
Field No.	By-Product Red Mud. No. 10	Limestone, No. 6A	Caliche Soil, St. Thomas, No. 1	Estate Windsor, St. Croix, No. 4	0-5+ ft No. 11C	5+ -8.5 ft No. 11B	8.5-11 ft No. 11A	0-3+ ft No. 9B	2+ -5+ ft No 8	6$^-$ -8+ ft No 9A
Clays [a]										
Smectite		M [b]	M	C	I	I	I	I	I	I
Regularly mixed-layered		nd [c]	M	nd	nd	nd	nd	nd	nd	? [d]
Kaolinite	nd	R	M	M	M	M	M	M	M	M
Clay-mica		nd	nd	nd	nd	nd	nd	nd	M	M
Vermiculite		nd	Z	nd	nd	nd	nd	nd	?	C
Chlorite		nd	M	nd	nd	nd	nd	nd	nd	nd
Nonclays										
Calcite	M	A	A	A	I	C	C	I	C	I
Quartz	nd	M	C	C	C	C	C	M	C	C
Plagioclase feldspar	nd	R	M	M	C	C	M	M	M	M
Potassium feldspar	M	R	nd	M	nd	nd	C	nd	nd	nd
Hematite	C									
Goethite	I									
Lepidocrocite	M									
Amorphous iron oxide	M	nd	nd	nd	nd	nd	nd	nd	nd	nd
Boehmite	I									
Anatase	C									
Rutile	?									

(a) Montmorillonitic clays.
(b) Letters indicate: (A) Abundant >50%, (I) Intermediate 25-50%, (C) Common 10-25%, (M) Minor 5-10%, (R) Rare <5%.
(c) Not detected.
(d) Tentative identification.

TABLE A3

Composition	Marl 6A, %	Lea,[2] Typical Raw Mix, %
SiO_2	12.19	14.30
Al_2O_3	2.56	3.03
Fe_2O_3	1.22	1.11
CaO	47.10	44.38
MgO	1.01	0.59
S	nd*	nil
SO_3	nd	0.07
Loss on ignition	36.02	35.86
K_2O	0.45	0.52
Na_2O	0.49	0.13
Total	101.04	99.99

*Not determined

elsewhere) compared to Lea's typical raw mix suggests that sample 6A may be a suitable raw material for the manufacture of portland cement.

13. The caliche sample (No. 1) is also high in calcite; it differs in composition from the marl sample (No. 6A) mainly in that the caliche sample contains more clays and other noncarbonate minerals. In addition to smectite and kaolinite which were found in all samples except the red mud, the caliche also contained a regularly mixed-layer clay, some chlorite, and possibly some vermiculite. The mixed-layer clay is characterized in the air-dry condition by a diffraction peak at about 12 angstroms and by a bulge in the 25- to 30-angstrom region. The 12-angstrom peak expands with the application of glycerol into the 14+-angstrom peak of the chlorite and vermiculite; the bulge probably moves but remains undefined. The mixed-layer clay is probably composed of smectite and either chlorite or vermiculite.

14. The data for the seven samples of Jealousy clay and alluvium are arranged by source and also by depth in Table A2. All of these samples contain smectite and kaolinite clays and calcite, quartz, and feldspar as common constituents. Sample 9A from the Estate Jealousy site appears to contain a small amount of regularly mixed-layer clay since the air-dry X-ray pattern shows a weak diffraction peak at 29.4 angstroms; this is probably like the mixed-layer clay found in the caliche sample (No. 1). Samples 8 and 9A from the Estate Jealousy site (alluvium) also appear to contain small amounts of clay-mica and vermiculite.

15. Comparison of the X-ray data for the Jealousy clays and alluvium by sources indicates the Estate Windsor sample contains less clay than the Estate Jealousy or Coble samples and the latter two are similar in amounts of clays.

16. Comparison of the X-ray data by depth within the Jealousy and alluvium samples indicates a tendency for the clay content to increase with depth. These comparisons were made by inspection of the patterns; they are not indicated by the semiquantitative data in Table A2.

17. The X-ray data suggest that the smectite in the nine samples that contained it is a divalent rather than a monovalent type.

REFERENCES

1. Bogue, R. H., The Chemistry of Portland Cement, 2d ed., Reinholt Publishing Corp., New York, 1955, p 38.

2. Lea, F. M., The Chemistry of Cement and Concrete, 3d ed., Edward Arnold, Ltd., London, 1970, p 21.

APPENDIX B: VIRGIN ISLANDS CLAYS

by

William B. Hall

1. The ten samples (1, 4, 6, 8, 9a, 9b, 10, 11a, 11b, and 11c) received from WES were dried, crushed, and ground to a suitable fineness for dry pressing and extrusion. Nine specimens of each clay were then fired at 1850 deg, 1950 deg, and 2050 deg F. After firing, specimens were allowed to age a few days to observe their stability. Samples 1, 4, and 6 were observed to slake off almost immediately, and continued to do so until the specimen was completely disintegrated. Specimens 11a, 11b, and 11c began to show pop-off defects after aging a few days. Both of these problems are due to excess $CaCO_3$ being present in the clays. The carbonate is converted to the oxide during the firing operation, and upon cooling and being exposed to air, the oxide hydrates into $Ca\ (OH)_2$. Samples 1, 4, 6, 11a, 11b, and 11c are not likely candidates for brick clays. Data from the pressed bars are given in Tables B1 and B2.

2. The remaining samples (8, 9a, 9b, and 10) were prepared for extrusion. Sample 10 had little if any clay particles present; therefore it was mixed with 9a to form an extrudable mixture of 33 percent 9a and 67 percent 10. The bars were extruded, dried, and then fired at 2050 deg F. All of the samples extruded very well, dried without any drying cracks, and matured at 2050 deg F. 9a and 9b exhibited some bloating during firing although the dry pressed bars of 9a and 9b did not bloat on firing at the same temperature. The bloating could be due to incomplete drying prior to firing. Data for the extruded bars are given in Tables B3 and B4. These data along with the excellent extrudability, drying properties, green strength, and dry strength show that clays 8, 9a, and 9b are suitable for commercial brick. In my opinion there are clays being utilized for brick manufacture in the U.S. that are not as desirable as these clays.

3. Additional work needs to be done to optimize the potential of these clays. This work includes:

TABLE B1

WEIGHT LOSS ON FIRING, (%), PRESSED BARS

Clay Number	Firing Temperature, F 1850	1950	2050
8	24.4	25.2	24.8
9A	29.6	32.2	33.1
9B	28.2	28.8	28.0
10	22.2	21.2	22.1
11A	19.2	19.3	18.6
11B	23.5	23.6	23.5
11C	30.3	29.4	29.5

TABLE B2

FIRING SHRINKAGE, (%), PRESSED BARS

Clay Number	Firing Temperature, F 1850	1950	2050
8	3.2	3.4	10.6
9A	2.0	2.6	3.9
9B	2.2	1.8	2.7
10	4.3	6.8	10.8
11A	0.2	1.6	7.9
11B	0.9	1.2	4.3
11C	1.3	2.3	0.3

TABLE B3

EXTRUDED SAMPLE DATA*

Clay	Weight Loss on Drying, %	Weight Loss On Drying And Firing, %	Drying Shrinkage, %	Drying and Firing Shrinkage, %
8	22.0	36.0	6.5	9.8
9A	22.7	29.8	7.0	8.4
9B	21.9	37.7	7.4	9.5
33 % 9a 67 % 10	23.0	34.8	7.5	10.9

* Based on four specimens for each clay.

TABLE B4

MODULUS OF RUPTURE, PSI, EXTRUDED AND FIRED BARS

Sample	Average Modulus of Rupture, psi	Equivalent Compressive Strength, psi*
8	1040	6,000
9A	2250	11,000
9B	2635	13,900
33 % 9A 67 % 10	2550	13,500

*American Ceramix Society Journal, Volume 35, page 311, 1952

Note: ASTM compressive strength classifications of Building and Facing Bricks are:

ASTM Grade	Compressive strength, psi
SW	3000
MW	2500
NW	1500

For the Virgin Islands and surrounding area, Grade NW is adequate.

a. Efforts to decrease the slightly high drying shrinkage by the use of sand, grog, or calcined clay.

b. Efforts to decrease the maturing temperature of the clays by the addition of local fluxing materials. This will give higher strengths in addition to lowering the firing temperatures.

c. Use of commercial extrusion additives to permit the use of smaller amounts of raw clay in body mixture which will lower shrinkage and help most of the other properties of the brick.

d. Determine calcining time-temperature for the clays.

4. In my opinion, these additional studies will permit the manufacture of a quality brick at lowest cost to the manufacturer and user.

APPENDIX C: A GENERAL SUMMARY OF INDUSTRIAL DEVELOPMENT LAW

A Summary of Industrial Law. Bill No. 6643 (11th legislature of USVI).

1. This law is intended for "...the promotion of the growth, development, and diversification of the economy of the Virgin Islands; to benefit the people of the Virgin Islands...promotion of capital formation for the industrial development of the Virgin Islands; and the preservation of the environment...." This law is essentially a tax exemption and subsidy (over a specified length of time) to encourage industrial developments, employment of residents of the Virgin Islands, and obtaining goods and services from Virgin Island concerns.

2. In order to qualify there must be a minimum investment of $50,000 exclusive of inventory. The assessed value of land and previously existing buildings on this land can make up to 20 percent of this $50,000 investment. In addition the fair market value of equipment leased for a minimum term of five years can be included in the above investment. The employer must employ at least ten people (an application can be made for a waiver of this requirement). Employers must be residents (i.e., domiciled) of the Virgin Islands. Non-residents have restrictions on their length of tenure before a resident must assume the position. Residents take precedence in filling jobs. If the concern will employ non-residents and the investment exceeds $3 million, then the concern must provide educational/vocational opportunities with the end result being residents assuming the jobs held by non-residents. The investing concern must also agree to purchase goods and services from resident contractors and businesses provided those bids do not exceed by 15 percent the bids of a non-resident business or contractor. The investing concern must also comply with local environmental codes which have become more exacting in recent years. For example, a clay pit must have a 100-ft margin around the site with some form of aesthetically pleasing "screen," such as trees. This is, of course, after zoning considerations have allowed the pit operation to come to pass.

3. The benefits that the investor will realize for meeting the aforementioned conditions are tax exemptions on:

a. Real property on the certified investment property.

b. Gross receipts taxes.

c. Excise taxes on materials required to construct, alter, extend, and reconstruct the physical plant or facility.

and nontaxable subsidies:

a. Ninety percent of customs duties and other taxes paid into the Virgin Islands Treasury.

b. Ninety percent of income tax liability to the Government of the Virgin Islands derived from business.

4. These benefits will last 20 years (or prorated for longer periods but no longer than 20 years @ 50 percent benefits). If this investment is in an economically depressed area (e.g., Frederiksted) another 5 years of 100 percent benefits are authorized.