THE CARBONATE FRACTION OF BEACH AND DUNE SANDS

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SUMMARY

The sand size carbonate fractions of beach and dune sands from the southeastern U.S. Atlantic coast were investigated from the standpoint of mineralogy, roundness and size distribution. The carbonate fractions of beach–dune sands used in this study range in abundance from less than 1 % to over 40 % and average about 10 %. Calcium carbonate is least abundant in Georgia beaches and increases slightly to the north and greatly to the south. The size distribution of the carbonate fraction is similar to that of the non-carbonate fraction since both have been distributed by the same processes. The variable flat shape of calcareous fragments causes the carbonate fraction to be usually coarser and more poorly sorted than the acid insoluble residues of the samples. No regional relationship between roundness and wave energies was found in sand size materials although field observations indicate high energies strikingly round gravel sized calcareous fragments. There is some tendency for angularity to increase with decreasing grain size in the sand sizes as with quartz grains. The mineralogy of beach sand carbonate fractions is characterized by the almost total absence of high Mg calcite. Aragonite is the dominant mineral.

INTRODUCTION

The calcareous material in beach and dune sands differs from other constituents in several ways. Generally it has the least resistance to abrasion of all materials present, and therefore, should disappear most rapidly and also be the first constituent to reflect the severity of abrasion processes. Calcium carbonate is highly vulnerable to solution; a property emphasized by the typically high porosities and permeabilities of beach and dune sands. Usually the carbonate fraction is of organic origin, has a very limited history of transportation, and in most cases represents the youngest component of the sediment.

In the past, most observations of the carbonate fraction of beach and dune sands have been concerned primarily with overall abundance. However, FOLK and

ROBLES (1964) studied several aspects of the pure carbonate beach sands of Isla Perez. They concluded that the effects of sedimentation processes on sediment parameters are essentially the same as those observed elsewhere on non-carbonate beach materials. CHAVE (1960, 1964) noted that abrasion of coarse calcareous skeletal materials produced large quantities of fines with a general lack of intermediate sized abrasion products. A survey of a variety of beach sands containing calcareous materials (CHAVE, 1960) indicated that a bimodal size distribution was common which reflected this lack of intermediate abrasion products. Apparently bimodal size distributions are not prevalent in the pure carbonate beach sands of Isla Perez (FOLK and ROBLES, 1964).

GILES and PILKEY (1965) noted that two factors control the abundance of the carbonate fraction in Atlantic southeastern U.S. beaches and dunes. The most important of these is the carbonate productivity in adjoining shallow waters. Of secondary importance is wave energy; high wave energies apparently cause increased fragmentation making more material available for widespread incorporation into the sediment.

Three aspects of the carbonate fraction of beach and dune sands from the southeastern U.S. Atlantic beaches are discussed in this paper. These are size distribution, roundness and mineralogy.

Beach and dune sands collected from the North Carolina Outer Banks to southern Florida were used in this study. The non-carbonate mineralogy of beach and dune sands over the same area (and using some of the same samples) was investigated in detail by GILES and PILKEY (1965).

The study area is a large re-entrant coastline. From either end wave energies decrease and tidal amplitudes increase. Georgia beaches are subjected to the lowest wave energies and greatest tidal amplitudes (TANNER, 1960).

METHODS

Sampling locations are shown in Fig.1 and listed in Table I. Beach samples were collected from the approximate mean high tide line. None of the samples was a shell hash although skeletal placers were present at several of the localities. Dune samples were collected from the top of the nearest beach ridge.

The size distribution parameters ascertained were mean grain size, sorting, skewness, and kurtosis, using FOLK and WARD's (1957) measures. Initially an untreated split of the sample was sieved using $1/2$ phi size intervals. Then the acid soluble fraction of each $1/2$ phi size fraction was determined by weighing before and after treatment with 10% hydrochloric acid. With these data it was possible to calculate size distribution parameters for the carbonate and non-carbonate fractions as well as the total untreated sample.

A second split of the sample was used for both roundness and carbonate mineralogical analyses. This split was sieved using 1 phi intervals.

Because of the differing natures of the materials involved, the use of standard quartz roundness outline charts as a basis for determination of roundness of the carbonate fraction was not successful. For this reason a new roundness scale was
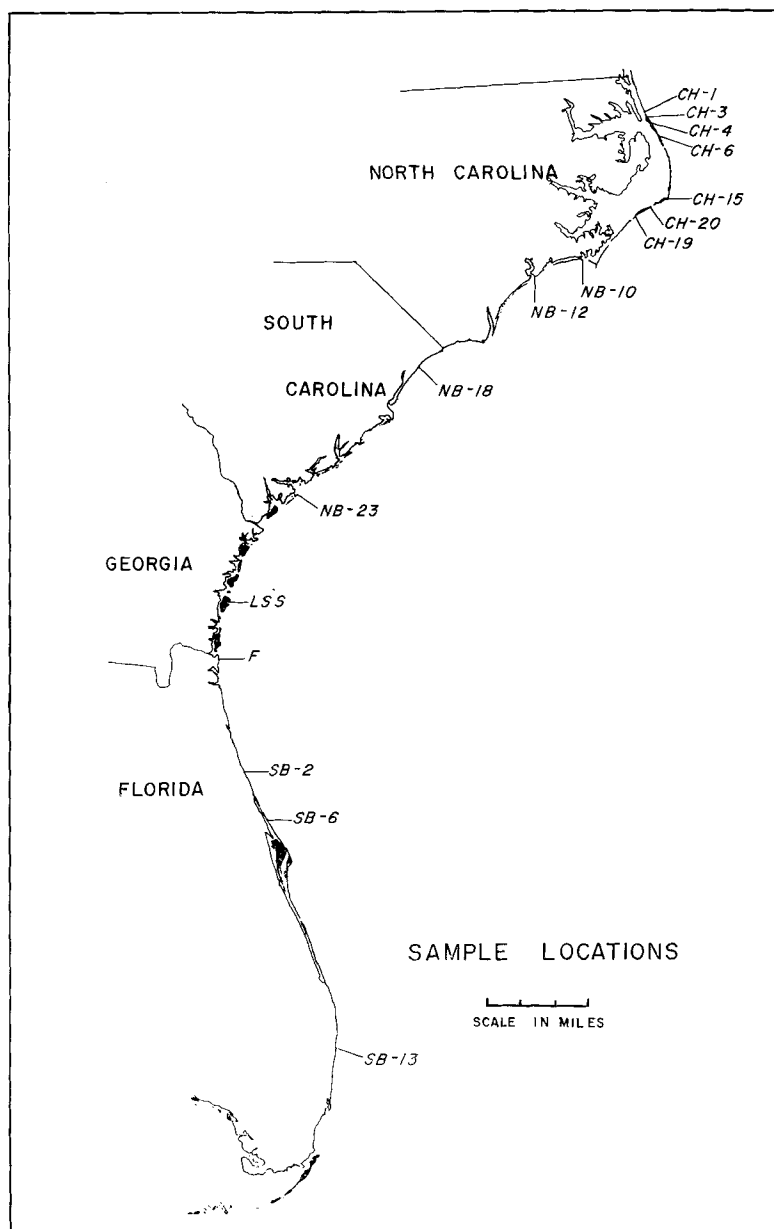

Fig.1. Map of study area showing sample locations.

devised (Fig.2). Roundness determinations were made by visual comparison of shell fragment outlines seen under the microscope and those shown in Fig.2.

Five roundness classes were arbitrarily defined. Class 0 (not shown in Fig.2) consists of whole shells which were rare in the observed size fractions of the samples studied. Class 1 fragments exhibit no apparent rounding of edges or corners and appear as though just broken with a hammer blow. Classes 2 and 3 are gradations between the fresh fragments and the highly rounded usually polished, essentially cornerless fragments making up class 4.

The grains used for roundness determination were individually picked out of the sample, ground up and sedimented on a glass slide for X-ray mineralogical determination. The percentages of aragonite, low Mg calcite and high Mg calcite were determined by methods previously described (PILKEY, 1964a). In many size fractions, insufficient material was available for quantitative analysis by the methods used.
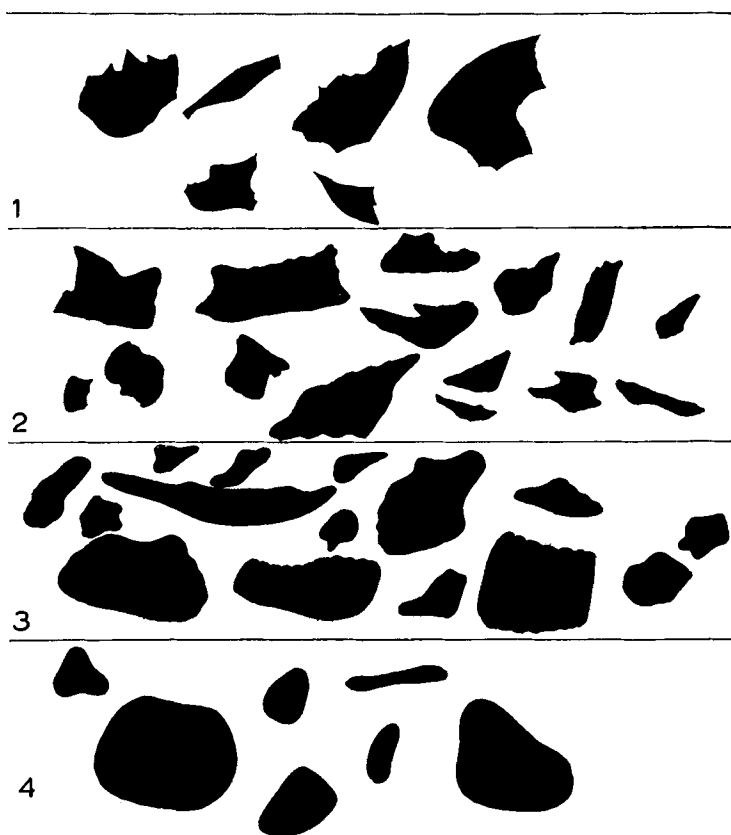

Fig.2. Roundness scale for calcareous shell material used in this investigation.

TABLE I

LOCATIONS OF SAMPLES UTILIZED IN THIS STUDY

Location No.	Location
CH-1	Coffrey's Inlet, 4 miles north of Duck, N. C.
CH-3	Hargraves Beach, N. C.
CH-4	Kill Devil Hills, N. C.
CH-6	Whalebone, N. C.
CH-15	Cape Hatteras, N. C.
CH-19	12 miles south of ferry landing, Ocracoke Island, N. C.
CH-20	northern end of Ocracoke Island, N. C.
NB-10	Ft. Macon Beach, N. C.
NB-12	New River Inlet, N. C.
NB-18	Myrtle Beach, S. C.
NB-23	Edisto Island, S. C.
LSS	Little St. Simons Island, Ga.
F	Fernandina Beach, Fla.
SB-2	5 miles south of Flagler Beach, Fla.
SB-6	15 miles south of Coranado Beach, Fla.
SB-13	Delray Beach, Fla.

ABUNDANCE

The percentage of $CaCO_3$ in the observed samples range from 0.3% in a North Carolina dune sample (CH-6) to 45.7% in a Florida beach sample (SB 13). Most Georgia beach and dune sands were too low in carbonate content to be studied by our techniques. Table II lists the percentage of $CaCO_3$ in each sample.

SIZE DISTRIBUTION

Fig.3 shows cumulative curves of the carbonate fraction and insoluble residue of each sample. Also illustrated is a histogram of the carbonate fraction size distribution. Table II is a summary of mean size, sorting, skewness and kurtosis data for the carbonate fraction, insoluble residue and total sample for each of the samples studied.

The mean diameter of the carbonate fraction is consistently greater than that of the insoluble residue or total sample. This difference is probably caused by the flattened shape of most carbonate particles. The settling velocity of a flat particle is equal to that of a sphere with some smaller diameter. Consequently in a given energy environment, the more nearly spherical quartz grains must be smaller than the carbonate grains. However, another factor is involved. Aragonite and calcite are slightly denser minerals than quartz. This would tend to increase the relative settling velocity

of the shell material and, other things being equal, the carbonate fraction would then be finer mean grain size than the insoluble residue. This is not the case because apparently the shape factor is dominant over the specific gravity factor. Furthermore the difference in specific gravity between shell material and quartz is lessened by the light organic matrix material of shells.
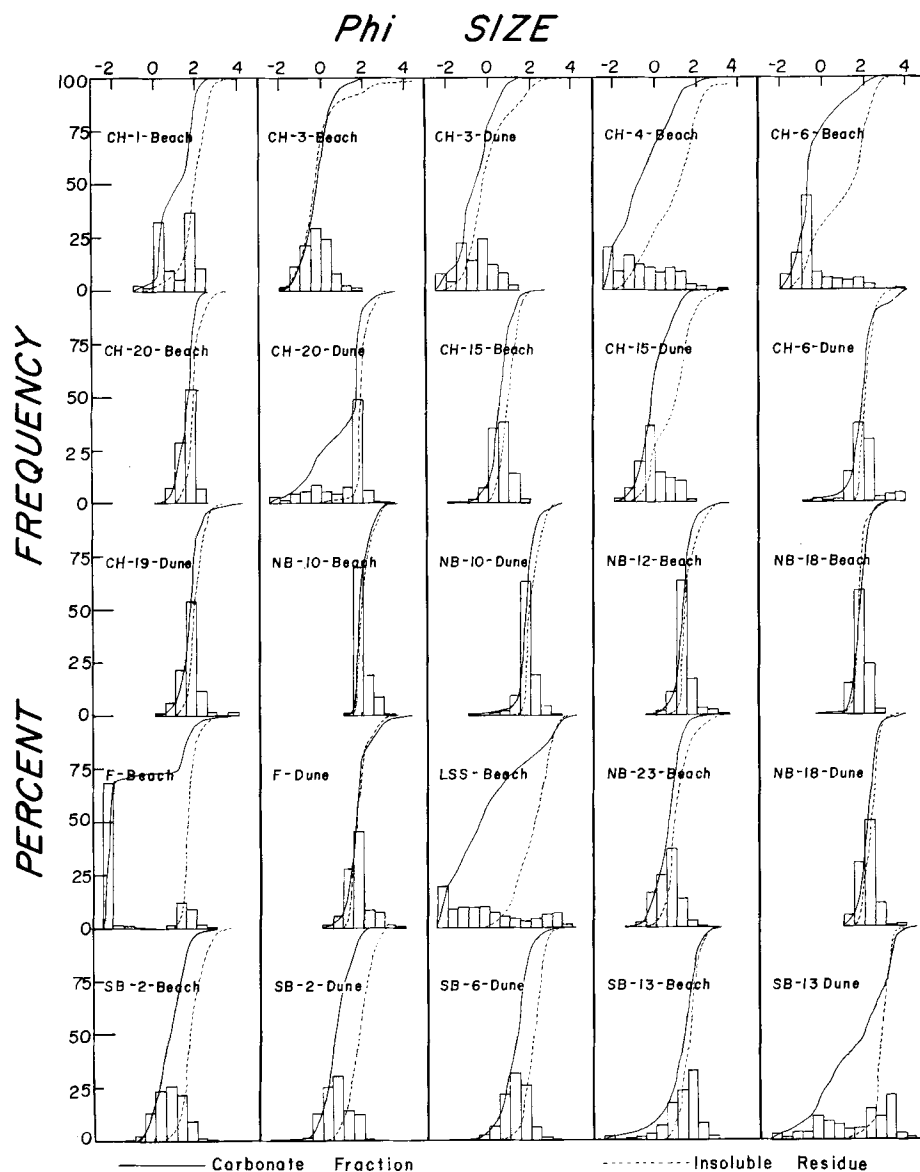

Fig.3. Figures illustrating the size distribution of investigated samples. The solid and dotted cumulative curves represent the carbonate and insoluble residue fractions, respectively. The histogram illustrates the size distribution of the carbonate fraction.

TABLE II

SUMMARY OF SIZE, SORTING, SKEWNESS AND KURTOSIS DATA FOR THE CARBONATE FRACTION (C), INSOLUBLE RESIDUE (IR) AND TOTAL SAMPLE (TS)

Sample No.	CaCO₃ (%)	Mean grain size			Standard deviation			Skewness			Kurtosis		
		C	IR	TS	C	IR	TS	C	IR	TS	C	IR	TS
CH-1-Beach	0.9	1.17	2.03	1.99	0.73	0.61	0.64	−0.14	0.04	0.04	0.59	1.31	1.28
CH-3-Beach	2.8	−0.23	−0.29	−0.28	0.27	0.93	0.87	−0.04	0.07	0.05	1.07	1.92	1.79
CH-3-Dune	5.2	−0.58	−0.01	−0.07	0.91	1.04	1.03	−0.02	0.21	0.21	1.15	1.23	1.25
CH-4-Beach	3.2	−0.62	0.86	0.81	1.58	1.27	1.24	−0.10	−0.20	−0.19	1.01	0.85	0.79
CH-6-Beach	1.9	−0.40	1.05	1.00	−0.03	1.29	1.29	0.24	−0.22	−0.23	1.60	0.65	0.65
CH-6-Dune	0.3	1.93	2.11	2.11	0.58	0.38	0.38	0.01	−0.12	−0.12	1.52	0.91	0.91
CH-15-Beach	4.1	0.56	0.96	0.95	0.45	0.43	0.43	0.00	0.00	0.00	1.00	0.89	0.85
CH-15-Dune	10.7	−0.08	0.80	0.70	0.76	0.86	0.77	0.26	−0.16	−0.12	1.10	0.79	0.76
CH-20-Beach	1.9	1.58	1.84	1.83	0.37	0.37	0.37	0.05	−0.08	−0.08	1.42	1.63	1.61
CH-20-Dune	1.8	1.02	1.95	1.90	1.14	0.31	0.31	−0.41	0.14	0.14	0.89	0.15	0.15
CH-19-Dune	1.4	1.68	1.96	1.94	0.41	0.37	0.37	−0.05	0.01	0.03	1.42	1.25	1.24
NB-10-Beach	1.9	1.94	2.00	2.00	0.35	0.34	0.34	0.18	0.19	0.19	1.27	1.16	1.16
NB-10-Dune	2.1	−1.83	2.05	2.03	0.37	0.39	0.38	0.08	0.19	0.15	1.48	1.19	1.12
NB-12-Beach	7.2	1.29	1.53	1.48	0.34	0.42	0.42	−0.03	0.16	0.17	1.38	1.63	1.77
NB-18-Beach	2.1	1.80	1.74	1.74	0.31	0.28	0.28	−0.01	−0.03	−0.03	1.01	1.25	1.25
NB-18-Dune	1.1	2.13	2.26	2.25	0.39	0.32	0.32	0.00	0.01	−0.01	1.08	0.86	0.84
NB-23-Beach	42.6	0.52	1.00	0.80	0.56	0.58	0.61	−0.06	0.14	0.04	0.99	2.42	1.90
LSS-Beach	5.7	−0.13	2.08	2.02	2.23	0.86	0.95	−0.08	−0.15	−0.13	0.93	0.79	0.90
F-Dune	1.9	1.67	1.74	1.74	0.48	0.42	0.42	0.02	0.08	0.08	1.51	1.37	1.37
SB-2-Beach	34.0	0.66	1.78	1.38	0.66	0.52	0.81	0.02	0.06	−0.11	0.89	1.29	1.18
SB-2-Dune	34.6	0.67	1.76	1.37	0.66	0.56	0.80	0.04	0.02	−0.10	1.08	1.05	0.98
SB-6-Dune	17.2	1.26	2.15	2.03	0.61	0.41	0.54	−0.03	0.00	−0.02	1.20	0.97	1.08
SB-13-Beach	45.7	1.26	1.56	1.41	0.59	0.43	0.56	−0.16	−0.08	−0.14	1.35	1.32	1.46
SB-13-Dune	3.9	1.68	2.88	2.86	1.59	0.31	0.36	−0.18	0.24	0.22	0.71	1.84	1.81

The carbonate fraction of these samples is generally not as well sorted as the total sample or insoluble residue. This is very likely due to the much greater variety of particle shape in carbonates as compared to quartz grains. This variety of shape causes variations of settling velocities for particles with the same intermediate diameter. The consequent greater range in variation in response of shell fragments to environmental energies results in slightly poorer sorting of the carbonate fraction. However, differences between the carbonate and non-carbonate fractions are not large, and sorting values range mainly between moderately good to very good according to FOLK and WARD's (1957) classification. FOLK and ROBLES (1964) noted some poor sorting values in their carbonate beach samples but these were invariably multicomponent samples. They observed best sorting values in "pure" sediment types or in samples made up of a single biologic component such as *Halimeda* flakes. The carbonate fractions of the southeastern U.S. beach and dune sands are probably dominated by the molluscan component which may account for their overall good sorting values.

FOLK and ROBLES (1964) noted that pure carbonate beach samples of Isla Perez tended to be negatively skewed, that is, skewed to coarse grain sizes. They attributed this to the presence of occasional coarse shells or other fragments and/or to the removal of fines by winnowing. However, the size distribution of the carbonate fraction of beaches in the present study area showed no such tendency toward negative skewness. Almost all of the observed samples exhibit nearly symmetrical skewness values. The total samples and insoluble residues also tend to exhibit a low degree of skewness and no preferred tendency toward either coarse or fine skewness was observed.

In terms of kurtosis, the southeastern U. S. beach samples have trends similar to the Isla Perez carbonate beach sands. Both the Isla Perez beach sands and the carbonate fraction of the present study area tend to be leptokurtic or excessively peaked.

The bimodal size distribution of beach sands noted by CHAVE (1960) was found in seven samples (Fig.3). This bimodal nature was attributed by Chave to the fact that abrasion of calcareous material produces fines with few intermediate sizes. However, in the case of the southeastern U. S. beach samples, it is apparent that the finer mode of the bimodal distribution usually occurs at or near the modal value of the insoluble residue curve (Fig.3). This would indicate that the bimodal distributions observed are caused not by a lack of intermediate size abrasion products, but more likely by addition of large carbonate particles. Perhaps removal of fines by wave energy or solution prevents formation of bimodal distributions in most samples.

Fig.4 is a plot of the mean grain size of the carbonate fraction and that of the insoluble residue. Beach and dune sands are shown by separate symbols. The relationship is direct; a strong indication that the same energy conditions controlling the grain size of the carbonate fraction also control the grain size of the non-carbonate fraction.
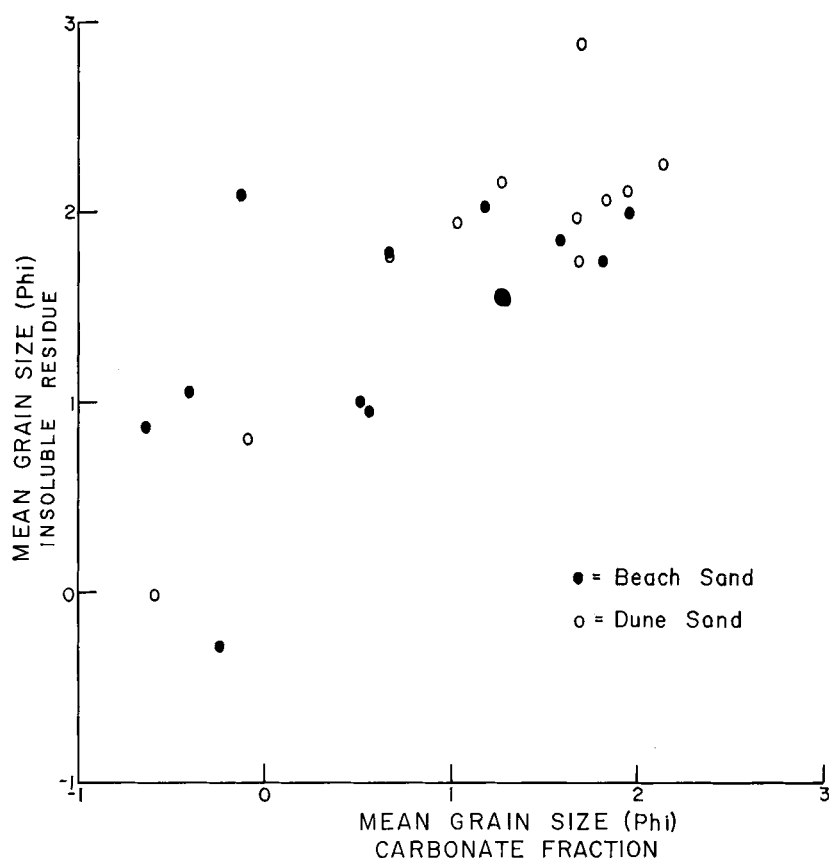
Fig.4. Plot of the mean grain size of the carbonate fraction versus that of the insoluble residue.

ROUNDNESS

The roundness of calcareous material larger than 2 mm obviously reflects wave energy. High energy beaches such as those in the vicinity of Cape Hatteras produce strikingly well rounded fragments whereas much of the coarse shell material in low energy Georgia beaches is unbroken.

In this investigation, the roundness of *sand size* calcareous beach materials was examined to semi-quantitatively ascertain the relationship between roundness and energy. Fig.5 is a plot of the roundness of the 1–2 phi size carbonate fraction versus shoreline distance from the northernmost sampling location. It is immediately apparent from Fig.5 that a clearcut energy–roundness relationship does not exist in the observed samples. North Carolina and Florida sand size calcareous fragments are rounded about the same as low energy Georgia material. Other sand size fractions

TABLE III

ROUNDNESS OF THE CARBONATE FRACTION OF INDIVIDUAL SIZE FRACTIONS

Location	Phi size fractions	Grains counted	Average roundness	Standard deviation roundness
CH-1	—1 to —2	4	3.75	–
	0 to —1	27	3.56	0.83
	1 to 0	117	3.20	0.52
	2 to 1	4	2.50	–
CH-3-Beach	—1 to —2	18	3.9	0.30
	0 to —1	31	3.6	0.70
	1 to 0	42	3.4	0.76
	2 to 1	26	3.4	0.66
	3 to 2	2	3.0	–
	4 to 3	2	3.0	–
CH-3-Dune	—1 to —2	26	4.0	0.19
	0 to —1	25	3.5	0.64
	1 to 0	49	3.4	0.80
	2 to 1	21	2.8	0.66
	3 to 2	6	3.3	0.46
	4 to 3	8	2.5	0.71
CH-4-Beach	—2 to —3	2	4.0	–
	—1 to —2	23	3.4	0.71
	0 to —1	82	3.1	0.86
	1 to 0	64	2.8	0.87
	2 to 1	50	2.6	0.84
	3 to 2	16	2.3	0.85
	4 to 3	7	2.0	0.00
CH-6-Beach	—1 to —2	12	3.8	0.37
	0 to —1	25	3.4	0.80
	1 to 0	25	3.4	0.86
	2 to 1	25	2.9	0.84
	3 to 2	10	3.0	1.00
CH-6-Dune	1 to 0	12	3.0	0.25
	2 to 1	25	2.3	0.71
	3 to 2	12	2.2	0.47
CH-15-Beach	—1 to —2	2	4.0	–
	0 to —1	30	3.1	0.65
	1 to 0	25	3.1	0.93
	2 to 1	27	2.6	0.83
	3 to 2	10	2.6	0.80
	4 to 3	10	1.4	0.66
CH-15-Dune	—1 to —2	15	3.2	0.68
	0 to —1	26	3.5	0.69
	1 to 0	25	3.3	0.79
	2 to 1	28	3.0	0.78
	3 to 2	8	2.2	0.42
	4 to 3	8	2.5	0.50
CH-20-Beach	0 to —1	2	3.5	–
	1 to 0	27	2.8	0.75
	2 to 1	24	3.0	0.77
	3 to 2	12	2.9	0.76

TABLE III *(continued)*

Location	Phi size fractions	Grains counted	Average roundness	Standard deviation roundness
CH-20-Dune	0 to —1	26	2.9	0.84
	1 to 0	28	2.9	0.81
	2 to 1	25	2.8	0.77
	3 to 2	9	3.4	0.68
	4 to 3	10	2.4	0.49
CH-19-Beach	1 to 0	28	2.8	0.68
	2 to 1	25	2.7	0.69
	3 to 2	10	3.5	0.67
	4 to 3	3	2.0	–
CH-19-Dune	1 to 0	26	2.6	0.68
	2 to 1	25	2.8	0.69
	3 to 2	9	2.6	0.49
	4 to 3	12	2.8	0.69
NB-10-Dune	1 to 0	26	2.7	0.81
	2 to 1	26	2.9	0.80
	3 to 2	10	3.1	0.83
	4 to 3	8	2.9	0.78
NB-12-Beach	0 to —1	7	2.4	0.50
	1 to 0	32	2.5	0.70
	2 to 1	27	2.3	0.45
	3 to 2	17	2.0	0.00
NB-12-Dune	2 to 1	27	2.7	0.80
	3 to 2	21	2.3	0.63
	4 to 3	9	2.4	0.68
NB-23-Beach	—1 to —2	6	2.3	0.47
	0 to —1	25	2.7	0.79
	1 to 0	25	2.5	0.70
	2 to 1	25	2.4	0.89
	3 to 2	10	2.4	0.49
NB-23-Dune	—1 to —2	4	2.7	–
	0 to —1	25	2.5	0.70
	1 to 0	25	2.4	0.63
	2 to 1	25	2.3	0.62
	3 to 2	10	2.5	0.50
LSS-Beach	—2 to —3	18 (15)	0.4	0.81
	—1 to —2	25 (5)	2.4	1.36
	0 to —1	25 (2)	3.2	1.17
	1 to 0	25	3.5	0.64
	2 to 1	25	3.2	0.76
	3 to 2	11	3.0	0.85
F-Beach	0 to —1	5 (1)	2.0	1.27
	1 to 0	25	3.0	0.85
	2 to 1	25	2.7	0.66
	3 to 2	12	2.7	0.83
F-Dune	1 to 0	25	2.6	0.69
	2 to 1	25	3.0	0.82

TABLE III *(continued)*

Location	Phi size fractions	Grains counted	Average roundness	Standard deviation roundness
SB-2-Beach	0 to —1	26	3.2	0.72
	1 to 0	30	2.7	0.60
	2 to 1	34	2.5	0.74
	3 to 2	26	2.1	0.25
	4 to 3	16	1.8	0.39
SB-2-Dune	0 to —1	29	3.1	0.64
	1 to 0	25	3.0	0.57
	2 to 1	26	2.8	0.77
	3 to 2	25	3.2	0.69
	4 to 3	6	3.0	0.82
SB-6-Beach	0 to —1	14	2.6	0.61
	1 to 0	67	2.5	0.63
	2 to 1	25	2.4	0.63
	3 to 2	29	2.5	0.72
SB-6-Dune	0 to —1	51	3.1	0.84
	1 to 0	25	2.9	0.80
	2 to 1	27	3.1	0.75
	3 to 2	25	2.9	0.82
	4 to 3	21	3.2	0.74
SB-13-Beach	—1 to —2	13	3.1	0.47
	0 to —1	29	3.1	0.78
	1 to 0	31	2.8	0.68
	2 to 1	16	2.7	0.68
	3 to 2	18	2.6	0.68
	4 to 3	25	2.4	0.74

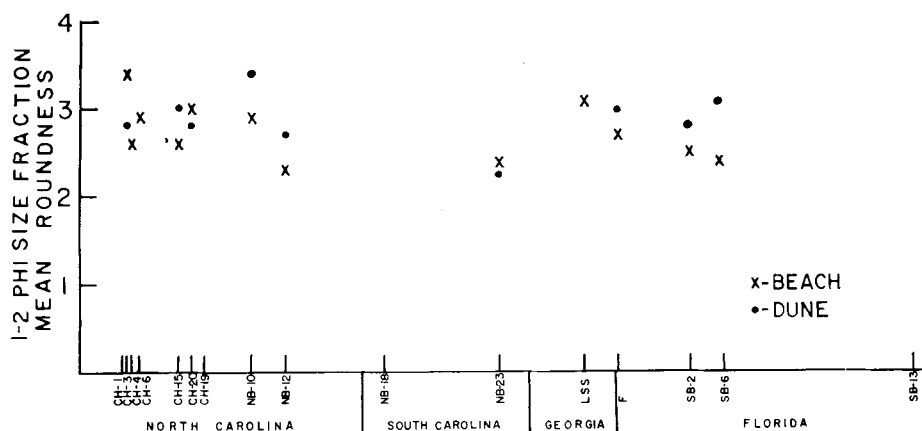* Number in parentheses designates number of whole shells (roundness = 0).

Fig.5. Plot of the roundness of the 1–2 phi size carbonate fraction versus shoreline distance from the northernmost sampling location.

not plotted in Fig.3 show a similar lack of relationship between roundness and wave energy.

The lack of an energy–roundness relationship in sand size is puzzling. Perhaps this is an indication that sand size calcareous material is derived by the gradual wearing down of coarser material rather than fragmentation. In this case, the roundness would be the same whether it was worn down rapidly in high energies or slowly in low energies. This idea is strengthened by CHAVE's (1960) tumbling barrel observations that coarse skeletal fragments are worn down through gradual abrasion rather than by fragmentation into intermediate sized particles. It is also possible that sand sizes are formed by fragmentation and are little rounded thereafter by either high or low energy environments.

Evidence favoring fragmentation as the dominant calcareous sand-forming mechanism is the decrease in roundness with decreasing grain size seen in some of the carbonate fractions of these beaches and dunes (Table III). Obviously, simply wearing down large fragments will not produce smaller, more angular fragments. This relationship between size and roundness can probably best be explained by assuming that the sand size material was produced by initial surf zone fragmentation of relatively fragile small shells, and that such fragmentation occurs in both high and low energy environments.

Decreasing roundness with decreasing size of quartz sand grains is a well established phenomenon and is generally attributed to differential rate of wear of coarse and fine grains. Coarse grains round fastest due to greater impact and a tendency to be transported by rolling rather than suspension (PETTIJOHN, 1957; FOLK, 1965). It is likely that this explanation applies to the size–roundness relationship of the carbonate fraction.

No consistent differences in the roundness of beach and dune carbonate fractions were noted. GILES and PILKEY (1965) observed that elongate heavy minerals were preferentially concentrated (slightly) in beach sands relative to dune sands in this same study region. Observation of the carbonate fraction indicated no clear tendency toward concentration of elongate shell fragments in beaches.

MINERALOGY

The mineralogy of calcareous marine organisms is discussed by CHAVE (1954) and LOWENSTAM (1954). The gross mineralogy of carbonate sediments has been studied by STEHLI and HOWER (1961) and CHAVE (1962). PILKEY (1964b) reported on the mineralogy of the carbonate fraction of the continental shelf and upper slope sediments adjacent to the present study area.

The dominant skeletal forming minerals of marine invertebrates are aragonite and high and low Mg calcite. Molluscs are by far the most important animals contributing sand size or larger carbonate material to beach and dune sands in the study area. These contribute aragonite and low Mg calcite but not high Mg calcite. Echi-

noids are the most important high Mg calcite contributors. Barnacles are common in these beach and dune sediments but foraminifera, sponges, coral, bryozoa, calcareous algae are only of minor importance in terms of the total sand size or larger calcareous material.

Table IV lists the percentage of aragonite in various size fractions of beach and dune sand carbonate fractions. The few samples containing traces of high Mg calcite are marked by an asterisk.

The most surprising aspect of these data is the lack of high and low Mg calcite relative to the average shelf sediment from which the beach carbonate fraction is largely derived. According to PILKEY (1964) sand size carbonate material on the adjacent shelf averages 67% aragonite, 11% high Mg calcite and 22% low Mg calcite. Since high Mg calcite is present in only trace amounts, the difference between the percentages of aragonite and 100% in Table IV is largely low Mg calcite. Thus, these beach sands exhibit considerably different carbonate mineralogy than shelf sands with respect to both low and high Mg calcite.

On the average, beach sands contain about 10% or 12% less low Mg calcite than the average adjacent shelf sand size carbonate fraction. The explanation for this difference is not clear. It is possible that the difference is original; that is, the nearshore calcareous fauna making up the beach sands contains less low Mg calcite than the average regional shelf fauna. Or perhaps the particular aragonite forms being contributed to these beaches are slightly more abrasion resistant than the low Mg calcite shells.

Possible explanations for the relative paucity of high Mg calcite in the calcareous fraction of beach sands include: (1) original difference or the high Mg calcite was never contributed to the beach; (2) the unstable high Mg calcite was dissolved or recrystallized (exsolved) on the beach; or (3) the high Mg calcite contributors are least resistant to abrasion.

The first explanation seems unlikely since echinoderms which are probably the most important local high Mg calcite contributors are common in adjacent shallow waters and PILKEY (1964) has noted the presence of high Mg calcite in sand size shelf calcareous materials. The possible solution or recrystallization of high Mg calcite is more difficult to evaluate. PILKEY and HOWER (1960) analyzed many whole echinoid tests from Pacific coast beaches and found no apparent alterations. Whether the same would hold true for fragmented and abraded sand size materials is another question. Microscopic observation of the material prior to mineralogical analysis indicated very little material of echidoderm origin to be present. Of course it is difficult to identify with certainty such abraded calcareous grains. Although solution or recrystallization may take place we feel that the most important reason for the lack of high Mg calcite in these beaches is the relatively fragile nature of starfish, sand dollars, and sea urchins and their consequent removal from sand sizes by abrasive processes.

Table V is a comparison of the average aragonite content of various size fractions of the carbonate fraction of beaches and dunes. It is apparent that no con-

TABLE IV

PERCENT ARAGONITE OF THE CARBONATE FRACTION OF VARIOUS SIZE FRACTIONS

Location No.	Size fraction (phi)					
	3 to 2	2 to 1	1 to 0	0 to —1	—1 to —2	—2 to —3
CH-1-Beach			79	87	100	
CH-3-Beach			94	87	100*	
CH-3-Dune			89	100	100	100
CH-4-Beach		88	88	92	100	100
CH-6-Beach		100	70	78		
CH-6-Dune					100	
CH-15-Beach		100		100	100	
CH-15-Dune		90[1]	96	100		
CH-19-Beach			100			
CH-19-Dune		90	89			
CH-20-Beach			82			
CH-20-Dune			70[1]	90		
NB-10-Dune			100			
NB-12-Beach			84	100[1]		
NB-23-Beach	100[1]	91	92	88		
NB-23-Dune		88	88	92	100	
LSS-Beach		100	87	85	87	76
F-Beach			91	100	100	100
SB-2-Beach			93	100	100	
SB-2-Dune		100	91	100	100	
SB-6-Beach			94	100		
SB-6-Dune			92	96	100	
SB-13-Beach				92		100
SB-13-Dune			86		100	
Average	100	94	89	94	99	95

* Trace of high Mg calcite.

TABLE V

COMPARISON OF THE ARAGONITE CONTENT OF BEACH AND DUNE CARBONATE FRACTIONS

Size fraction (phi)	Beach	Dune
2 to 1	96	92
1 to 0	88	88
0 to —1	92	97
—1 to —2	98	100
—2 to —3	94	100

sistent difference in the mineralogy of these two types of sediments exists. This indicates that the relatively greater degree of subaerial exposure of dune calcareous materials has not resulted in detectable amounts of solution of aragonite.

There appear to be no consistent differences between the carbonate mineralogy of various sand sized fractions (Table IV and V).

CONCLUSIONS

(1) The grain size of the carbonate fraction tends to be coarser than that of the insoluble residue or total sample. This is probably related to the flat shape of most calcareous particles and the consequent decrease in settling velocity.

(2) The sorting of the carbonate fraction tends to be slightly poorer than that of the insoluble residue or total sample. This is very likely due to the great varieties of shapes of calcareous particles, hence varying settling velocities as opposed to the more or less equidimensional shape of quartz grains.

(3) A direct relationship exists between the grain size of the carbonate fraction and that of the insoluble residue (quartz). This is because the same energy processes influence both components.

(4) Previous experimental work has shown that abrasion of calcareous skeletal material produces fines with few intermediate sized particles. Thus a bimodal size distribution would be expected. However, a bimodal size distribution of the carbonate fraction of beach–dune sands is exception rather than rule. Removal of the fines by wave energy or solution probably prevents formation of bimodal distribution in most samples.

(5) On the basis of limited data from low energy beaches, it appears that no obvious regional relationship exists between wave energy and the roundness of sand size calcareous fragments. Field observations indicate a good relationship to exist between gravel sized shell material roundness and wave energy.

(6) With decreasing grain size (within the sand range) roundness of the carbonate fraction often, but not always, decreases. Increasing angularity in the fines indicates that this material is not derived primarily by wearing down of coarser particles but rather by fragmentation of coarser particles.

(7) Beach-sand carbonate fractions are deficient in low and high Mg calcite and tend to be enriched in aragonite relative to the typical carbonate fraction mineral assemblage in adjacent continental shelf sediments. In fact, high Mg calcite is essentially absent in beaches and dunes. This is attributed mainly to the fragile nature of the high Mg calcite contributors and their resultant rapid physical breakdown. The possibility of solution or recrystallization of unstable high Mg calcite in the intertidal zone is doubtful but cannot be eliminated. The near-absence of low Mg calcite in beach–dune sands is more difficult to explain. It may simply be an original difference related to the nature of skeletal material available for incorporation in the sediment.

(8) There is no consistent difference between the carbonate mineralogy of various size fractions within the sand range.

(9) There is no consistent difference between the carbonate mineralogy of beaches and dunes. Thus there is no evidence of significant mineralogical alteration as a result of differences in extent of short term subaerial exposure in beaches and dunes.

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