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SEDIMENTOLOGICAL SURVEY ON SOME SAMPLES OFF SOUTHWESTERN LITTORAL OF SAINT VINCENT ISLAND [1]

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Saint Vincent Island, situated in the Caribbean Sea on latitude 13°10'N and longitude 60°97'W , lies midway between Grenada and St. Lucia and almost on the same latitude as Barbados, which is about 87 miles away.

About sixty samples of the southwestern littoral of that island have been collected by scientists and technicians from the Department of Geology of the University College of London, in May 1971 , using the launch Providence of the H. M. S. Hecla. All these samples have been observed macroscopically, from which twenty seven have been chosen for grain size analysis, taking into account depth, components and the positions of the island's three main embayments. No samples have been collected in Kingstown Bay, but for the purpose of this study this is not relevant, because that bay can afford the only anchorage of any importance in the island and the aspects of the sediments should be quite different.

A separation of heavy minerals and the study of sediments under a binocular microscope have been carried out, as well as chemical and petrological analysis. All the results together with some reference papers have been discussed, in an attempt to ascertain the contribution made by the volcanic material, and whether they are more closely related to river transportation or other means of transport.

GENERAL ASPECTS OF THE AREA

Morphology

The topographic surface of Saint Vincent-Island is irregular and in most places steep and precipitous; it consists of a central range of mountains, throwing off lateral spurs to the sea, this is particularly marked on the coast under observation. The chief features of topographic interest are the Soufrière mountains at the North end of the island, with numerous peaks one of which is the Soufrière Volcano, the most recently active of all West Indian volcanoes. Its crater is approximately circular, measuring 3 miles in circumference and rising to about 2,700 ft .

Numerous rivers dissect the island, the chief being Calliaqua, York and Buccament rivers, from whose estuaries and bays the samples under analysis have been collected. The rivers enter the sea through narrow gorge like ravines (figure 1) , and flat topped ridges striking ou to the sea.

The coast is generally bold and rocky (Wurtz, 1964) but in many places there are sandy bays, such as Calliaqua Bay.

Geology

Volcanic conglomerates, breccias and boulder formation alternate with tuffs, ashes and basaltic lava flows (Earle, 1924) . The lava flows vary in thickness from 40 — 20 ft and show columnar jointing as seen near Camdem Bay. In the southwestern littoral, among the more important lava flows is that forming Cane Garden Point, at the south side of Kingstown Bay. The rocks are typical Augite and Olivine basalts. On the east side of the island pyroclastic rocks dominate over massive lavas.

In the hills around Kingstown finer ash beds and laterite decomposition products of igneous rocks "in situ", also predominate.

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(1) — This contribution is a resumed version of a paper that was submitted to the University of London, in partial fulfillment of the requirements for Master of Science degree.

As stated by Earle (1924), there is a marked resemblance between the latest erupted rocks and those laid down earlier on the island.

The last violent eruption of the Surfrière Volcano occurred in 1902 and it was of the explosive variety, consisting of ash, scoriae, cinders, lapilli etc., lava flow being entirely absent.

There are no limestones or marine sediment developed on St. Vincent, and there is no evidence of folding or violent earth movements other than volcanic.

About the origin of the Lesser Antilles, it is said that if the continents are regarded as having drifted westward into the Pacific Ocean basin, the larger islands of the Caribbean are the fragments of the narrow Mezosoic eugeosynclinical belts, if we consider the connections existed between North and South America and Antarctica at the beginning of Tertiary times.

Currents

Wurts (1964) studying this area said that at a distance of 5 miles or more from the coast the tidal currents are negligible, and within one mile of the coast tidal streams predominate over the current.

According to Wurst, at Calliaqua Bay the northwesterly tidal stream attains a velocity of about 2¼ knots, and at Cane Garden Point and Johnson Point 1½ and 1¾ knots, respectively. In spring there is an opposite stream south going off Calliaqua and south-southwest going off Cane Garden and Johnson Point, and obtains a rate of 1, 2 and 1¾, respectively.

The tidal streams sweep round, sometimes attaining a rate of nearly two knots.

Bathymetry

The bathymetry of the studied area has been carried out using a "Kelvin Hughes Echo Sounder" types 171-172 and also using side--scan sonar. The intention was to examine the formation of sand wave which would be a good indication of bottom currents and resulting movement of volcanic minerals.

On the other hand, figure 1 also shows the supposed isobathymetric lines, where there was great concentration of stations (all the samples were taken for helping the drawing of these isobathymetric lines because no other source of depth information of this specific area has been found). The exact position and depth of each station can be seen in table I.

TECHNIQUE FOR SAMPLES RECOVERY

The samples were recovered using a Van Veen Grab which has the following specifications: horizontal locking bar = 10 inches; horizontal diameter (closed) 8 inches and open = 14 inches, approximately.

The navigation has been made in the launch already referred. The sextant was used for position fixing and enabled a high degree of accuracy, involving the measurement of the horizontal angles between three points of known position. The proximity of all the stations to the coast has enabled accurate fixes at all sample stations.

LABORATORY TREATMENT OF SEDIMENT SAMPLES

Preparation for Wet Sieving

In the laboratory the samples were stored in bulk with alcohol for preserving the microfauna. The samples were split into two parts by comparing their volumes, having been washed with fresh water on a sieve of mesh 63 micra.

Therefore no sample has been taken in equal quantity. Hexametaphosphate, the common dispersant for clays, has been added to the samples. The weight of clay plus silt was obtained by dividing the amount of the total mud fraction into two parts, this has been the only way we found to get approximately proportional parts of each sample, for size greater than and less than 63 micra. After separation the sands were dried at a temperature of 60°C. The mud fraction takes at least one day to settle and is then decanted off and dried at a temperature of 80°C. Higher temperature may destroy the organic matter in the samples.

Mechanical Sieving

The coarse fraction (greater than 63 micra) was then mechanically shaken (Rotap Shakes) through a bank of twelve 8 inches diameter brass sieves for fifteen minutes. The sediment on each sieve was weighed and recorded. The mesh sizes selected, correspond to the standard phi class intervals proposed by Folk (1957) — see table II.

SEDIMENTARY PARAMETERS

The statistical parameters were obtained by plotting the cumulative curves of the samples on semi-log paper (figure 2). These parameters include measures of average size expressed as median, mean and mode; measure of uniformity (sorting of the sediments); measure of skewness or asymmetry and measures of Kurtosis or peakdness. The results are shown in table III.

Median

This value is expressed either in phi units or in millimetres and corresponds to the 50% mark on the cumulative distribution. As calculating of median does not include the extremes of the curve it is invalid for bimodal samples. In table III the accuracy of this measure is shown by comparing its values

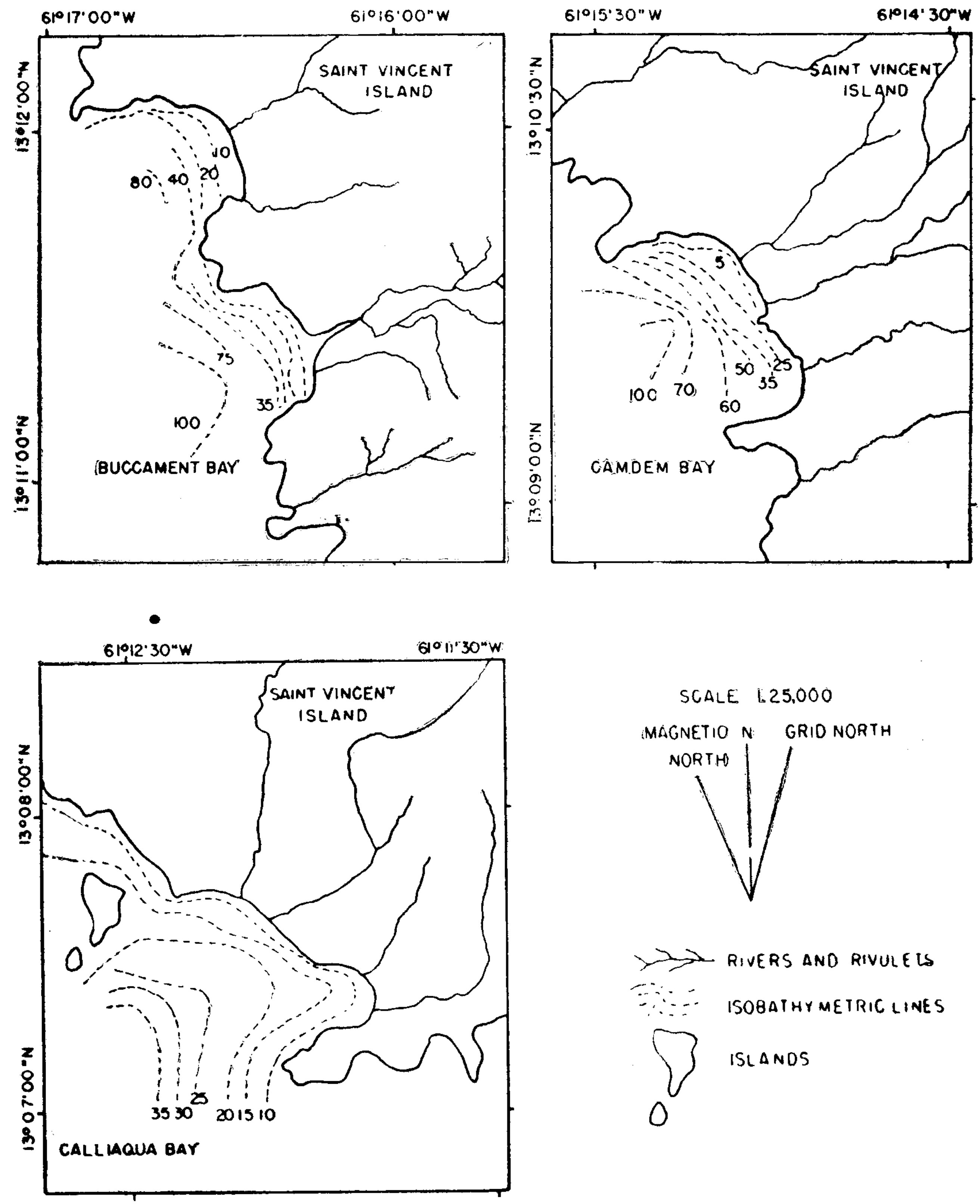


Figure 1 — Isobathymetric lines of Buccament, Camdem and Calliaqua Bays, worked out by the values of the depth of each grab station.

TABLE I

Exact position of the stations where the samples were collected.

Stations	Depth (m)	Latitude (N)	Longitude (W)
2089	18	13°10'11"	61°15'14"
2090	33	13°10'08"	61°15'21"
2091	41	13°10'07"	61°15'22"
2092	95	13°09'95"	61°15'29"
2093	32	13°09'93"	61°15'09"
2094	75	13°09'87"	61°15'23"
2095	25	13°09'81"	61°14'97"
2096	50	13°09'83"	61°15'01"
2099	71	13°11'53"	61°16'59"
2101	9	13°11'55"	61°16'47"
2103	14	13°11'47"	61°16'30"
2108	18	13°11'40"	61°16'32"
2110	8	13°11'28"	61°16'25"
2112	97	13°11'30"	61°16'45"
2114	47	13°11'58"	61°16'74"
2115	27	13°12'03"	61°16'72"
2118	9	13°11'92"	61°16'48"
2122	38	13°11'78"	61°16'55"
2124	78	13°11'86"	61°16'65"
2132	13	13°13'87"	61°16'73"
2140	55	13°12'05"	61°17'00"
2146	62	13°10'08"	61°15'48"
2150	9½	13°07'52"	61°11'62"
2152	11	13°07'40"	61°11'80"
2155	36	13°07'48"	61°12'28"
2158	14	13°07'69"	61°11'99"
2161	13	13°07'87"	61°12'33"

with those of the mean. The correlation is consistent, except for sample 2094 which is strongly bimodal.

Mean

Among the measure of average grain size, the mean is probably the most sensitive to environmental differences. It indicates the central tendency of the average size of the sediment; in terms of energy, it means the velocity of depositing agent. It is also dependent however upon the size distribution of the available source material.

In this paper we have used the Graphic Mean (Folk 1957), given by the formula (phi 16 + phi 50 + phi 84)/3. This value has the advantage that it corresponds to the mean computed by the method of moments, and has an efficiency of 88%, compared with 74% of Inman's original formula, according to McCamon (1962).

The values of mean plotted against those of sorting (figure 3), seem to present some correlation with the well sorted, being the finer ones and the poorly sorted corresponding to the coarser ones (0 to -1 phi). From the same figure, skewness is apparently independent of the mean.

Mode

The mode is the most frequently occurring grain diameter of the sediment.

The samples were divided into two groups: unimodal, which represents the majority, and bimodal (seven samples).

A bimodal or polymodal distribution may result from extreme variation in the velocity of depositing agent, and there is no relation between mode and grain size in the samples under investigation as proved, comparing samples 2146 and 2150. The most common mode range between 2 and 3 phi, either unimodal or bimodal samples.

In Camden Bay samples 2089, 2090, 2091 (figure 4) aligned perpendicular to York River mouth show the mode in 3.00 phi, which could be an indication of constant energy in that place; sample 2092 (figure 4) show the mode in 3.78 phi, but it is possibly associated with depth.

Sorting

The formula used to measure the uniformity of sorting of the sediments was the Inclusive Graphic Standard Deviation, proposed by Folk (1957):

$$\frac{\text{phi } 84 - \text{phi } 16}{4.0} + \frac{\text{phi } 95 - \text{phi } 5}{6.6}$$

TABLE II

Mesh size and phi units used in mechanical sieving.

Mesh		Aperture (micra)	Phi units $-\log_2$ diam. (mm)	Texture
ASTM	BS			
5	4	4000	—2.0	
10	8	2000	—1.0	granule
14	12	1410	—0.5	
18	16	1000	0.0	very coarse sand
25	22	710	0.5	
35	30	500	1.0	coarse sand
45	44	354	1.5	
60	60	250	2.0	medium sand
80	85	177	2.5	
120	120	125	3.0	fine sand
170	170	88	3.5	
230	240	63	4.0	very fine sand

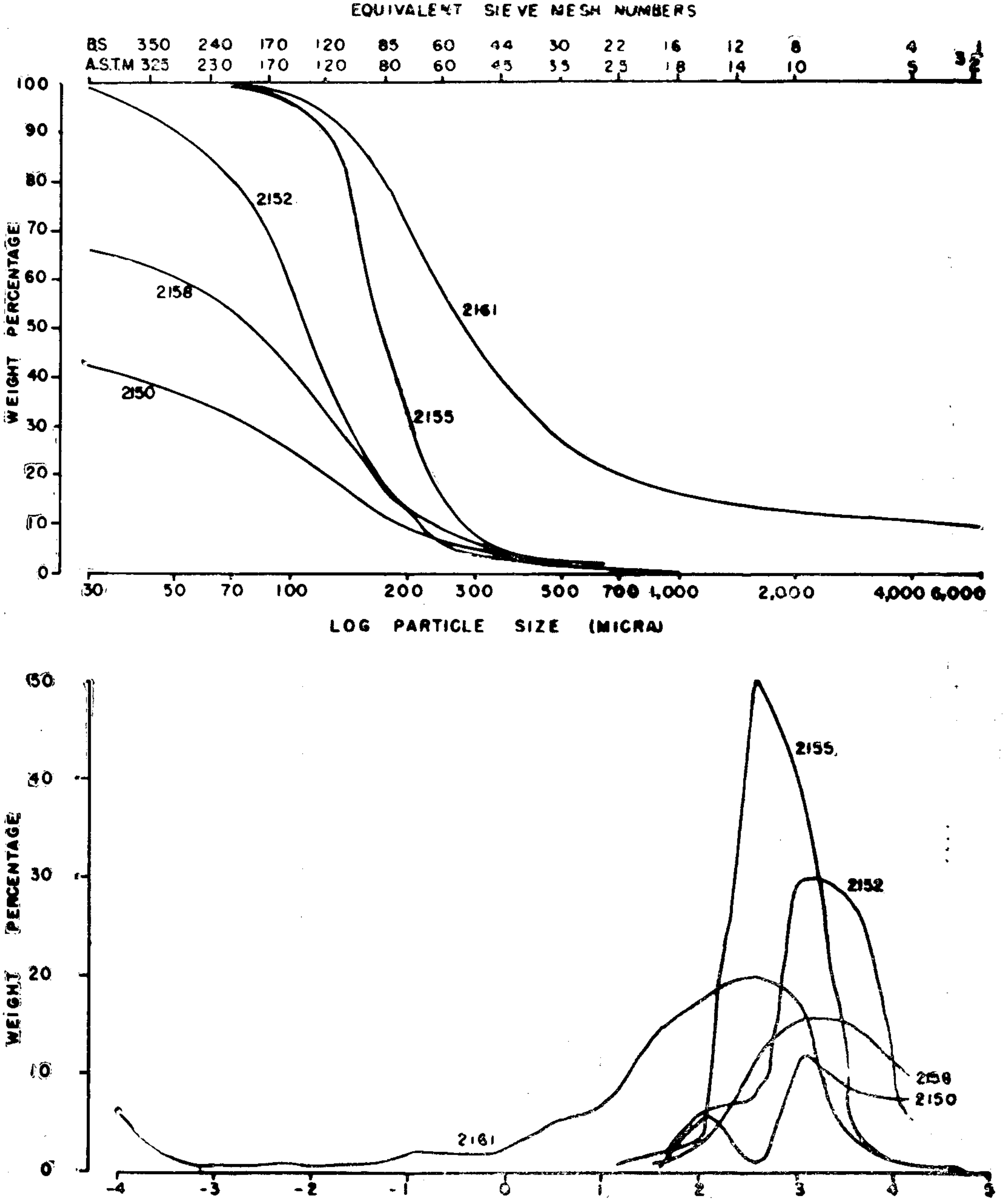


Figure 2 — Upper — Cumulative curves of the samples of Calliaqua Bay (Gradative increase in sands). Lower — modal frequency of the same samples.

Sorting has been used ever since Udden (1914) compared the ratio of sucessive classes, in histograms with the total spread as a measure of sorting. Trask (*in* Folk, 1957) suggested a measure 50 = $\sqrt{Mm\ 25/mm75}$, which was later converted to the phi scale by Krumbein — see Krumbein & Pettijohn (1966). Folk points out that this measure is inaccurate, because it ignores sorting in the "tails" of the curve. He stresses the importance of

TABLE III

Statistical parameters of the grain size analysis of the sediments.

Sample (no.)	Median (phi)	Mean (phi)	Sorting	Skewness	Kurtosis
2089	2.380	3.403	1.131	0.062	0.595
2090	2.380	2.293	0.882	0.078	0.553
2091	1.970	1.913	0.987	—0.097	0.465
2092	2.823	2.860	1.049	—0.303	0.322
2093	0.950	1.067	1.167	0.143	0.509
2094	1.700	1.500	1.617	—0.174	0.350
2095	2.500	2.337	0.931	—0.206	0.503
2096	1.250	1.183	1.617	—0 017	0.531
2099	0.450	0.477	1.478	0.040	0.503
2101	2.000	1.967	1.493	—0.029	0.437
2103	0.950	1.067	1.167	0.143	0.509
2108	1.750	1.777	0.978	0.036	0.527
2110	2.750	2.713	1.022	—0.830	0.418
2112	2.130	2.403	1.323	0.303	0.684
2114	0.750	0.817	1.108	0.119	0.565
2115	0.850	0.867	1.237	0.017	0.458
2118	2.870	2.870	0.862	0.016	0.554
2122	0.150	0.193	2.067	0.212	0.316
2124	2.600	2.400	1.108	0.386	0.288
2146	0.250	0.357	2.178	0.412	0.378
2150	—	—	—	—	—
2152	3.130	3.264	0.774	0.228	0.769
2155	—	—	—	—	—
2158	2.480	2.487	0.347	0.034	0.426
2161	1.760	1.830	1.172	—	—

including as much of the curve as possible.

The scale used by Folk (1957) for sorting classification is as follows:

under 0.35 phi = very well sorted
0.35 — 0.50 phi = well sorted
0.50 — 0.71 phi = moderately well sorted
0.71 — 1.00 phi = moderately sorted
1.00 — 2.00 phi = poorly sorted
2.00 — 4.00 phi = very poorly sorted
over 4.00 phi = extremely poorly sorted

Based on this classification, the samples were divided into four groups: very well sorted, poorly and very poorly sorted. These parameters may be related to the size of the source materials. In Calliaqua Bay, where there are sandy beaches, very well sorted samples occur off shore (generally the materials of beaches are very well sorted). Plotting mean values against sorting shows some dependence between them, as referred to before. Conversely, the coefficient of correlation (worked out by computer programme) was 0.76 which reveals a poor correlation. Udden (*in* Kidd, 1971) points out that the difference in density of the fluid and the transported grains is important in the sorting processes. He reasoned that the greater the difference, the better sorted the distribution. This point is discussed later, in connection with heavy minerals.

Skewness

Skewness measures the asymmetry of the frequency distribution and marks the position of the mean with respect to the median. If the sediment is coarsely skewed, it means that the mean is toward the coarser side of the median. Early measures of this parameter was given by Pettijohn (phi quartile skewness) — see Kumbrein & Pettijohn (1966) followed by Inman (*in* Inman *et al.*, 1963) with the Graphic Skewness. Folk (1957) points out that the first is not sorting independent, being dependent on sorting, and the second measures only the skewness in the central part of the curve. Inclusive Graphic Skewness (combining Inman's measure with an analogous for tails) has been used in this project and is represented by

$$SK = \frac{\text{phi } 16 + \text{phi } 84 - 2 \text{ phi } 50}{2\,(\text{phi } 84 - \text{phi } 16)} + \frac{\text{phi } 5 + \text{phi } 95 - \text{phi } 50}{2\,(\text{phi } 95 - \text{phi } 5)}$$

A positive value means that the amount of fine exceeds the coarser fraction; conversely, a negative value means the coarse fraction is dominant. Skewness expresses the result of mixing of two normal populations in different proportions.

The following limits were used to define the skewness of the samples:

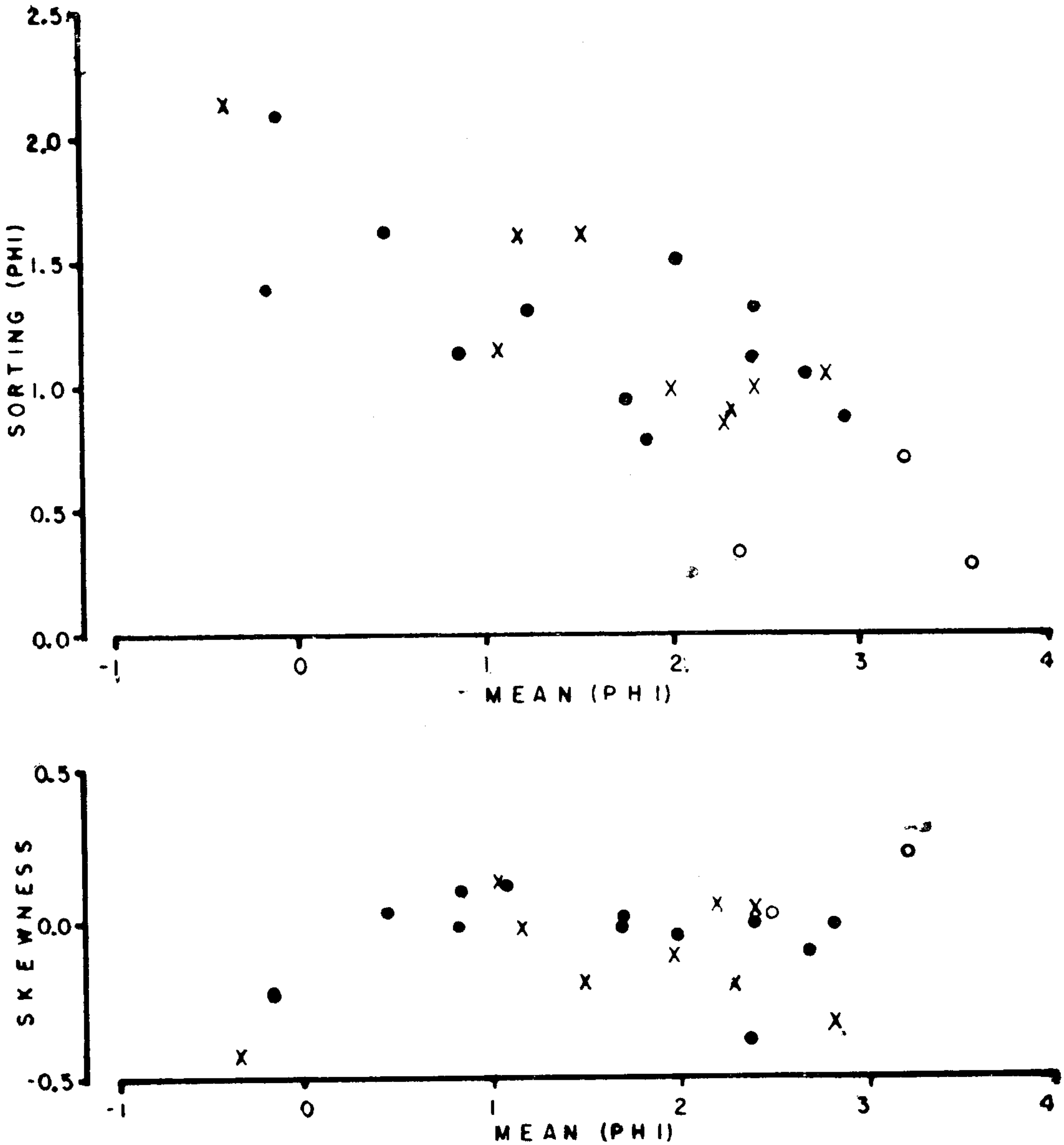


Figure 3 — Values of mean plotted against sorting and skewness. "x" — samples from Camdem Bay, "." — from Buccament Bay and "o" from Calliaqua Bay.

from + 1.00 to + 0.30 = strongly fine skewed
from + 0.30 to + 0.10 = fine skewed
from + 0.10 to — 0.10 = near symmetrical
from — 0.10 to — 0.30 = coarse skewed
from — 0.30 to — 1.00 = strongly coarse skewed

From the above limits it is assumed that the curves are symmetrical at 0.0 and the degree of asymmetry increases, as far as the skewness departs from 0.0. The samples were divided into three main groups: fine skewed, near symmetrical and coarse skewed; few samples were strongly coarse skewed. Values of skewness were plotted against kurtosis, and show a good correlation, in spite of the values of kurtosis varying over very short distances. Skewness greater or less than zero, means kurtosis is greater or less than 0.4 (figure 5). The relation between skewness and sorting in figure 6 shows little correlation. The nearly

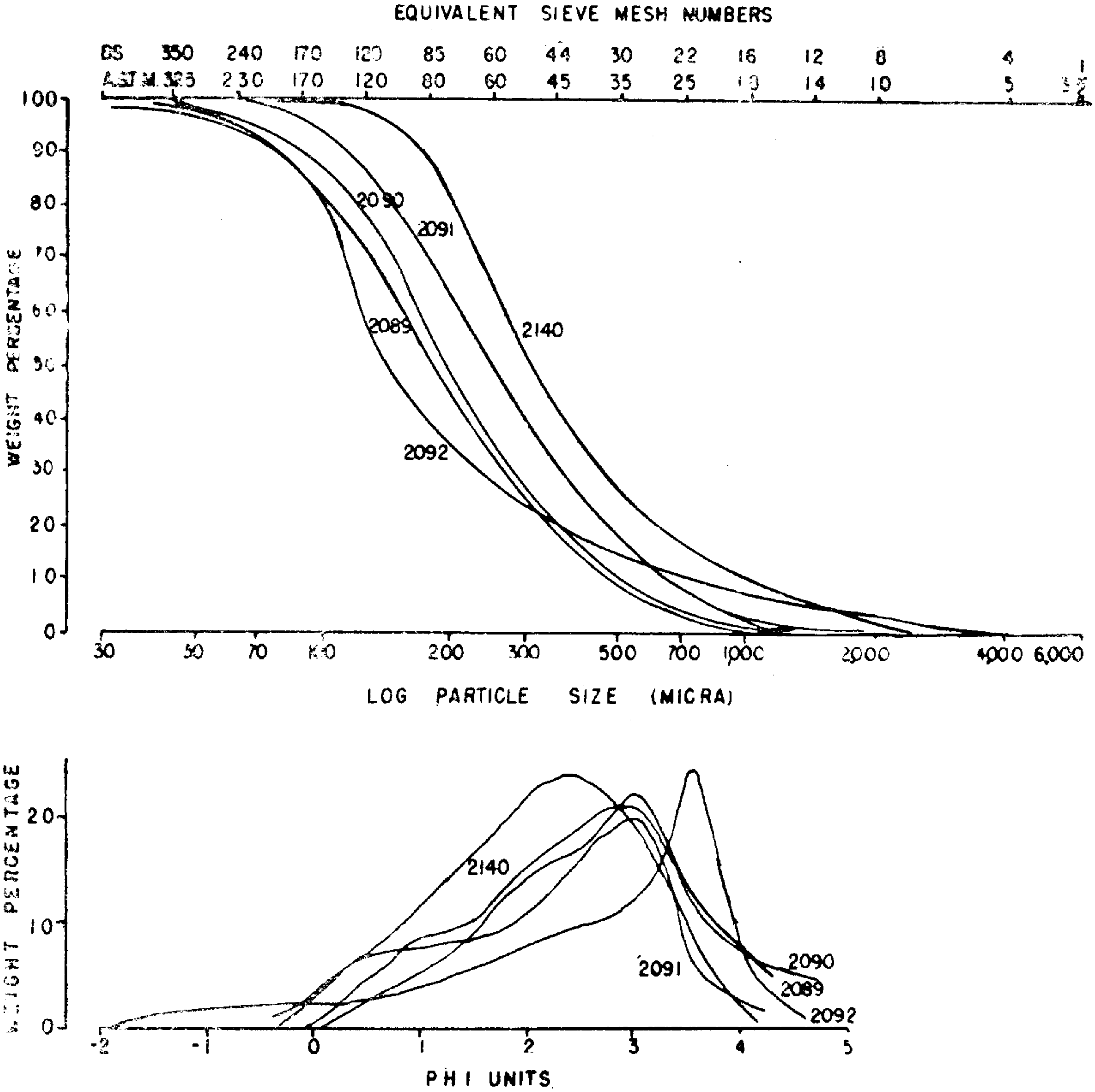


Figure 4 — Upper — Cumulative curves of samples of Camdem Bay, all of them presenting almost the same distribution, with the exception of sample 2092. Lower — Coincidence of mode in three of aproximately the same depth.

symmetrical samples range between very well sorted to poorly sorted.

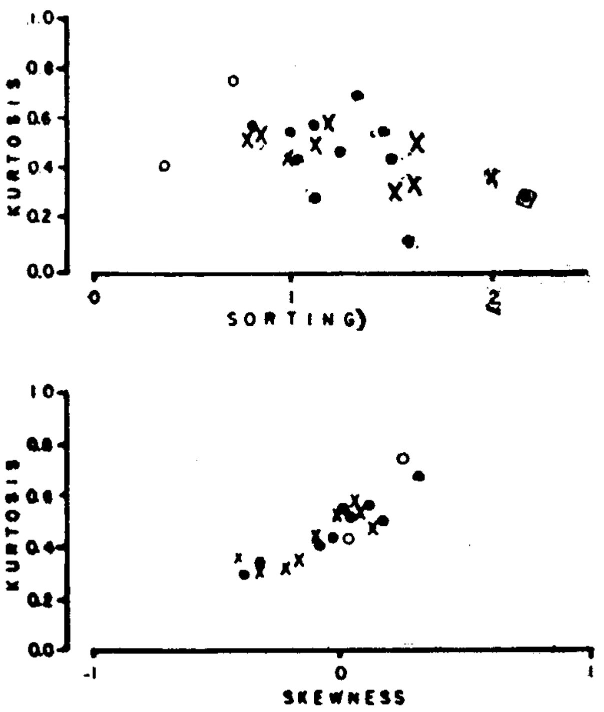
Kurtosis

Kurtosis is a measure of peakdness of a size frequency curve, or the measure of departure from the Guassian Normal probability. The formula used here was that indicated by Folk (1957)

$$Kg = \frac{\text{phi } 95 - \text{phi } 5}{2.44\ (\text{phi } 75 - \text{phi } 25)}$$

limits — under 0.67 = very platykurtic
0.67 = 0.90 = platykurtic
0.90 = 1.11 = mesokurtic
1.11 = 1.50 = leptokurtic
1.50 = 3.00 = very leptokurtic
over 3.00 = extremely platykurtic

Samples under research range from 0.3 to 0.6, which confirms that they are all very platykurtic, with the exception of samples 2112 and 2152 that range between 0.67 and 0.90 (platykurtic); the latest ones present the same value for skewness. This is appa-

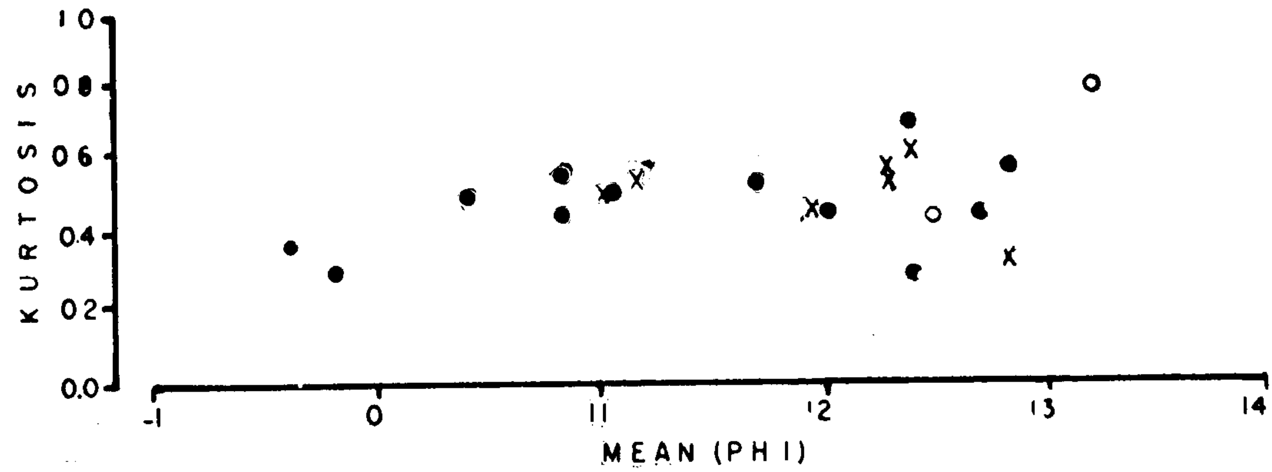


rently the only correlation. This parameter would be very useful in delimiting mixing and sorting zones, and zones of turbulence by both wind and wave action. Friedman (*in* Kidd, 1971) showed that most sands were leptokurtic and it is not the case in this area. Kendall and Stuart (*in* Sahu, 1962) stated that kurtosis should not be interpreted as describing the peakdness, because it indicates really a ratio of sorting within the central 90% of the distribution of the central 50%.

MICROSCOPIC ANALYSIS

The microscopic analysis of the sand fraction might indicate the different sedimentary environments using the general aspects of the planktonic and benthonic biofacies, land derived materials or authigenic mineral concentrations.

Figure 5 — Spotted diagram showing some correlation between skewness and kurtosis, but no marked dependency between sorting and kurtosis.



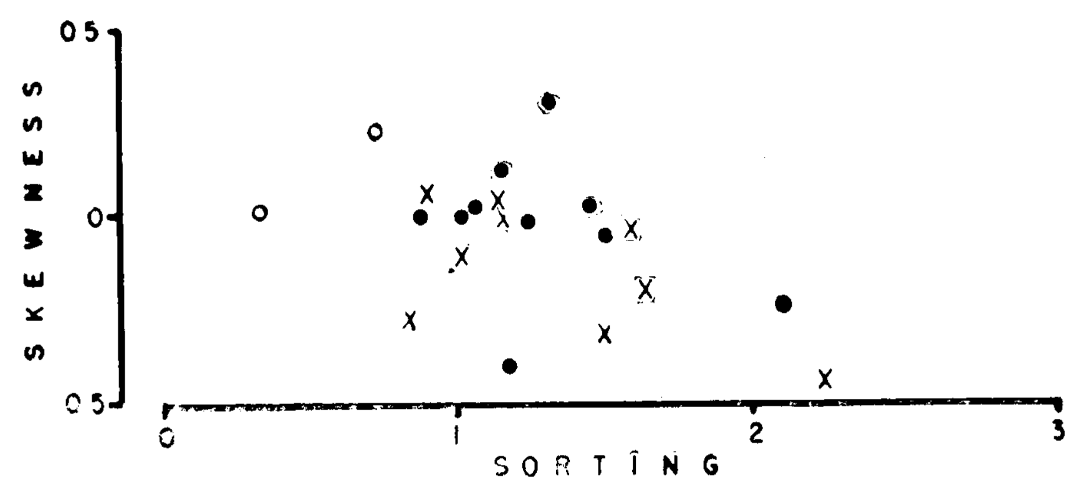


Figure 6 — The distribution of points about the line of value zero (skewness) ranges between very well sorted to poorly sorted. It means that there is no correlation between these values.

At first, each fraction of all samples used in grain size analysis have been studied by a brief binocular microscopic examination. After this, 12 samples (4 of each main bay) have been chosen, and a study made of the mineralogy and shape. The petrological microscope has been used for the determination of the principal heavy minerals.

Chief Components of the Sediments

The sediments could be divided into four categories, on the basis of its components: biogenous materials derived from the skeletons of molluscs, coral, calcareous algae, bryozoans etc.; terrigeneous material derived from erosion of the volcanic formations and brought by the rivers into the sea; non-volcanic terrigeneous material; and mixture of biogenous and volcanic material.

The relative abundance of the minerals was determined by point counting and expressed as percentages. Weight percentages give unsatisfactory data, especially where calcareous fragments were abundant (as in the coarse fractions).

Twelve samples were studied in detail and classified according to size corresponding to granule; very coarse, coarse, medium, fine and very fine fraction.

Calcareous fragments were assumed to be all calcareous elements, with the exception of planktonic and benthonic foraminiferids. The principal components of these elements are mollusc shells, corals, bryzoans, echinoderms, pteropods, algae. The algae were not present in samples close to the mouth of the rivers, because they require clear water in order to survive. They are characterized by short ramified branches compdletely broken and worn. They may represent fragments of *Halymeda* Lamouroux. They are associated with the fine fraction, possibly due to its rapid disintegration.

Volcanic rock fragments show a greenish colour. These fragments were treated with concentrated hydrochloric acid, and they do not show any effervescency but the solution became bright yellow, which suggests ferromagnesium components. There are some porous fragments among them.

Rock fragments include all those other than volcanic rock fragments, such as sandstones and conglomerates.

The distinction between quartz and calcite was made using concentrated hydrochloric acid. Calcite generally also presented an opaque aspect, whereas quartz has a vitreous aspect sometimes very well shaped with microstriations. The mechanical hardness preserves quartz, lack of cleavage and its chemical stability. Some crystals are often penetrated by channels produced perhaps, when the surrounding melt was still very hot. Quartz was invariably colourless and completely transparent.

In general, feldspars have a milky texture and exhibit three directions of cleavage. Orthoclase is the stable form found in most igneous rocks, which have cooled more slowly.

Dark minerals were assumed to include all the minerals with colours varying from green to yellow and brown, that appear to be derived from volcanic rocks. Generally the growth of the various minerals have interfered with one another, so that they form granular aggregates in which very few grains are euhedral.

Vegetals were the fragments of plants carried out by the rivers.

The genera and species of foraminiferids are dependent on the grain size. In the very coarse sand *Archais angulatus* Fichtel et Moll is predominant, whereas in the coarse sand *Amphistegina* Fichtel et Moll is more common. *Miliolidae* occur in some samples, and in the sediments of Calliaqua Bay there is an association of *Ammonia* Linnaeus. The planktonic foraminiferids, are associated with the fine fraction, possibly due to some currents from the open-sea penetrating the embayments.

The attempt to work out the percentage of components in each sample is shown in table IV.

Shape and Roundness

There are many factors that control shape and roundness, such as the original shape of the fragment, its structure (cleavage or bedding), the durability of the material, the maturity of the geological action to which the fragment was subjected, and the time or distance to which the action was extended.

The most common methods for determining the shape and roundness of grains involve visual comparison with images or the measurement of the diameter, surface area or volume of the grains.

The choice of method depends on the use to be made of the results, on the time available and on the size of material to be studied. In this project, owing to the lack of time for doing more accurate measurements, the visual comparison was used, according to Towbridge & Mortimore (*in* Kumbrein & Pettijohn, 1966).

The significance of the results, the difference between shape (sphericity) and roundness have been discussed for many years. Waddel (*in* Kumbrein & Pettijohn, 1966) was the first to differentiate them as two independent variables. He pointed out that roundness was an expression of sharpness of the coarseness and edges of a grain,

TABLE IV

Percentages of the components worked out on each sample.

Location	Station (no.)	Calcareous fragments	Volcanic fragments	Other rocky fragments	Vegetals	Quartz	Calcite	Feld-spars	Bentonic forami-niferids	Planctonic forami-niferids	Dark	Pellet
Calliaqua Bay	2150	25	—	—	35	24	1	2	1	—	3	18
	2152	17	2	11	15	18	—	8	12	2	9	—
	2155	7	—	18	35	20	—	—	10	—	8	2
	2158	4	—	35	40	15	—	—	—	—	5	—
Buccament Bay	2103	5	22	38	1	26	7	—	—	4	20	—
	2112	7	30	23	10	15	3	—	1	6	4	—
	2115	50	13	11	—	10	4	—	3	1	15	—
	2124	25	27	24	—	15	9	4	2	1	2	—
Camden Park	2089	2	20	35	—	40	—	6	4	1	12	—
	2094	25	20	8	—	15	4	5	4	3	15	—
	2092	9	13	22	1	16	3	8	3	5	19	—
Bay	2146	80	1	6	—	5	4	—	1	1	2	—

whereas shape is related to the form of the grain independent of the sharpness of its edges, i. e., how close the grain approaches to the sphere in form.

The degree of sphericity is an important factor, because the sphere has the smallest surface area in proportion to volume of any solid, resulting in a higher settling velocity. Sphericity also influences transportation by traction, since a sphere will roll more easily than solids of other shapes.

Samples from Calliaqua Bay are on the whole well rounded, with the coarser grades much better rounded than the finer grades. Pellets presented roundness 0.8 and sphericity 0.4 whatever fraction they were in sample 2150 . These roundness values decrease in sample 2152 and sphericity increases; this could be an indication of direction of transportation, and a decrease in roundness could be due to fracturing and chipping. Quartz in the finer fraction has a roundness 0.5 and sphericity 0.4 sometimes with a smooth and polished surface. In the northwestern part of that bay (sample 2158) quartz grains are well rounded and have good sphericity and most of them are dull, which could be due to the presence of vegetals and also because the samples were not very well washed. The volcanic fragments showed no relationship between shape and roundness.

Camden Bay (sample 2146) shows a different aspect in the quartz grains. The grains are very angular with clean glassy fracture, sometimes with a frosted and corroded surface, perhaps due to the solvent action of alkalis liberated from the decomposition of feldspars. Frequence of grain shows that only small number of feldspars were recorded. This could be due to decomposition of original ones.

In Buccament Bay there appears to be a relation between roundness and shape of the volcanic fragments. They are well rounded and have a sphericity of 0.8 in most samples with no apparent change with increasing distance from the coast.

Heavy Minerals

The proportion of heavy minerals in each bay is shown in figure 7 . For samples 2150 , 2152 , 2155 and 2158 (Calliaqua Bay), the concentration of heavy minerals increases as the grain size decreases. The larger proportion of heavy minerals occurs in the very fine fractions. Buccament Bay and Camden Bay do not show this gradual increase, and the larger proportion of heavy minerals also occurs in the very coarse fraction (sample 2095) .

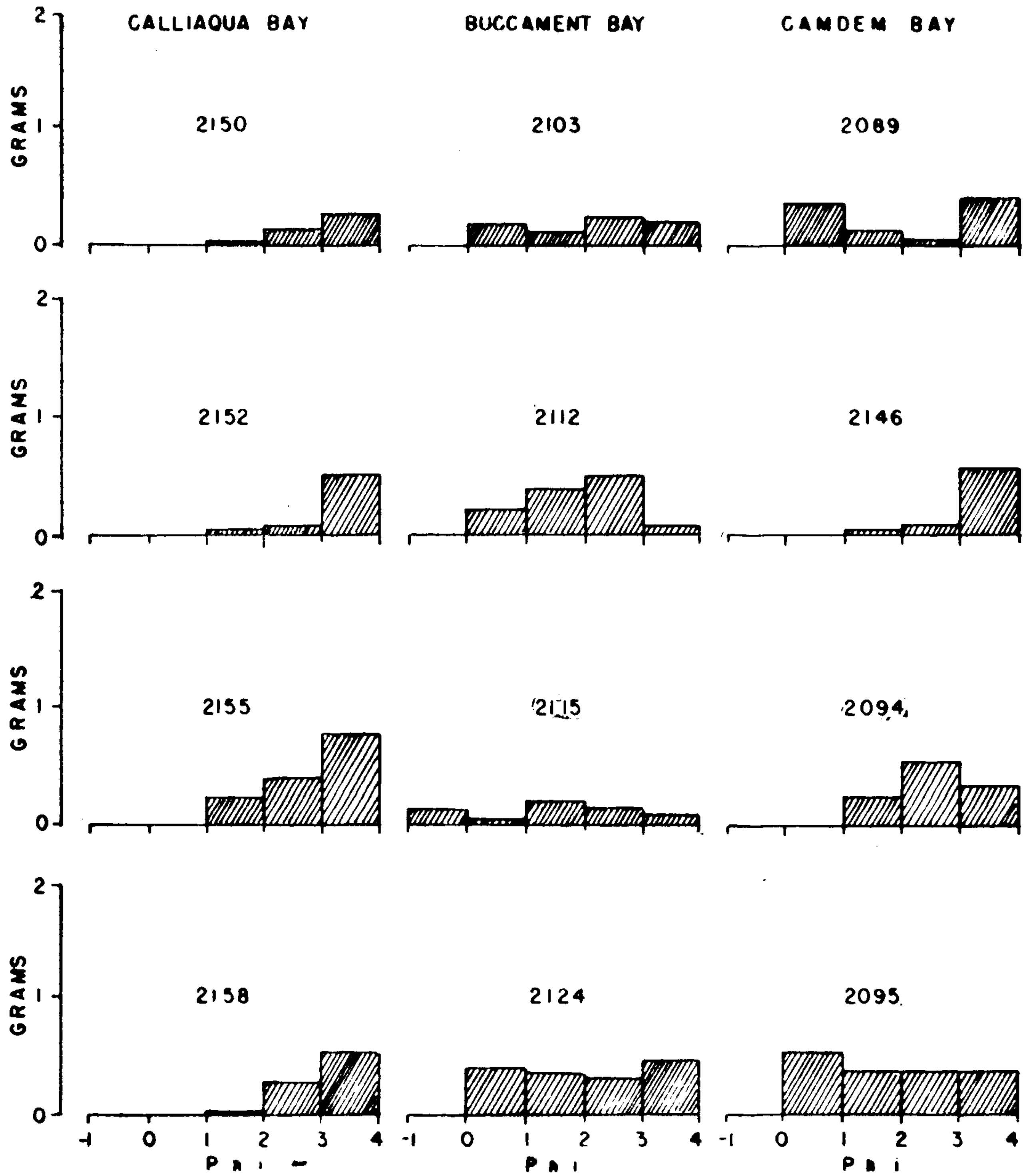


Figure 7 — Distribution of heavy minerals in the three bays.

Under the microscope the sediments of Calliqua Bay showed the heavy minerals, with some degree of rounding.

A dark mineral, possibly magnetite, predominates (when doing the titration of samples for chemical analysis, a lot of granules were stirring up because of the action of magnetic stirrer). On the other bays this dark mineral was less common.

The principal mineral is olivine, green in colour, frequently occurring as crystal, with no pleochroism but parallel extinction. At times, it occurs as irregular and much fractured grains (figure 8), showing traces of decomposition. Alteration proceeds most readily along the cracks and at the margin of crystals. A relatively common grain is a deep brown euhedral mineral, with characteristic pleochroism tending to green which could be hypersthene. Another common grain is a brown to colourless mineral, either prismatic or rounded grains. These minerals possibly correspond to the black grains seen under the binocular microscope. They are not pleochroic and have high extinction. It is possibly augite, which conforms with the geology of the island.

This association leads one to suggest that the sediments are being derived from gabbro, dolerite or basalt, in this particular case it could be from olivine basalt, the characteristic rock of the island. The opaque minerals, magnetite and ilmenite both occurring in igneous rocks, especially basic and ultrabasic type, as a possible source of derivation.

CHEMICAL ANALYSIS

Only two samples have been taken for calcium carbonate analysis. The results are not worth of mention here (see table V) .

DISCUSSION

Calliaqua Bay

The distribution of sediments in this bay shows that in the northwestern part, the sediments are predominantly mud, with a small portion of very fine sand. Towards the northwestern entrance sediments become gradually more sandy. This relation is shown in figure 9 . The sediments near the coast are very well sorted, with a near symmetrical distribution and classified according to the mean, which ranges between 1.0 and 2.0 phi (figures 10-12) . Heavy minerals are distributed mainly in the very fine fraction, and the isobathymetric lines are shallower than elsewhere in the studied area. The beaches are very sandy, which are usually very well sorted. The tidal streams predominate over currents, thus this bay could receive a great contribution, either from degradation of beaches or direct supply from rivers. The first process would occur as follows: the back swash from the beach during ebb tide has a velocity sufficient to elutriate silt grains, which may collect into rivulets eroding small rill channels across the beach. Some water is drawn by capillary action to the sand surface. Sediments are moved on, off and along the beaches as either bed load or suspended load under the action of waves or tide streams. When an incoming oscillatory wave breaks or spills in the plunge zone, it swashes up the foreshore, and there is a diminution of velocity, which is a function mainly of the beach gradient.

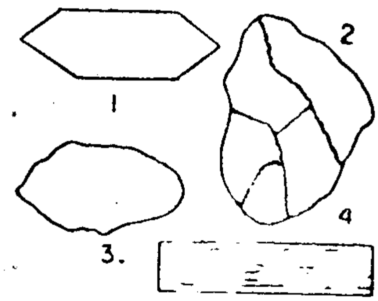


Figure 8 — The most characteristic mineral grains of the studied slides. 1 — olivine, 2 — broken olivine, 3 — clynopiroxene, 4 — hypersthene.

The agrading or degrading of a beach and the value of the beach gradient is a function of several variables, one of which is the position of the ground water table under the beach. A degraded beach may be in equilibrium during the saturated state, but may be agraded when dry and normal wave action returns. A high water table results in pronounced beach erosion, conversely a low water table may result in pronounced agradation of foreshore. Hence the humidity or dryness of

TABLE V

Values of $CaCO_3$ and CO_3 in a shallow and deep sample.

Shallow sample (2089)			Deep sample (2092)		
Micra	$\%CO_3$	$\%CaCO_3$	Mesh (B.S.)	$\%CO_3$	$\%CaCO_3$
2000	13.58	22.62	8	6.20	10.32
1410	17.50	29.15	12	6.20	10.32
1000	10.93	18.20	16	7.93	13.21
710	6.20	10.32	30	13.14	24.74
500	12.40	20.60	52	11.10	18.49
354	12.41	20.67	60	6.51	10.84
250	3.01	4.99	72	0.30	0.49
177	12.10	20.15	85	9.71	16.17
125	14.80	7.98	100	0.47	0.78
88	1.78	2.96	150	2.08	3.46
62	0.75	1.19	240	9.20	15.32
PAN	1.22	2.03	PAN	5.52	9.31

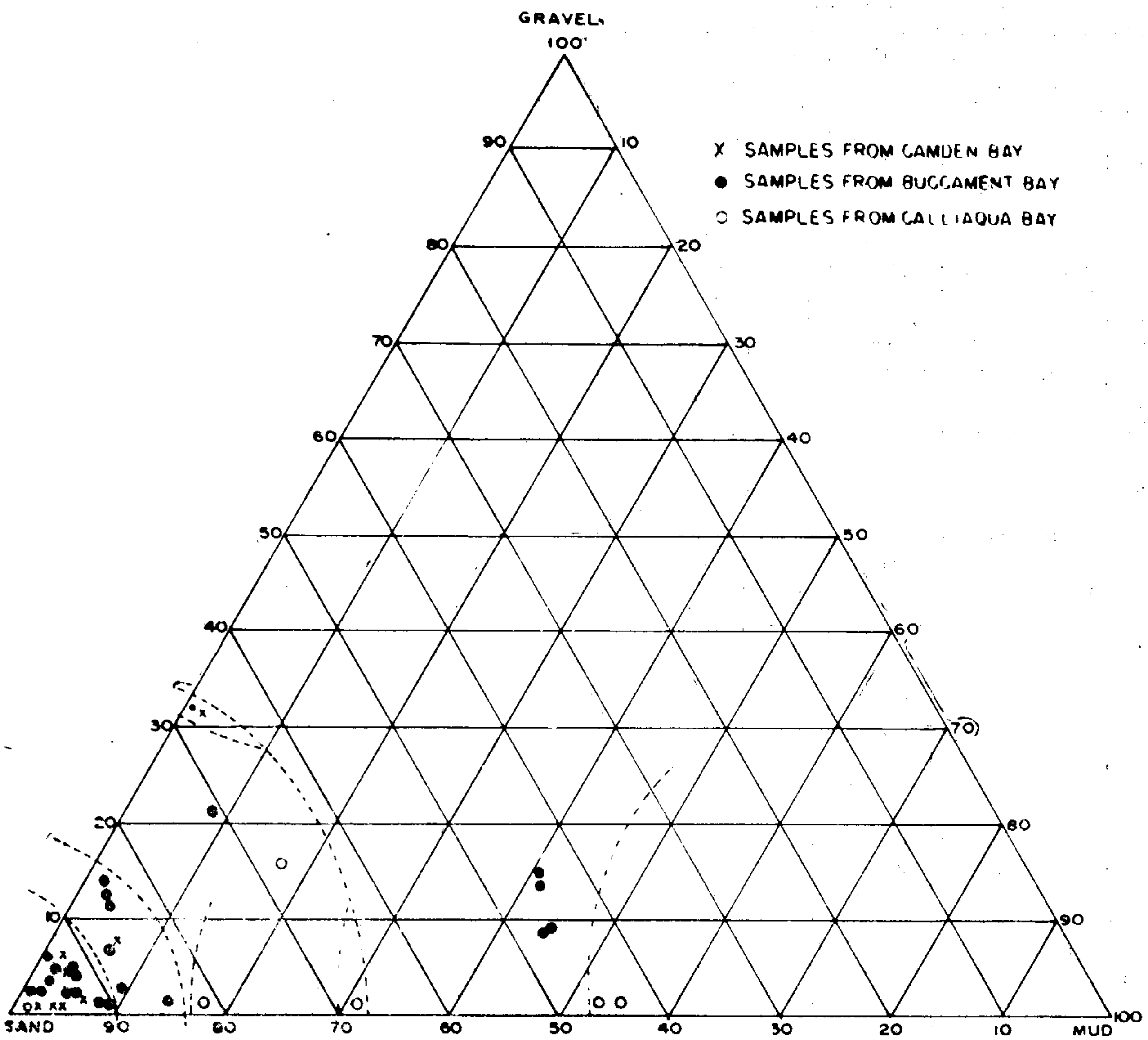


Figure 9 — Triangular diagram providing a good clue on the distribution of the texture of sediments on the three embayments referred to above.

the beaches contributed an important factor to its erosion or agradation. There is a lack of data, however, on features of this bay, so these processes cannot be confirmed.

Camden Park Bay

Samples of this bay are predominantly sandy and the only one which contains a great amount of gravel does not seem to reflect an increase in the energy of the environment, rather it is asociated with the carbonate content. Figure 11 shows that there is some relation between composition and sorting: poor sorting characterizes the predominance of volcanic sediments and moderate sorting characterizes the calcareous ones. Then, sorting here, does not indicate a fluctuation in the kinetic energy conditions of the depositing agent, but it depends only on the source of materials. Comparing figures 11 and 1 , there is a tendency of fine sand to exceed the coarse one in the down isobath direction. The bathymetry of this bay attains 100 m within the embayment, whereas in Calliaqua Bay it reaches only about 35 metres. Here, there are no sandy beaches, only a bold and rocky coast (figure 13) . This suggests some relation between the lithology on land and bathymetry of the bays.

Sample 2146 is classified as very coarse sand (figure 10) very poorly sorted (figure 11) and strongly coarse skewed (figure 12) , and is still bimodal. At first it seems to be a result of extreme variations in velocity of depositing action; however it is more likely due to the size of the organic particles. In some instances it is difficult to decipher whether a true reef is being described or simply a mound like

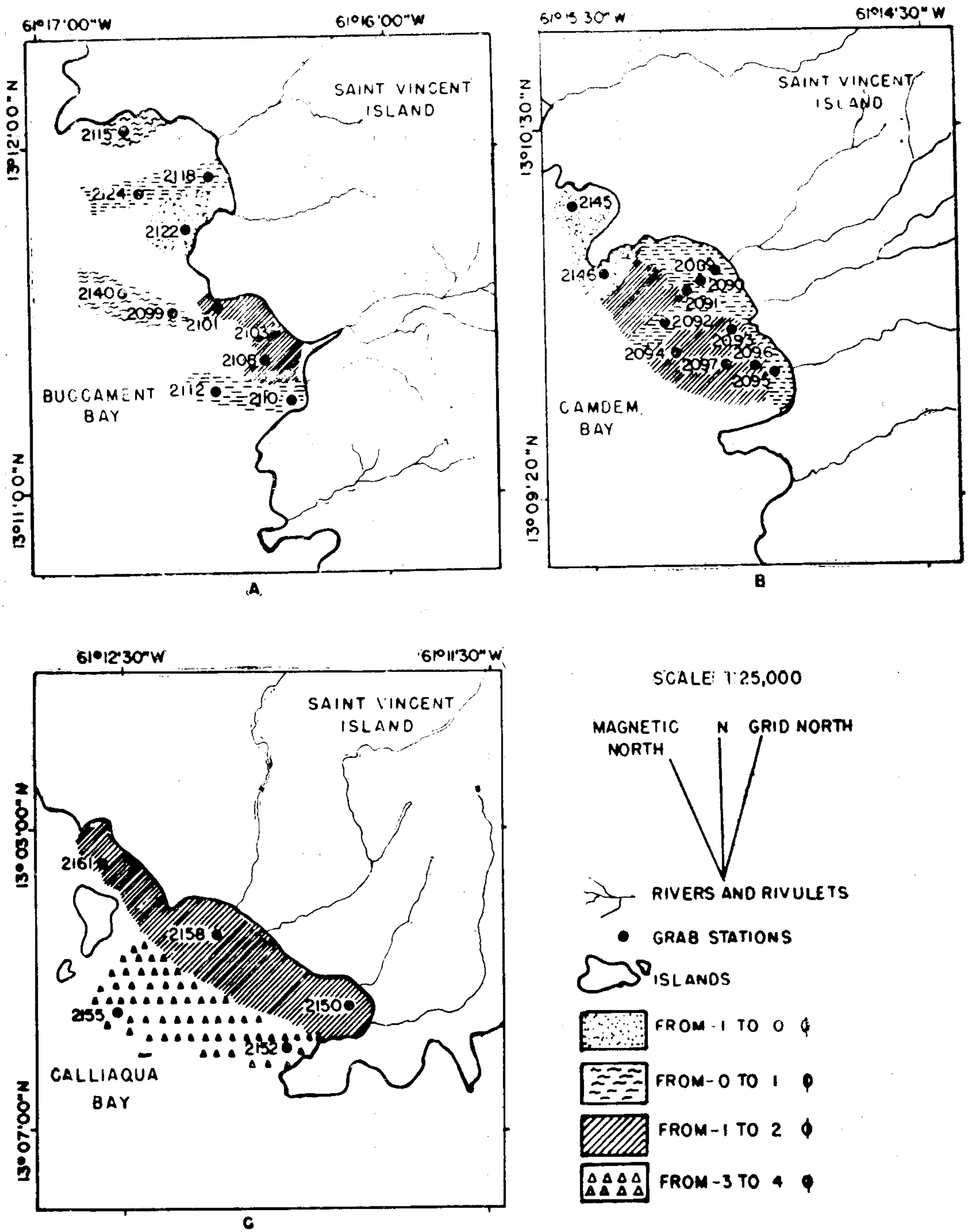


Figure 10 — Attempt to bound the mean value of the samples which have been analysed granulometrically.

structure, composed of abundant or scanty unbinding organic detritus.

Samples predominantly yellow in colour (figure 11) contain grains with a different degree of roundness and sphericity, and a different size range. The difference in size may be compensated by the differences in density, so that the grains of two different species can be hydraulically equivalent. The lighter constituents (shells) decrease in amount with decrease in size. The heavy minerals show fluctuation within the size with

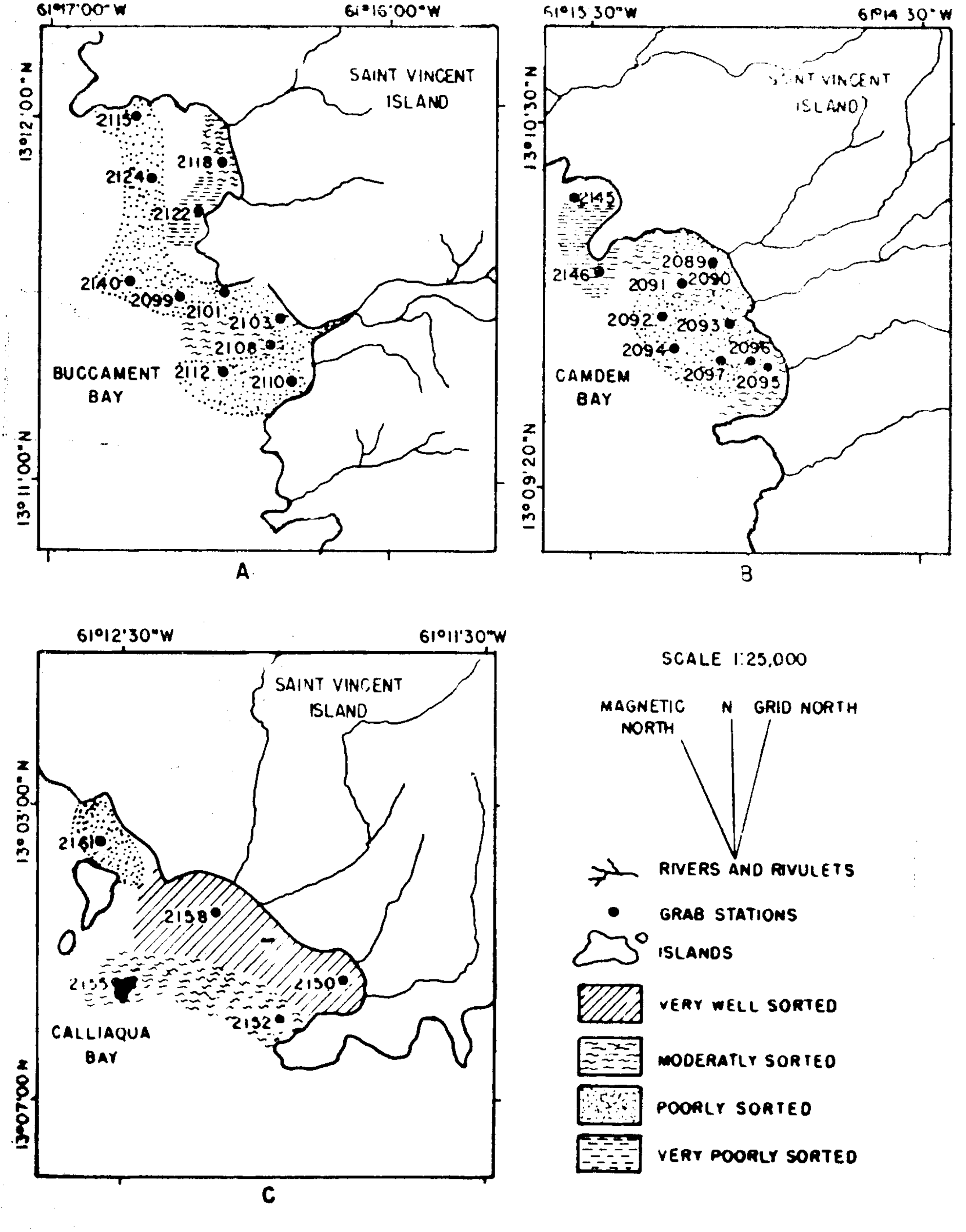


Figure 11 — Distribution of sorting measures of the bays.

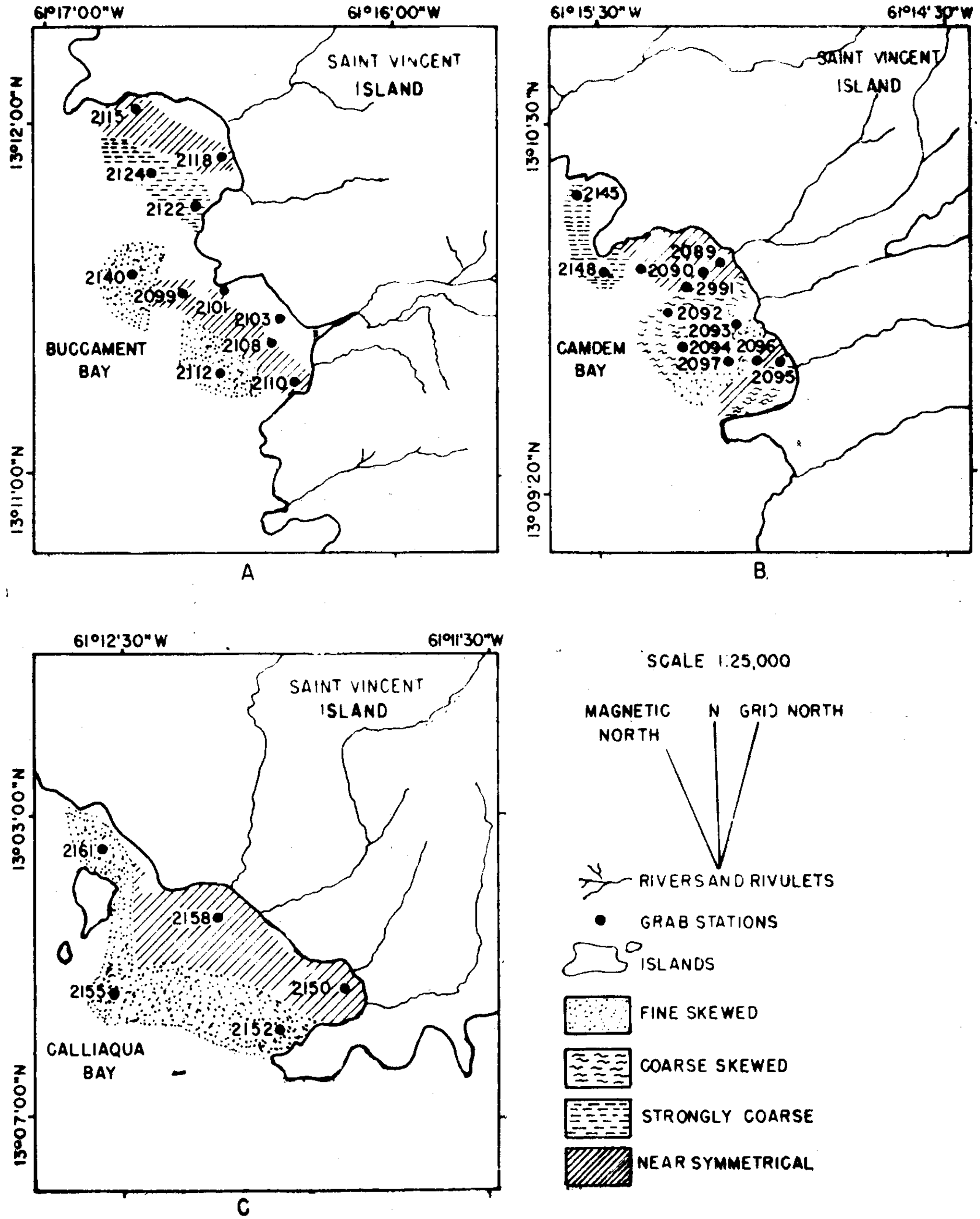


Figure 12 — Distribution of skewness on the samples. A — Buccament Bay, B — Camdem Park Bay an C — Calliaqua Bay.

respect to its accumulation. There is a clear correlation between bathymetry and volcanic fragments, as shown in figure 11 .

Buccament and Layout Bay

Samples 2103 , 2099 and 2114 are located in straight line towards the coast and are all bimodal. Here again, the last two are calca-

Figure 13 — Part north of the studied area close to the station number 2132, showing the bold and rocky aspect of the coast.

reous. The river may influence the sediments, change in energy may be reflected in the bimodal distribution of the calcareous sands (figure 14) as well as in sample 2103. Almost all the samples in these bays have shown *Globigerina*, which can be an indicator of currents from the open sea. Figure 11 shows that most of the area is composed of sands with poor sorting, either being calcareous or volcanic sand. Comparing the samples of this area with other bays (figure 9), most of them are included in the sand fraction with about 90% of sand. The calcareous sands are bounded with those from Camden Park Bay showing a gravel population. Comparing with those of Calliaqua Bay, samples lie at the bottom of the triangle, growing progressively from mud to sand.

The value of kurtosis in the whole samples seem to be useless in delimiting mixing and sorting zones and areas of turbulence, caused by both wind or wave action.

CONCLUSIONS

The bathymetry of the studied area may be correlated with the lithologies exposed on land; where there is a bold and rocky coast, the bay has a steep gradient, as in Buccament (figure 15) and Camden Park Bays (figure 16) where there are sandy beaches, the corresponding bays are a maximum of 35 m in depth (Calliaqua Bay).

Four types of sediments have been classified: (i) biogenous materials derived from the skeletons of molluscs, corals, bryozoans, calcareous algae, pteropods — an association characteristic of coral reefs; (ii) terrigenous material derived from erosion and weathering of the volcanic Island formations and brought down by rivers into the sea; (III) terrigenous materials without volcanic fragments; (iv) mixture of biogenous and volcanic sediments.

There was no indication of volcanic ash being distributed off shore in this area. This fact could be due to the last violent volcanic eruption being restricted to the northern part of the Island, and the direction of main concentration of currents does not allow the ashes to be moved southwest.

In Calliaqua Bay there is almost complete absence of volcanic rock fragments, but a predominance of terrigenous sands derived from soils subject to intense agricultural activity. The amount of volcanic fragments increases toward northwest as well as distribution ' of heavy mineral towards coarser fraction.

The most common heavy mineral was olivine, followed by hypersthene and clinopyroxene, characteristic of gabbros, dolerites and basalts. Owing to the predominance of olivine, the source of sediments seems to be olivine-basalt, which occur all over the Island.

The calcareous sands may be derived from reefs or bioclastic deposition. Almost all the samples contained more than 80% of sand (table VI), and only three samples showed more than 30% of gravel. This reflected no energy or direction of currents, because almost all the gravel fraction comprised shell fragments.

The sedimentary parameters are influenced by the source of materials. In Calliaqua Bay, tidal streams and waves could be responsible for the infilling of the bay, and carrying the very well sorted materials of the beach towards the shore.

The tidal streams seem to be the predominant influence on the distribution of sediments, which is associated with the bathymetry. In Camden Park Bay, currents possibly comming from open sea, reach the bay in its northeast extremity, and follow a clockwise movement into the bay as figure 11 seems to reveal, and this is supported by the *Globigerina* in some samples of this area.

The distribution of volcanic minerals along the shore of the rivers, thin sections of samples of rocks, beaches and shallow water

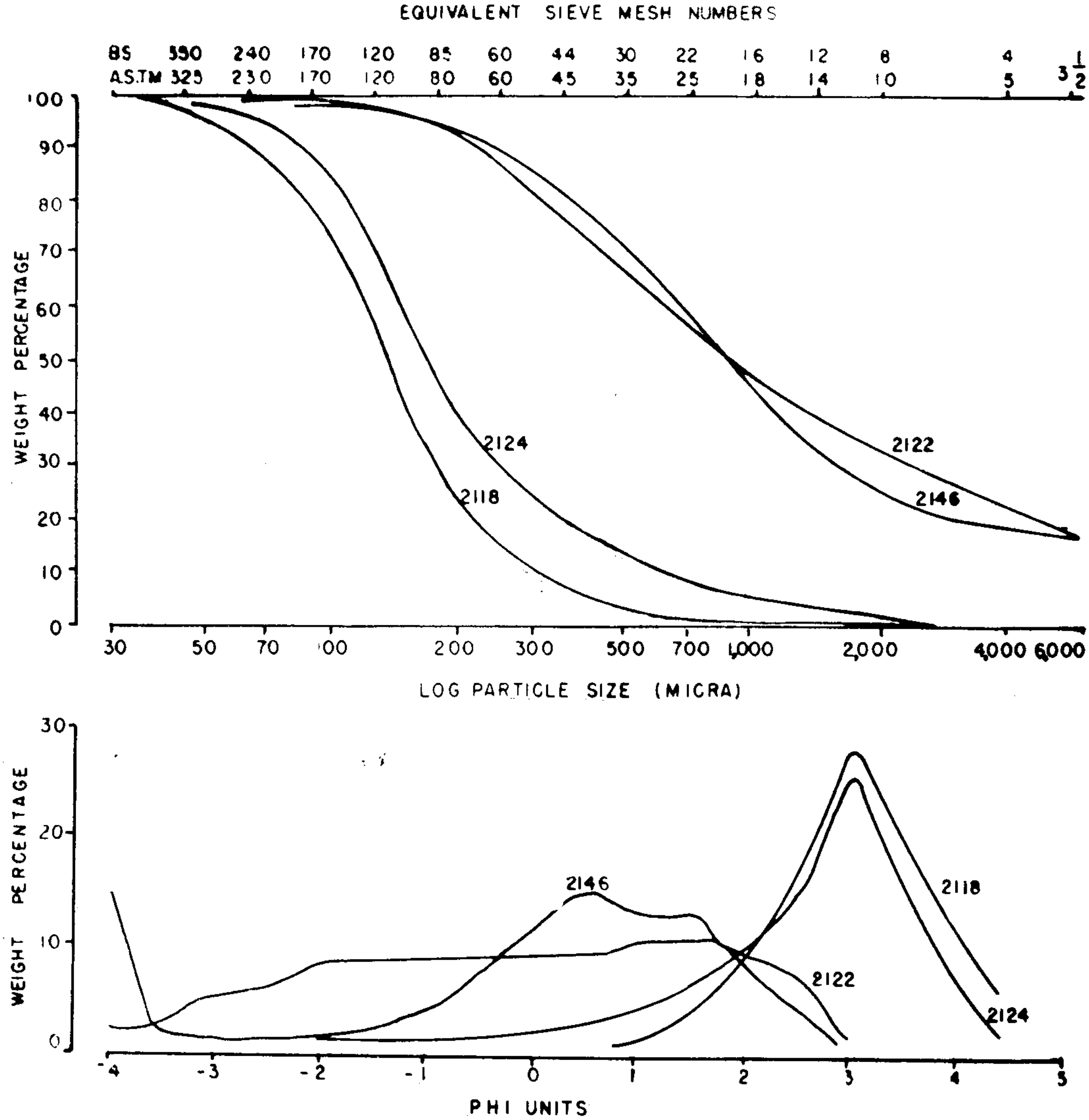


Figure 14 — Buccament Bay — distribution of the cumulative curves and frequence curves.

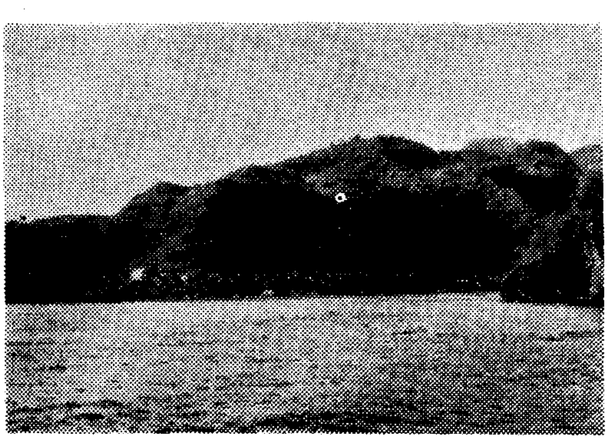


Figure 15 — Buccament Bay — Morphological aspects of the coast.

Figure 16 — Camdem Park Bay — Morphological aspects of the area.

TABLE VI

Sediment type of the studied area.

Sample (no.)	Gravel (%)	Sand (%)	Mud (%)
2089	—	92.74	7.46
2090	—	97.09	2.91
2091	0.05	98.83	1.12
2092	3.07	92.13	3.50
2093	1.70	97.64	2.36
2094	6.45	91.75	1.80
2095	—	95.18	4.82
2096	7.91	87.49	4.60
2097	11.48	87.34	1.17
2099	14.76	83.84	1.35
2101	1.36	88.68	9.96
2102	—	95.06	4.93
2103	—	94.00	6.00
2104	—	89.19	10.81
2105	20.39	78.08	1.57
2106	11.46	88.88	0.65
2107	—	72.95	0.62
2108	—	97.40	2.60
2110	—	91.15	8.85
2112	—	85.81	14.91
2114	4.00	93.00	3.00
2115	6.14	93.53	0.03
2118	—	95.90	4.10
2122	32.34	67.30	0.24
2124	1.62	95.13	3.25
2146	32.47	67.12	0.61
2150	0.30	43.65	56.05
2152	0.46	83.17	16.30
2155	0.71	98.85	0.46
2158	—	68.61	31.39

sands, must be undertaken in further studies. X-ray diffraction analysis to determine the principal components of the calcareous fraction (calcite, aragonite), as well as study of the stability of beaches (agradation or degradation), could provide better and more accurate information. The study of some samples east of the Island could indicate the importance of wind on the amount of volcanic sediments offshore. It is necessary to have a better knowledge of the weathering, drainage, climate, pluviometry, oceanographic processes affecting the area, to obtain better results in a study such as this.

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ABSTRACTS

This paper deals with the sedimentological studies on some samples off the southwestern littoral of Saint Vincent Island, on the Caribbean Sea.

It has been investigated how far offshore is the influence of terrigeneous sediments, derived from volcanic rocks and delivered into the sea by the rivers.

By means of interpretation of statistical parameters stemmed from twenty-seven grain size analysis, the different mechanisms or processes of different condition of sedimentation have been analysed. The distribution of heavy minerals, calcium carbonate, as well as the type of sediments and bathymetry have been studied. The discrimination between volcanic and organic sediments has been done mainly by microscopic standpoint.

Calliaqua Bay seems to be the part of northewstern littoral which has received less amount of volcanic sands. The heavy minerals in this bay differ from the other ones in shape and concentration, and the volcanic rock fragments are much more spread in Layout and Buccament Bays, at times showing fenocrist on the green mass of the fragment. These rock fragments get larger distribution as far as the northwestern extremity of the area has been reached.

The sediments were divided into four categories on the basis of its components: terrigenous material derived from erosion of volcanic island formations; terrigenous materials derived from areas with intensive agricultural activites; biogenous material derived from the skeletons of molluscs, corals, etc.; mixture of volcanic materials and biogenous materials in different proportions.

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