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# A Lithologic Analysis of the Galveston Beach Sand With Special Emphasis on Heavy Minerals

By

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# I. INTRODUCTION

In this thesis, mineralogical and textural analyses of the sand-silt beach deposits of Galveston Island, Texas, are presented, with special emphasis on heavy minerals. It is the intent of the author; 1) to describe the mineralogical composition of each of the heavy mineral suites, and to test the significance of variations found among 4 of the more dominant heavy minerals (zircon, tourmaline, hornblende, and garnet); 2) to describe the size-distributions of the zircon and tourmaline present in each heavy mineral suite; and 3) to postulate means or conditions by which any mineralogical or size-distribution variations may be explained.

The present study is concerned with the sand beach which circumscribes Galveston Island. The island is composed of recent sandy and silty sediment and occupies a position at the mouth of Galveston Bay some 50 miles south of Houston. Inasmuch as Galveston Island is essentially an over-sized off-shore bar, which, for the most part, separates the Gulf of Mexico from Galveston Bay, the beaches that rim the island consist of two contrasting sedimentary environments. A frontal beach environment occurs on the Gulf side of the island, whereas a back-bay environment exists on the bay side. The present thesis is largely concerned with the determination of any consistent differences, mineralogical or textural, which might exist between the beach sands formed under these differing conditions.

Galveston Island extends in a NE - SW direction and is approximately 30 miles long. Samples were taken on both sides of the island at roughly 5-mile intervals. This sampling procedure made possible the grouping of samples in pairs, one from the front-beach and one from the back-beach, and provided opportunity for a continuous check of variations as the laboratory work progressed. The sampling procedure and sample grouping is explained more thoroughly in the next section.

This thesis is the third in a series concerned with the petrologic and lithologic properties of Gulf Coast sediments, the two previous being written by Powell (1957) and Dawson (1958).

## II. PROCEDURE

### A. Sampling Procedure

Samples were taken at 5-mile intervals along the beach on both sides of Galveston Island (see Plate 1). Care was taken to obtain the sample from a depth below tidal influence, yet still containing the characteristics of the beach sand. A level of 2 feet below the surface was chosen as the approximate point from which to collect the sample. With regard to distance from the water, all samples were taken at what was estimated to be the mid-point between high and low tide. In all, 14 samples were obtained, and, owing to the similar 5-mile spacing of both Gulf and Bay side samples, they were grouped into pairs in the order of 1 and 1a, 2 and 2a, etc. on to 7 and 7a; the subscript "a" indicates those samples taken from the bay or back-bar beaches. The amount of sample taken from each location was enough to fill a one-quart ice-cream container.

### B. Laboratory Procedure

1. Preliminary treatment including carbonate and iron removal.

Fifty grams were taken from each sample, dried under a heat lamp, and disaggregated by means of a wooden rolling pin. Each 50 gram portion was placed in a beaker and boiled in a 2N hydrochloric acid solution with crystals of stannous chloride added. The total weight of calcareous and ferruginous matter thus removed is shown for each sample in Table 1. Unfortunately, the process was not entirely satisfactory, as shown by the fact that much of the heavy residue later analyzed consisted of iron oxides and iron-coated quartz grains.

2. Heavy mineral removal.

Following removal of carbonates and most of the ferruginous matter, 7 grams (approx.) were removed from each purified sample and subjected to a centrifuging process for removal of heavy minerals. Each 7 gram portion was placed in a lusteroid centrifuge tube, which was then filled with a sufficient amount of Bromoform. The tube containing the sample portion and the heavy liquid was then placed in the centrifuge and centrifuged for 5 minutes at approximately 2, 500 r.p.m. After allowing time for complete separation of light and heavy fractions, the bottom of each tube was placed in crushed dry ice and allowed to freeze. As soon as the liquid in the tube was frozen, the bottom, which contained the heavy mineral separate, was severed from the rest of the tube, placed in filter-paper, and the liquid allowed to melt. The heavy minerals were then dried and recovered from the filter-paper. This process was repeated twice more for each sample portion, making each heavy mineral suite examined the product of 3 centrifuging operations. After their separation and recovery, the heavy minerals were weighed, and their weight percents determined for each sample (Table 2). The collected heavy minerals were then mounted in Canada Balsam and subjected to optical analysis and identification.

3. Heavy mineral identification.

Identification of the component minerals of each suite was made with the use of a Zeiss-Winkel Polarizing Microscope and a mechanical stage. Owing to a profusion of heavy minerals, each sample was represented by two heavy mineral slides with the exception of samples 1 and 3a, for which only one heavy mineral slide was made. After identification of the various minerals, grain counts of at least 300 grains per slide were performed on each slide. The number percentages of each heavy mineral found are shown on Table 3. The most prominent minerals are opaques, zircon, tourmaline, hornblende, garnet, kyanite, and epidote. Lesser amounts of sphene, monazite, staurolite, rutile, feldspar, pyroxenes, and apatite were found.

4. Size-distribution analysis of zircon and tourmaline.

Following identification and tabulation of the amount of heavy minerals in each sample, a size-distribution analysis, by number percentage, was performed on zircon and tourmaline for each sample.

For this process, the same Zeiss-Winkel microscope and mechanical stage were used. Only samples yielding a minimum of 300 zircon grains and 215 tourmaline grains were tabulated. The maximum diameter of each zircon and tourmaline grain was measured and placed, for tabulation, in the appropriate millimeter interval; the intervals were established on the basis of a $1/\sqrt{2}$ factor. All measurements were made with a 10x objective and a calibrated eye-piece. The scale of the eye-piece at this power is 20 intervals = 1/4 mm., 10 intervals = 1/8 mm., etc. The maximum diameters counted ranged from approximately 1/4 mm. to 0 mm. From the data obtained, number percentages of the various diameter intervals were calculated, cumulative frequency curves were plotted on log-probability paper, and sorting coefficients, skewnesses, and median diameters were derived. The parameters of size-distribution for zircon and tourmaline are tabulated on Tables 4 and 5; number percentages for zircon and tourmaline are shown on Tables 6 and 7.

5. Size-distribution analysis of the bulk sample.

For determining the size-distribution of each bulk sample, 30 grams of purified sample (from which ferruginous and calcareous matter had been removed) were run through a conventional Tyler Ro-tap for a 7 minute period. Each sieve fraction was examined and weighed to determine the weight percent of each size-grade. Table 8 shows the weight percent of each size-grade for every sample. Alternating sample pairs were then put through another sieve analysis involving more closely spaced mesh intervals; the results are shown in Table 9. From both sievings, statistical parameters of each sample were calculated; these are shown in Table 10.

## III. RESULTS

### A. Mineralogical

1. Identification of heavy mineral separates.

Following separation and mounting of the heavy minerals, microscope identification of the minerals was performed. The minerals identified were zircon, tourmaline, garnet, hornblende, kyanite, staurolite, sphene, monazite, epidotes, rutile, feldspar, apatite, pyroxenes, quartz and opaque minerals. As was briefly mentioned earlier, an abundance of quartz grains settled out with the heavy mineral suite. It was found upon examination that the quartz grains contained numerous cavities, and that many of them were coated with a ferruginous substance. The presence of quartz grains in the heavy minerals nullifies any validity of weight percent measurements contained in Table 2, and casts doubt on the accuracy of the number percentages of opaque minerals tabulated from the heavy mineral suites.

2. Relative abundance of the heavy minerals.

Table 3 shows the relative abundance by number percent of the heavy minerals found in each sample. Excluding the opaque minerals, the most abundant minerals were found to be hornblende, zircon, tourmaline, garnet, and sphene and monazite combined. From a tabulation of the average number percentages of the above minerals for the front-beach samples and back-beach samples, the following relationships were found:

| MINERAL | AVERAGE NO. % FRONT-BEACH | AVERAGE NO. % BACK-BEACH |
|---|---|---|
| Hornblende | 15.82 | 15.90 |
| Zircon | 14.89 | 14.95 |
| Tourmaline | 10.98 | 11.61 |
| Garnet | 8.55 | 7.03 |
| Sphene & Monazite | 6.98 | 5.43 |

On the basis of the above table, there appears to be no evidence for any significant mineralogical difference between the two beaches. Although Table 3 will evidence the fact of sudden fluctuations in mineralogy between individual samples, no consistent trend or continuous change in mineral content along either front- or back-beach warrants attention.

3. Variance analysis of zircon, tourmaline, garnet and hornblende.

After comparing the average number percentages of the dominant minerals from the front- and back-beaches of the island (concluding therefrom that no large-scale mineralogical differences existed) a variance analysis was performed on the 4 most abundant minerals. The analysis was designed to determine whether or not any of the 4 minerals varied significantly in abundance either parallel to the beaches or from one beach to the other. The variance analysis involved establishing a column and row relationship between front- and back-beach samples for each of the four minerals. This was facilitated greatly by using the sample pairs as columns ( a total of 7) and the respective beach samples as rows (a total of 2). Once the column and row diagram had been set up satisfactorily, normalizing transformation values of the number percentage for each mineral were calculated for each sample and placed in the appropriate position in the diagram. The transformation (Kelley; 1947; page 596) involves changing a relatively small percent number, which cannot be used as an absolute value in calculations, to a corresponding number (arcsin square-root-of-X) which can.

Once having changed the number percentages to their corresponding arcsin square-root-of-X numbers, the transformed values were analyzed by means of the method shown in Dixon and Massey; 1951; page 143. All conclusions concerning variance of any of the 4 minerals were based on a 90% level of significance, or an F-value of 90(Hoel; 1954; pp. 322 - 326).

The illustration below indicates the method used to arrange the necessary row and column construction. The number adjacent to each sample number is the transformed figure of the corresponding number percent value for that sample.

GARNET

| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | Row Sums |
|---|---|---|---|---|---|---|---|---|
| | .9614 | .9273 | .9443 | .9973 | .9443 | .9773 | 1.0056 | 6.7575 |
| | .9793 | 1.1681 | 1.0353 | 1.0759 | .9614 | .9973 | 1.0759 | 7.2932 |
| | 1a. | 2a. | 3a. | 4a. | 5a. | 6a. | 7a. | |
| Column Sums | 1.9407 | 2.0954 | 1.9796 | 2.0732 | 1.9057 | 1.9746 | 2.0815 | |
| | | | | | | Total Sum | | 14.0507 |

It can be seen from the diagram that this method gives a graphic picture of the sampled area against a background of possible mineralogical variation. The numbers representing Row Sums and Column Sums are simply the sums of the transformed numbers forming the respective rows and columns. These row and column sums are used in the variance analysis method, explained by Dixon and Massey on page 143. The illustration below is exemplary of a final result of the variance analysis. The numbers appearing are dependent on the transformed numbers just tabulated, and hence are dependent on the number percentage of the mineral being analyzed in each sample. The F-values are from Tables in Hoel (1954) pp 322-325.

Variance Analysis of Garnet

| | Sum of Squares | d.f. | Mean Square | | |
|---|---|---|---|---|---|
| Column Means | .0180 | 6 | .0030 | :: | .0030/.0029 = 1.0344 |
| Row Mean | .0204 | 1 | .0204 | :: | .0204/.0029 = 7.0344 |
| Residual | .0179 | 6 | .0029 | :: | $F_{90}(6,6) = 3.05$ |
| Total | .0563 | 13 | | :: | $F_{90}(1,6) = 3.78$ |

Conclusions: Since, at the 90% level of significance, the final Row calculation exceeds the value of F(1, 6), there appear to be significant Row Effects. More simply, there is a variation in the abundance of garnet from the front- to the back-beach on Galveston Island to the degree that there is not 90% evidence to the contrary. The exact reverse holds for Column Effects.

Tests identical to the one just shown were performed on zircon, tourmaline, hornblende, and garnet (shown above). The results of the variance analyses are as follows:

Zircon:---- significant column effects; no row effects.

Tourmaline: significant column effects; no row effects.

Garnet:---- significant row effects; no column effects.

Hornblende: no significant row or column effects.

From the above results, it can be seen that the relative abundances of zircon and tourmaline vary parallel to the two beaches, while the relative abundance of garnet varies from one beach to the other. Hornblende shows no consistent variation in abundance in either way. Although the three variances found are real, they are, nonetheless, quite small. In section IV more will be said concerning the real significance and importance of these variances.

B. Textural

1. Size-distribution of zircon and tourmaline

From the information shown in Tables 4 and 5, the size-distribution parameters of zircon and tourmaline have been calculated. The average sorting coefficient for zircon is 1.23; for tourmaline 1.12. The average skewness of zircon is 0.988; of tourmaline 1.000. The average median diameter of zircon is 0.105 mm.; of tourmaline 0.127 mm. Both the skewness and median diameter figures indicate that the zircon fraction of the heavy mineral suites contains a greater abundance of smaller grains than does the tourmaline fraction. This is further supported by Plate 2, which shows zircon and tourmaline size-distributions in the same sample.

From the parameters shown in Tables 4 and 5, and from the average figures discussed above, it is evident that both zircon and tourmaline grains in the samples listed are very well sorted and show but negligible deviation from straight line plots on log-probability paper. Again, Plate 2 exemplifies this relationship. One would expect, as a result of the high degree of sorting and low skewness found in the distribution of both minerals, that some degree of hydraulic equivalence would exist between the minerals in each sample, (Rittenhouse (1943), Rubey (1933), Pettijohn (1949)). From an analysis, however, of the median diameters of zircon and tourmaline from the same samples, it was found that no such equivalence exists. The data below expresses the settling velocities, according to Stokes' Law, for zircon and tourmaline grains (based on their median diameters) from the same samples.

| Units in mm/sec | Sample No. | Settling Vel. from $V = 2/9gr^2(d - d_1)/n$ | |
|---|---|---|---|
| | | Zircon | Tourmaline |
| | 1a. | 7.0632 | 6.0514 |
| | 2. | 10.2024 | 6.8670 |
| | 3. | 7.8480 | 7.3248 |
| | 4. | 9.4176 | 7.3248 |
| | 5. | 10.2024 | 7.3248 |
| | 6. | 9.4176 | 8.6982 |

The consistent lack of correlation between the settling velocities of zircon and tourmaline grains in the sample is indicative either of some post-depositional factors causing grains out of hydraulic equilibrium to be found together, or of a lack of applicability of Stokes' Law in this case, or possibly both. More will be said concerning this situation in a later section.

2. Size-distribution of bulk samples

Size-distribution data for each bulk sample were obtained from weight percent measurements of the various size fractions following sieving of the samples. The tabulation of parameters in Table 10, calculated from cumulative frequency curves, indicates the high degree of sorting and low skewness for each sample. Average measurements made on each parameter for front- and back-beach samples give the following information: Front-beach: sorting coefficient 1.14; skewness 1.02; median diameter 0.118 mm. Back-beach: sorting coefficient 1.15; skewness 0.997; median diameter 0.118 mm. These figures, when compared to each other and to the average parameter figures for all 14 samples (sorting coefficient 1.15, skewness 1.01, median diameter 0.118 mm.), show both beach sands to be extremely well-sorted, to be log-normally distributed by weight (e.g. Plate 3), and to have the same median diameter. It is of interest to note that the average median diameters of the two beach sands are the same, whereas the back-beach samples show a displacement toward the finer grain-sizes relative to the front-beach samples. Tables 8 and 9 account for this apparent discrepancy in that they show the back-beach samples to have a greater abundance of the finer material, and, in general, of the coarser. In contrast, the front-beach samples generally have a greater abundance of the middle size-grades, thus equalizing the spread of the back-beach size grouping and giving identical median diameters to both beach sands.

Discussion as to the possible causes of a greater abundance of coarser material in the back-beach samples, the reverse of what might logically be expected, is given in the final section.

## IV. SUMMARY & CONCLUSIONS

### A. Mineralogical

From the information obtained by microscopic identification and analysis of each heavy mineral suite, and from the results obtained through a variance analysis of the most abundant non-opaque heavy minerals, the author concludes that no significant mineralogical variations exist between the two beaches. The fluctuations of mineral abundances encountered during grain-counting are attributed to local concentration of various minerals by wave and tidal-current action. It is further concluded that negligible systematic mineralogical variation exists parallel to the beaches, and that whatever differences are found are also caused by wave and current activity. For all practical purposes, the two beaches of Galveston Island may be considered to be identical insofar as heavy mineral compositions are concerned.

### B. Textural

The following conclusions are drawn concerning the textural properties of both beach sands studied; the conclusions are based on data obtained from cumulative frequency plots on log-probability paper and calculated statistical parameters:

1. Average statistical parameters for front- and back-beach sands, (section III-B), show that both sands have nearly identical sorting coefficients and bulk median diameters; back-beach sands

show a greater abundance of finer material, indicated by a skewness less than 1.0.

2. Average statistical parameters for zircon and tourmaline grains, (section III-B), show the tourmaline in the heavy mineral suites to be better sorted and to have a larger average median diameter in relation to zircon; zircon, as indicated by skewness calculations, is more abundant in the finer grain sizes than tourmaline; the average median diameter of zircon grains from the back-beach is .098 mm., as compared to .112 mm. for zircon grains from the front-beach.

3. Bulk samples of both beach sands are extremely well-sorted, and are log-normally distributed by weight. The zircon and tourmaline fractions of each sample analyzed are log-normally distributed by number.

C. Environmental

Any research on the mineralogical and textural properties of an off-shore bar such as Galveston Island necessitates the recognition of two influencing environments: the environment of the bar itself (#1), which can be subdivided into ocean-front and back-bay environments, must be analyzed against a background of the tectonic environment (#2) of the province in which it lies--namely the Gulf Coast. Owing to reasons discussed in this section, the writer feels that the beach sands studied have been mineralogically controlled by the tectonics of the Texas Gulf Coast and have been texturally controlled by the local environments present on either side of the island.

Two facts point to local control of textural properties. The first factor is the apparent removal from the front-beach of much of the coarsest fraction (1/4 - 1/8 mm. size grade) and nearly all of the finest fraction (less-than 1/16 mm. size grade). Removal of the finer particles by elutriation is expected in the light of the known effect of wave activity on beach sands. A removal, however, of much of the coarsest material, relative to the less affected sands of the back-beach, is somewhat unexpected. The combination of removal of fine and coarse material serves to concentrate the sediment of the front-beach into a more limited size interval, which in turn produces excellent sorting. Table 11 shows the comparative weight-percent of each size grade from each sample listed. A greater abundance in the back-beach samples of the 1/4 - 1/8 mm. particles indicates less agitation by current and wave activity in the back-beach environment than in the front-beach environment. This conclusion is further supported by a greater abundance of the finer material in the back-beach sediment, indicating that wave and current activity has not been intense enough to remove the finer material to the degree that it has been removed from the front-beach. Inman (1949) has shown that under conditions of fluid activity such as exist in a beach environment, grains between 1/4 and 1/8 mm. in size are most easily transported by surface creep, saltation, and suspension. It is the opinion of the present author that the tendency of this size-grade to be selectively removed explains the lesser abundance of these particles in the front-beach sands relative to the back-beach sands. As Inman points out, the direction of particle transport (seaward or shoreward) depends on the amplitudes and velocities of waves; low amplitudes and velocities cause a shoreward particle migration, and high amplitudes and velocities cause a seaward particle migration by suspension. Evidently, wave intensity has been sufficient to remove the finer particles of the front-beach by suspension while also transporting the 1/4 - 1/8 mm. size particles in a seaward or shoreward direction. In the case of prolonged shoreward transportation, the particles would become subject to aeolian activity and thus be removed from the tidal beach.

The second fact in support of local environmental control of the beach sand textures is the lack of hydraulic equivalence between zircon and tourmaline grains from the same heavy mineral suites. According to Stokes' Law, grains having equal settling velocities (dependent on their specific gravities and diameters) are deposited together under conditions of laminar fluid flow. Since other work has shown the law to be valid (Rittenhouse; 1943) under specified conditions, grains out of hydraulic equilibrium must necessarily have been influenced locally after initial deposition, assuming they were deposited in equilibrium. Comparison of zircon and tourmaline grains from the heavy mineral suites analyzed shows a complete lack of hydraulic equivalence between grains of the same suites (section III-B). The writer attributes these discrepancies to wave and current activity on both beaches. Tides, eddies, longshore currents, and breakers may serve to perform a random re-shuffling of minerals regardless of their specific gravities or diameters. Indeed, roundness and sphericity of the grains might have much more bearing than density on their re-deposition as a result of activity by waves and currents of greatly fluctuating intensities.

In summary, the writer finds both front- and back-beach deposits to be similar mineralogically, whereas certain size-distribution differences exist between the two beaches. The observations on both properties are explained by 1) an over-all mineralogical control exercised by the tectonic province in which Galveston Island lies, and 2) local textural control exercised by the ocean-front and back-bay environments of the respective beach sediments.

TABLE 1

RESULTS OF PRELIMINARY IRON AND CARBONATE REMOVAL

EXPRESSED IN WEIGHT PERCENT

| Sample No. | Sample Wt. | Wt. Loss | Wt. % Loss |
|---|---|---|---|
| 1. | 50 g. | 1.5 g. | 3.0 |
| 1a. | 50 g. | 2.1 g. | 4.2 |
| 2. | 50 g. | 1.9 g. | 3.8 |
| 2a. | 50 g. | 9.0 g. | 18.0 |
| 3. | 50 g. | 1.0 g. | 2.0 |
| 3a. | 50 g. | 2.5 g. | 5.0 |
| 4. | 50 g. | 1.7 g. | 3.4 |
| 4a. | 50 g. | 4.0 g. | 8.0 |
| 5. | 50 g. | 0.4 g. | 0.8 |
| 5a. | 50 g. | 3.5 g. | 7.0 |
| 6. | 50 g. | 2.7 g. | 5.4 |
| 6a. | 50 g. | 3.5 g. | 7.0 |
| 7. | 50 g. | 2.0 g. | 4.0 |
| 7a. | 50 g. | 1.6 g. | 3.2 |

TABLE 2

RESULTS OF CENTRIFUGE OPERATION
EXPRESSED IN WEIGHT PERCENT

| Sample No. | Wt. of Sample Centrifuged | Wt. of Sample Recovered | Wt. % Recovered |
|---|---|---|---|
| 1. | 510 m.g. | 20 m.g. | 3.92 |
| 1a. | 510 m.g. | 55 m.g. | 10.78 |
| 2. | 525 m.g. | 75 m.g. | 14.28 |
| 2a. | 535 m.g. | 40 m.g. | 7.47 |
| 3. | 515 m.g. | 20 m.g. | 3.88 |
| 3a. | 525 m.g. | 70 m.g. | 13.33 |
| 4. | 500 m.g. | 50 m.g. | 10.00 |
| 4a. | 530 m.g. | 20 m.g. | 3.77 |
| 5. | 500 m.g. | 179 m.g. | 35.80 |
| 5a. | 520 m.g. | 85 m.g. | 16.34 |
| 6. | 500 m.g. | 1 30 m.g. | 26.00 |
| 6a. | 500 m.g. | 20 m.g. | 4.00 |
| 7. | 500 m.g. | 45 m.g. | 9.00 |
| 7a. | 500 m.g. | 89 m.g. | 17.80 |

TABLE 3

DATA SHOWING RELATIVE ABUNDANCE
OF HEAVY MINERALS IN EACH SAMPLE
EXPRESSED IN NUMBER PERCENT

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 1. 300 grains | Zircon | 14.0 |
| | Tourmaline | 19.3 |
| | Garnet | 9.0 |
| | Hornblende | 19.3 |
| | Kyanite | 5.6 |
| | Staurolite | 2.0 |
| | Sphene & Monazite | 7.0 |
| | Opaques | 22.0 |
| | Epidote | 1.6 |
| | Rutile, Feldspar, Apatite | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| la. 300 grains | Zircon | 16.3 |
| | Tourmaline | 13.6 |
| | Garnet | 10.3 |
| | Hornblende | 9.6 |
| | Kyanite | 4.0 |
| | Staurolite | 3.0 |
| | Sphene & Monazite | 7.0 |
| | Opaques | 31.6 |
| | Epidotes | 3.6 |
| | Rutile, Feldspar, Pyroxenes | Remainder |
| 300 grains | Zircon | 15.3 |
| | Tourmaline | 14.3 |
| | Garnet | 7.0 |
| | Hornblende | 11.3 |
| | Kyanite | 6.0 |
| | Staurolite | 2.0 |
| | Sphene & Monazite | 8.0 |
| | Opaques | 32.6 |
| | Epidotes | 2.6 |
| | Feldspar, Pyroxenes | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 2. 300 grains | Zircon | 11.3 |
| | Tourmaline | 16.0 |
| | Garnet | 11.6 |
| | Hornblende | 12.3 |
| | Kyanite | 4.0 |
| | Staurolite | 1.6 |
| | Sphene & Monazite | 6.4 |
| | Opaques | 31.0 |
| | Epidotes | 5.2 |
| | Feldspar, Pyroxenes | Remainder |
| 300 grains | Zircon | 17.4 |
| | Tourmaline | 10.7 |
| | Garnet | 7.9 |
| | Hornblende | 13.3 |
| | Kyanite | 3.6 |
| | Sphene & Monazite | 9.2 |
| | Opaques | 33.3 |
| | Epidotes | 2.6 |
| | Staurolite, Pyroxenes, Feldspar | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 2a. 320 grains | Zircon | 20.3 |
| | Tourmaline | 16.2 |
| | Garnet | 3.7 |
| | Hornblende | 13.4 |
| | Kyanite | 1.6 |
| | Sphene & Monazite | 5.6 |
| | Opaques | 32.4 |
| | Epidotes | 1.6 |
| | Pyroxenes | 2.8 |
| | Feldspars | 1.8 |
| | Staurolite, Rutile, Pyroxenes | Remainder |
| 311 grains | Zircon | 14.7 |
| | Tourmaline | 15.4 |
| | Garnet | 4.8 |
| | Hornblende | 11.2 |
| | Kyanite | 5.1 |
| | Sphene & Monazite | 6.1 |
| | Opaques | 34.0 |
| | Epidotes | 2.6 |
| | Pyroxenes | 2.6 |
| | Feldspars | 1.6 |
| | Rutile, Apatite | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 3. 305 grains | Zircon | 13.4 |
| | Tourmaline | 13.7 |
| | Garnet | 9.5 |
| | Hornblende | 15.4 |
| | Kyanite | 2.3 |
| | Sphene & Monazite | 7.5 |
| | Opaques | 29.5 |
| | Epidotes | 3.6 |
| | Pyroxenes | 3.3 |
| | Feldspar, Rutile | Remainder |
| 307 grains | Zircon | 10.7 |
| | Tourmaline | 7.1 |
| | Garnet | 9.7 |
| | Hornblende | 24.4 |
| | Kyanite | 2.6 |
| | Sphene & Monazite | 10.4 |
| | Opaques | 28.3 |
| | Epidotes | 4.2 |
| | Pyroxenes | 1.9 |
| | Staurolite, Rutile, Feldspar | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 3a. 308 grains | Zircon | 9.7 |
| | Tourmaline | 17.8 |
| | Garnet | 7.1 |
| | Hornblende | 17.8 |
| | Kyanite | 5.8 |
| | Sphene & Monazite | 4.8 |
| | Opaques | 29.5 |
| | Epidotes | 4.5 |
| | Pyroxenes | 1.9 |
| | Staurolite, Feldspar | Remainder |
| 4. 300 Grains | Zircon | 17.6 |
| | Tourmaline | 14.3 |
| | Garnet | 8.0 |
| | Hornblende | 12.6 |
| | Kyanite | 3.3 |
| | Sphene & Monazite | 8.3 |
| | Opaques | 28.6 |
| | Epidotes | 5.0 |
| | Pyroxenes | 1.3 |
| | Feldspar, Staurolite, Rutile | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 300 grains | Zircon | 16.6 |
| | Tourmaline | 4.3 |
| | Garnet | 7.6 |
| | Hornblende | 16.3 |
| | Kyanite | 4.6 |
| | Sphene & Monazite | 7.6 |
| | Opaques | 32.0 |
| | Epidotes | 6.7 |
| | Pyroxenes | 3.0 |
| | Rutile, Staurolite, Feldspar | Remainder |
| 4a. 302 grains | Zircon | 12.5 |
| | Tourmaline | 9.9 |
| | Garnet | 5.9 |
| | Hornblende | 17.2 |
| | Kyanite | 3.3 |
| | Sphene & Monazite | 7.9 |
| | Opaques | 33.7 |
| | Epidotes | 6.3 |
| | Pyroxenes | 1.6 |
| | Staurolite, Rutile, Feldspar | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 300 grains | Zircon | 19.6 |
| | Tourmaline | 8.0 |
| | Garnet | 6.3 |
| | Hornblende | 17.6 |
| | Kyanite | 4.7 |
| | Sphene & Monazite | 7.3 |
| | Opaques | 30.0 |
| | Epidotes | 6.0 |
| | Pyroxenes | Remainder |
| 5. 302 grains | Zircon | 17.8 |
| | Tourmaline | 9.9 |
| | Garnet | 10.2 |
| | Hornblende | 10.2 |
| | Kyanite | 4.9 |
| | Sphene & Monazite | 4.6 |
| | Opaques | 36.4 |
| | Epidotes | 4.9 |
| | Pyroxenes, Rutile | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 300 grains | Zircon | 13.6 |
| | Tourmaline | 14.0 |
| | Garnet | 8.6 |
| | Hornblende | 12.3 |
| | Kyanite | 3.0 |
| | Sphene & Monazite | 8.6 |
| | Opaques | 34.3 |
| | Epidotes | 4.7 |
| | Pyroxenes, Feldspar, Staurolite | Remainder |
| 5a. 300 grains | Zircon | 12.3 |
| | Tourmaline | 10.3 |
| | Garnet | 9.6 |
| | Hornblende | 22.0 |
| | Kyanite | 3.7 |
| | Sphene & Monazite | 3.3 |
| | Opaques | 29.0 |
| | Epidotes | 6.3 |
| | Pyroxenes | 2.3 |
| | Feldspar, Mica, Rutile | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 300 grains | Zircon | 19.0 |
| | Tourmaline | 12.0 |
| | Garnet | 9.0 |
| | Hornblende | 13.6 |
| | Kyanite | 3.3 |
| | Sphene & Monazite | 5.0 |
| | Opaques | 27.3 |
| | Epidotes | 6.6 |
| | Pyroxenes | 2.0 |
| | Rutile | 1.7 |
| | Feldspar, Mica | Remainder |
| 6. 307 grains | Zircon | 23.7 |
| | Tourmaline | 6.8 |
| | Garnet | 10.0 |
| | Hornblende | 6.8 |
| | Sphene & Monazite | 7.4 |
| | Opaques | 35.5 |
| | Epidotes | 6.2 |
| | Pyroxenes | 1.3 |
| | Kyanite, Staurolite, Rutile | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 303 grains | Zircon | 27.0 |
| | Tourmaline | 6.9 |
| | Garnet | 6.2 |
| | Hornblende | 8.5 |
| | Kyanite | 1.6 |
| | Sphene & Monazite | 5.6 |
| | Opaques | 34.6 |
| | Epidotes | 7.6 |
| | Pyroxenes, Staurolite | Remainder |
| 6a. 310 grains | Zircon | 18.7 |
| | Tourmaline | 6.4 |
| | Garnet | 9.0 |
| | Hornblende | 17.4 |
| | Kyanite | 3.5 |
| | Sphene & Monazite | 2.9 |
| | Opaques | 31.2 |
| | Epidotes | 6.8 |
| | Pyroxenes | 1.6 |
| | Staurolite, Rutile | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 300 grains | Zircon | 17.3 |
| | Tourmaline | 9.0 |
| | Garnet | 7.0 |
| | Hornblende | 18.0 |
| | Kyanite | 2.3 |
| | Sphene & Monazite | 3.6 |
| | Opaques | 31.6 |
| | Epidotes | 6.3 |
| | Staurolite | 1.7 |
| | Rutile | 2.0 |
| | Pyroxenes, Feldspar | Remainder |
| 7. 303 grains | Zircon | 5.2 |
| | Tourmaline | 10.5 |
| | Garnet | 6.9 |
| | Hornblende | 28.0 |
| | Kyanite | 2.0 |
| | Sphene & Monazite | 3.6 |
| | Opaques | 26.7 |
| | Epidotes | 9.2 |
| | Pyroxenes | 3.3 |
| | Staurolite | 2.6 |
| | Rutile, Feldspar, Apatite | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 300 grains | Zircon | 5.3 |
| | Tourmaline | 9.3 |
| | Garnet | 6.0 |
| | Hornblende | 26.3 |
| | Kyanite | 4.0 |
| | Sphene & Monazite | 4.6 |
| | Opaques | 29.0 |
| | Epidotes | 8.7 |
| | Pyroxenes | 1.6 |
| | Staurolite | 2.0 |
| | Feldspar | 1.7 |
| | Rutile, Amphiboles | Remainder |
| 7a. 302 grains | Zircon | 9.2 |
| | Tourmaline | 8.2 |
| | Garnet | 7.9 |
| | Hornblende | 16.2 |
| | Kyanite | 3.0 |
| | Sphene & Monazite | 3.9 |
| | Opaques | 39.7 |
| | Epidotes | 7.9 |
| | Pyroxenes | 1.6 |
| | Staurolite, Andalusite, Apatite | Remainder |

TABLE 3 (cont.)

| Sample No. & Grains Counted | Mineral Tabulated | Number Percent Of Mineral |
|---|---|---|
| 303 grains | Zircon | 9.5 |
| | Tourmaline | 9.9 |
| | Garnet | 3.9 |
| | Hornblende | 21.7 |
| | Kyanite | 2.3 |
| | Sphene & Monazite | 5.2 |
| | Opaques | 36.9 |
| | Epidotes | 6.3 |
| | Pyroxenes | 1.3 |
| | Staurolite | 1.3 |
| | Rutile, Apatite, Feldspar | Remainder |

TABLE 4

SIZE DISTRIBUTION PARAMETERS OF ZIRCON*

| Sample No. | So | Sk | Md |
|---|---|---|---|
| 1a. | 1.262 | 0.888 | .096 mm. |
| 2. | 1.180 | 1.000 | .117 mm. |
| 3. | 1.197 | 1.000 | .104 mm. |
| 4. | 1.177 | 1.000 | .110 mm. |
| 4a. | 1.250 | 1.000 | .100 mm. |
| 5. | 1.162 | 1.000 | .118 mm. |
| 5a. | 1.348 | 1.012 | .090 mm. |
| 6. | 1.282 | 1.054 | .100 mm. |
| 6a. | 1.186 | 1.000 | .113 mm. |
| 7a. | 1.235 | 0.927 | .102 mm. |

* Only samples giving over 300 grains have been tabulated.

TABLE 5

SIZE DISTRIBUTION PARAMETERS OF TOURMALINE*

| Sample No. | So | Sk | Md |
|---|---|---|---|
| 1a. | 1.211 | 1.000 | .115 mm. |
| 2. | 1.000 | 1.000 | .125 mm. |
| 3. | 1.116 | 1.066 | .127 mm. |
| 4. | 1.111 | 1.000 | .128 mm. |
| 5. | 1.148 | 0.937 | .129 mm. |
| 6. | 1.146 | 1.000 | .138 mm. |

* Only samples giving over 215 grains have been tabulated.

TABLE 6

RESULTS OF SIZE ANALYSIS OF ZIRCON, BY MAXIMUM DIAMETER, EXPRESSED IN PERCENT

| Maximum Diameter Interval | .2503 mm to .1770 mm | .1770 mm to .1252 mm | .1252 mm to .0885 mm | .0885 mm to .0626 mm | .0626 mm to .0442 mm | Less than .0442 mm |
|---|---|---|---|---|---|---|
| Sample No. | | | | | | |
| 1a. | .65 | 18.42 | 41.77 | 27.30 | 10.85 | .98 |
| 2. | 2.44 | 36.28 | 44.81 | 13.71 | 2.13 | .30 |
| 3. | 1.05 | 27.46 | 48.24 | 22.53 | .70 | 0 |
| 4. | 3.40 | 27.55 | 53.25 | 15.17 | .62 | 0 |
| 4a. | 1.64 | 20.32 | 45.90 | 20.32 | 11.14 | .65 |
| 5. | 3.79 | 37.00 | 46.48 | 11.76 | .94 | 0 |
| 5a. | 2.32 | 20.00 | 30.46 | 25.34 | 17.44 | 4.41 |
| 6. | 2.58 | 32.31 | 52.01 | 12.60 | .48 | 0 |
| 6a. | .85 | 21.12 | 42.41 | 24.87 | 8.51 | 2.21 |
| 7a. | 3.21 | 23.44 | 40.64 | 24.76 | 6.23 | 1.70 |

TABLE 7

RESULTS OF SIZE ANALYSIS OF TOURMALINE, BY MAXIMUM DIAMETER, EXPRESSED IN PERCENT

| Maximum Diameter Interval | .2503 mm to .1770 mm | .1770 mm to .1252 mm | .1252 mm to .0885 mm | .0885 mm to .0626 mm | .0626 mm to .0442 mm | Less than .0442 mm |
|---|---|---|---|---|---|---|
| Sample No. | | | | | | |
| 1a. | 3.21 | 36.24 | 39.90 | 13.30 | 7.34 | 0 |
| 2. | 1.63 | 51.83 | 45.30 | .81 | .40 | 0 |
| 3. | 2.99 | 51.31 | 44.19 | 1.50 | 0 | 0 |
| 4. | 3.25 | 49.76 | 45.58 | 1.39 | 0 | 0 |
| 5. | 2.39 | 54.58 | 38.24 | 3.98 | .79 | 0 |
| 6. | 4.08 | 61.63 | 31.02 | 3.26 | 0 | 0 |

TABLE 8

RESULTS OF SAMPLE SIEVE
ANALYSIS EXPRESSED IN WEIGHT PERCENT

| Mesh Size | 40 | 60 | 120 | 230 | 270 | 325 | -325 |
|---|---|---|---|---|---|---|---|
| Sample No. | | | | | | | |
| 1. | 0 | .06 | 24.70 | 75.06 | .08 | .06 | .03 |
| 1a. | 0 | .38 | 29.39 | 54.82 | 3.49 | 6.02 | 5.86 |
| 2. | 0 | .82 | 37.88 | 61.01 | .16 | .07 | .03 |
| 2a. | 0 | 1.76 | 63.98 | 31.82 | 1.01 | .74 | .65 |
| 3. | 0 | 2.77 | 50.30 | 46.74 | .13 | .03 | .01 |
| 3a. | .02 | .16 | 31.81 | 67.34 | .38 | .13 | .11 |
| 4. | 0 | .44 | 34.70 | 64.68 | .13 | .02 | .01 |
| 4a. | 0 | .03 | 28.53 | 65.40 | 2.82 | 1.96 | 1.23 |
| 5. | 0 | .06 | 17.48 | 81.62 | .24 | .05 | .01 |
| 5a. | 0 | .17 | 41.33 | 44.88 | 3.52 | 5.64 | 4.42 |
| 6. | .01 | 1.33 | 51.27 | 46.41 | .51 | .33 | .10 |
| 6a. | 0 | .89 | 53.05 | 35.71 | 3.92 | 3.92 | 2.49 |
| 7. | 0 | .17 | 28.46 | 71.18 | .12 | .03 | .01 |
| 7a. | 0 | .04 | 26.82 | 68.97 | 1.30 | 1.15 | 1.70 |

TABLE 9

RESULTS OF SELECTED SAMPLE SIEVE ANALYSIS EXPRESSED IN WEIGHT PERCENT

| Mesh Size | 100 | 120 | 140 | 170 | 200 | 230 | -230 |
|---|---|---|---|---|---|---|---|
| Sample No. | | | | | | | |
| 1. | 11.81 | 10.92 | 46.82 | 25.09 | 4.87 | .32 | .13 |
| 1a. | 19.75 | 11.90 | 26.40 | 15.82 | 9.13 | 3.40 | 13.58 |
| 3. | 36.62 | 14.79 | 34.45 | 11.88 | 1.95 | .16 | .12 |
| 3a. | 15.05 | 15.06 | 42.95 | 19.20 | 6.43 | .96 | .32 |
| 5. | 6.67 | 10.98 | 54.37 | 23.30 | 4.02 | .39 | .23 |
| 5a. | 30.85 | 15.88 | 23.00 | 10.00 | 7.85 | 2.94 | 9.44 |
| 7. | 12.74 | 12.15 | 44.64 | 24.42 | 5.39 | .29 | .20 |
| 7a. | 24.24 | 12.96 | 42.69 | 14.18 | 2.56 | .47 | 2.87 |

TABLE 10

SIZE DISTRIBUTION PARAMETERS OF BULK SAMPLES

| Sample No. | So | Sk | Md |
|---|---|---|---|
| 1. | 1.141 | 0.945 | .112 mm. |
| 1a. | 1.175 | 1.018 | .110 mm. |
| 2. | 1.195 | 0.960 | .125 mm. |
| 2a. | 1.216 | 0.997 | .140 mm. |
| 3. | 1.253 | 1.196 | .125 mm. |
| 3a. | 1.091 | 0.902 | .115 mm. |
| 4. | 1.110 | 0.979 | .115 mm. |
| 4a. | 1.091 | 0.942 | .110 mm. |
| 5. | 1.069 | 0.991 | .115 mm. |
| 5a. | 1.204 | 1.055 | .120 mm. |
| 6. | 1.124 | 1.021 | .125 mm. |
| 6a. | 1.195 | 0.881 | .125 mm. |
| 7. | 1.087 | 1.048 | .115 mm. |
| 7a. | 1.091 | 1.190 | .115 mm. |

TABLE 11

COMPARISON OF FRONT- AND BACK-BEACH GRAIN-SIZES, FROM SELECTED SAMPLES, EXPRESSED IN WEIGHT PERCENT

(A) 1/4 - 1/8 mm. size grade

| | | | | | |
|---|---|---|---|---|---|
| FRONT | #1 | #3 | #5 | #7 | |
| Bulk Sample | 22.73 | 51.41 | 17.65 | 24.89 | Avg. 29.17 |
| BACK | #1a | #3a | #5a | #7a | |
| Bulk Sample | 31.65 | 30.11 | 46.73 | 37.20 | Avg. 36.42 |

(B) 1/8 - 1/16 mm. size grade

| | | | | | |
|---|---|---|---|---|---|
| FRONT | #1 | #3 | #5 | #7 | |
| Bulk Sample | 77.10 | 48.44 | 82.08 | 74.74 | Avg. 70.59 |
| BACK | #1a | #3a | #5a | #7a | |
| Bulk Sample | 54.75 | 69.54 | 43.79 | 59.90 | Avg. 56.99 |

(C) Less than 1/16 mm. size grade

| | | | | | |
|---|---|---|---|---|---|
| FRONT | #1 | #3 | #5 | #7 | |
| Bulk Sample | 0.13 | 0.12 | 0.23 | 0.20 | Avg. 0.17 |
| BACK | #1a | #3a | #5a | #7a | |
| Bulk Sample | 13.58 | 0.32 | 9.44 | 2.87 | Avg. 6.55 |

Bulk samples here include only material caught on and between 100 - 230 mesh.

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Plate 1. Index map showing sampled area.

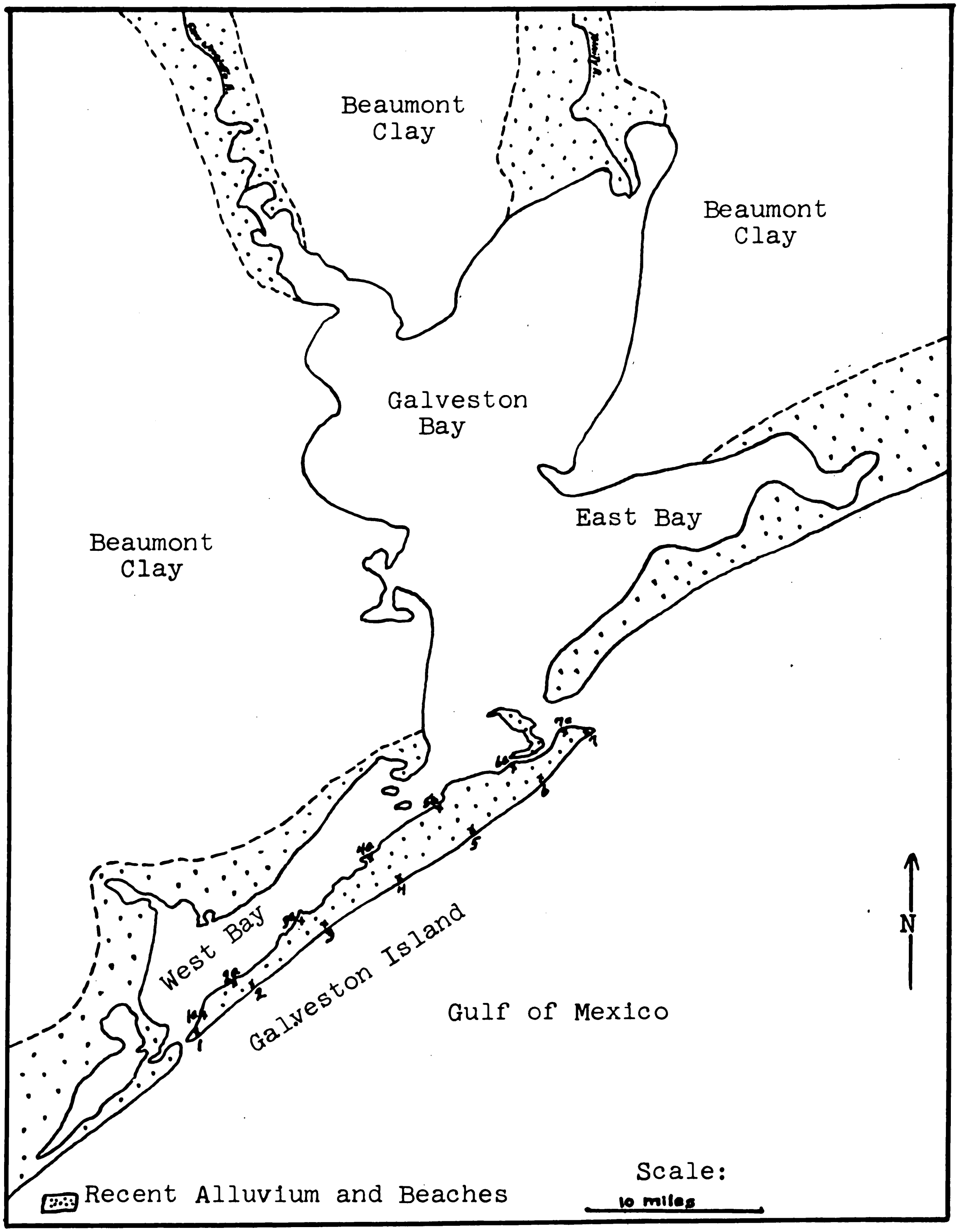

Plate 2. Zircon and tourmaline size-distribution of sample 4.

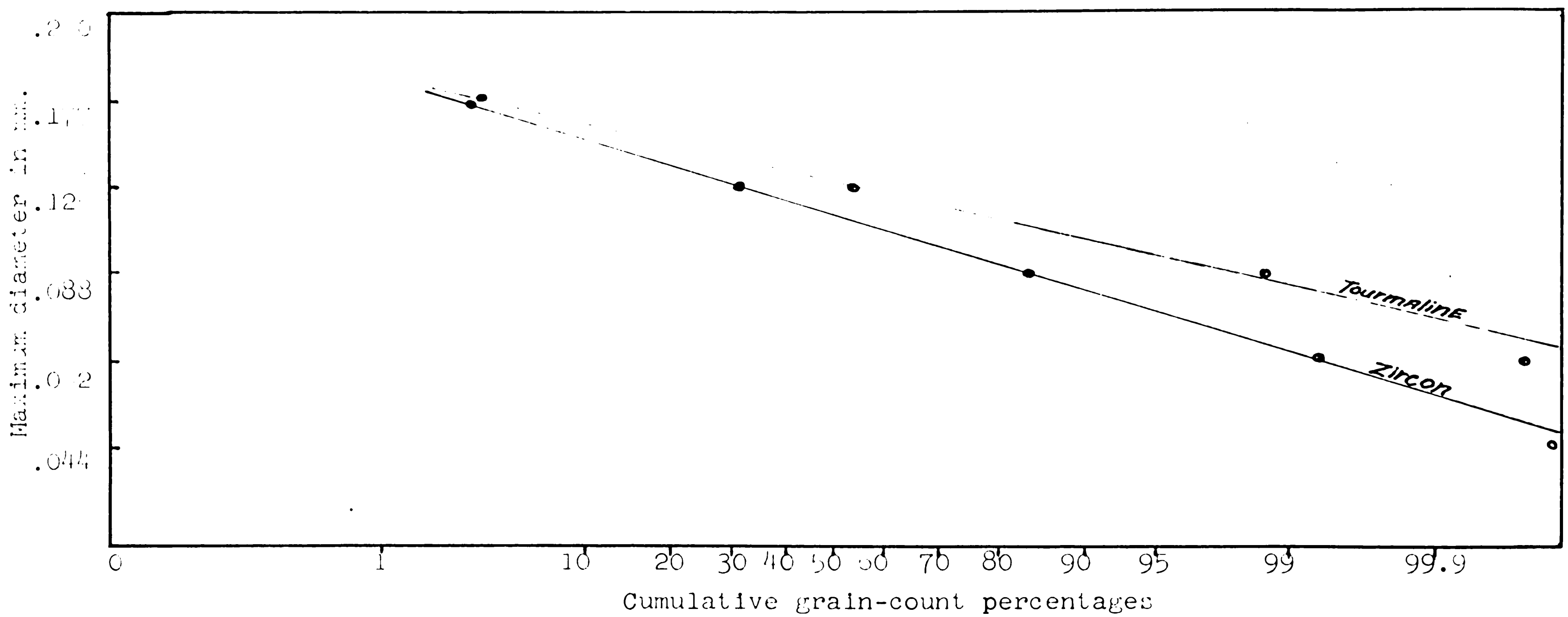

Plate 3. Size-distribution of bulk samples 1 and 3a.

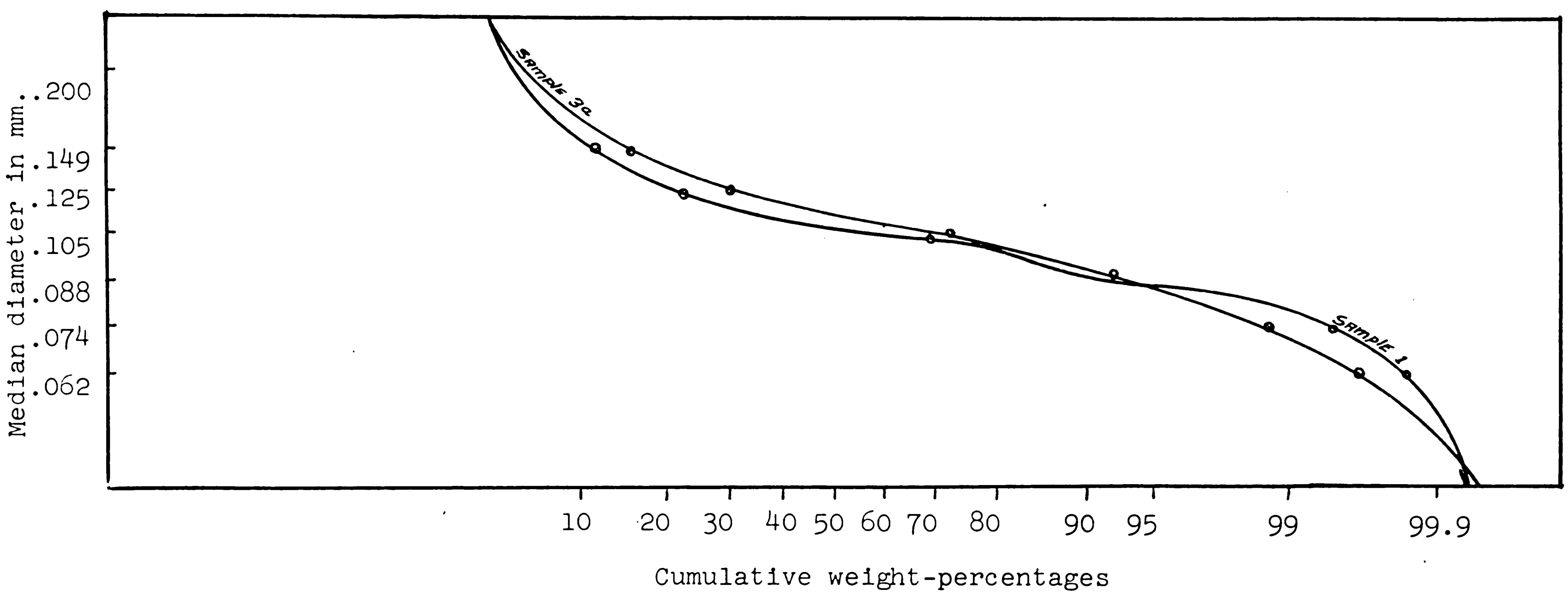

Plate 4. Size-distribution of bulk samples 5a and 7.