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FIGS. 1–8, DECEMBER, 1965

ATLANTIC BEACH AND DUNE SEDIMENTS OF THE SOUTHERN UNITED STATES[1]

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ABSTRACT

Over 50 pairs of beach and dune samples and 40 river samples were collected from the North Carolina outer banks to Miami Beach, Florida. Median grain size, sorting, percent calcium carbonate and heavy and light mineralogy were determined. Mineralogical counts were made on the .125 – .25 mm size fraction only.

Apparently beach and dune sands are derived both from nearby rivers and from preexisting sediment on the adjacent shelf. Beach and dune sands contain an unstable assemblage of heavy minerals, unlike the assemblage noted in rivers draining only coastal plain sediments. The heavy mineral assemblage of rivers draining the piedmont is unstable and more closely resembles that of beaches and dunes. Regional mechanical sorting effects are not of primary importance in determining the composition of the heavy mineral suite.

Grain size of beach and dune sand is controlled mainly by wave energy and is finest in Georgia and becomes coarser to the north and south. The carbonate content is lowest in Georgia sediments and increases strongly to the south and slightly to the north. The carbonate content is controlled by availability of materials and also by wave energy. The most consistent difference between beaches and dunes is the relative abundance of elongate minerals in beach sediments.

INTRODUCTION

This study was initiated for the purpose of determining the nature and sources of beach and dune sediments as well as regional sorting effects. Between north of Cape Hatteras, North Carolina and Miami Beach, Florida 53 beach and 50 dune samples were collected. Forty river samples were obtained from the same area (fig. 1). Grain size sorting and the heavy and light mineralogy were determined on all samples. In order to facilitate the provenance and regional sorting aspects of this study, all mineralogical determinations were made on a single size fraction; fine grained sand (.125–.25 mm). Thus it is important to note that conclusions regarding the beach and dune sediments must, strictly speaking, apply only to the particular size fraction examined. However, in all probability conclusions concerning the fine sand size fraction apply to all fractions of most of the well-sorted beach and dune sands.

Studies of sediment distribution on the southern United States continental shelf include those of Stetson (1938) and Gorsline (1963). Pilkey (1963) investigated the heavy mineral content of these sediments. Studies of nearshore and beach heavy mineral distribution in this area have been performed by Tyler (1934), Miller (1945), Casperson (1948), Neiheisel (1958, 1959 and 1962), and McCauley (1960) among several others. These studies were concerned with more local effects than the present study. Also the data of the present study and those of the previous studies are not entirely comparable because most of the previous studies are concerned with total mineralogy rather than that of a single size fraction.

Regional studies of beach and nearshore heavy mineral distribution have not been performed in this area previously. The Gulf of Mexico has been investigated in this respect, however (Van Andel and Poole, 1960; Hsu, 1960). Sediments from the southern United States Atlantic Coast differ from those of the Gulf Coast in several respects. Of particular importance is the fact that the provenance of Gulf Coast material is much more varied and complex.

Henry and Price (in preparation) review the general physiographic, climatic, and oceanographic characteristics of the study area. Most of the area is part of a large shoreline re-entrant extending between Cape Hatteras and Palm Beach, Florida. The Georgia coast is in the deepest part and approximate center of this re-entrant. From either end wave energy, wave height and windiness decrease and the tidal amplitude increases. These lateral changes in environmental factors, particularly wave energy, are important in determining the nature of sediment types and will be referred to in later sections. W. Armstrong Price (personal communica-

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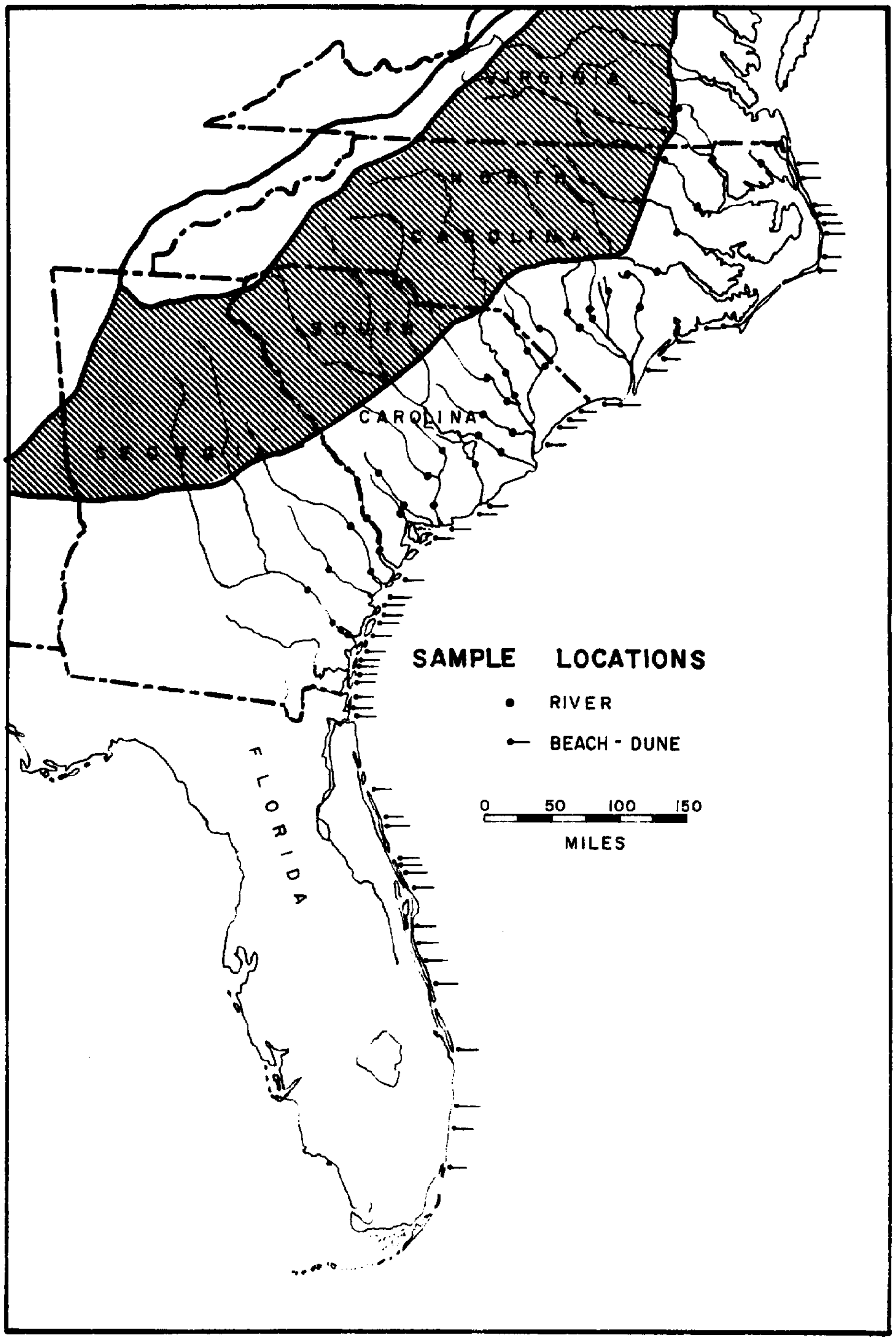

FIG. 1.—Index map of study area showing collecting localities of beach, dune, and river samples, river drainage basins and generalized geology. Shaded area is the piedmont province.

tion) has pointed out that the results of this study should be applicable to the investigation of local coastal re-entrants as well as regional ones.

METHODS

Field.—At each collecting locality, beach samples were collected on the upper foreshore at what appeared to be the approximate high tide line. Samples were also obtained from the top of the nearest dune or beach ridge. Lateral distance between the two samples ranged from a minimum of 5 yards to a maximum of 250 yards, probably averaging close to 20 yards. River samples were collected almost exclusively from the upstream side of highway bridges. Although precautions were taken to sample natural appearing beaches and dunes, the possibility of contamination of some sand samples due to artificial beach construction cannot be eliminated, particularly in southern Florida. Figure 1 shows all collecting localities.

Laboratory.—All samples were dried and sieved using Udden-Wentworth intervals. Beach and dune samples were treated with hydrochloric acid to determine the carbonate content and then resieved.

Heavy minerals were separated from the acid-treated .125–.250 mm size fraction (fine sand) using standard bromoform heavy liquid techniques. The light residue of the heavy mineral separation was mounted on slides and the K-feldspars and plagioclase feldspars were stained using standard techniques. Grains that were deeply eteched by the hydrofluoric acid but not stained by subsequent staining procedures were considered to be chert. After counting both heavy and light minerals, heavy mineral percentages were calculated on a non-opaque basis and light mineral percentages were calculated on a carbonate-free, heavy mineral-free basis.

RESULTS

Figure 2 is a plot of the median grain size and sorting (Trask's sorting coefficient) of the acid insoluble residue of both beach and dune sediments. Figures 3 and 4 illustrate the light mineralogy, carbonate, and total heavy mineral

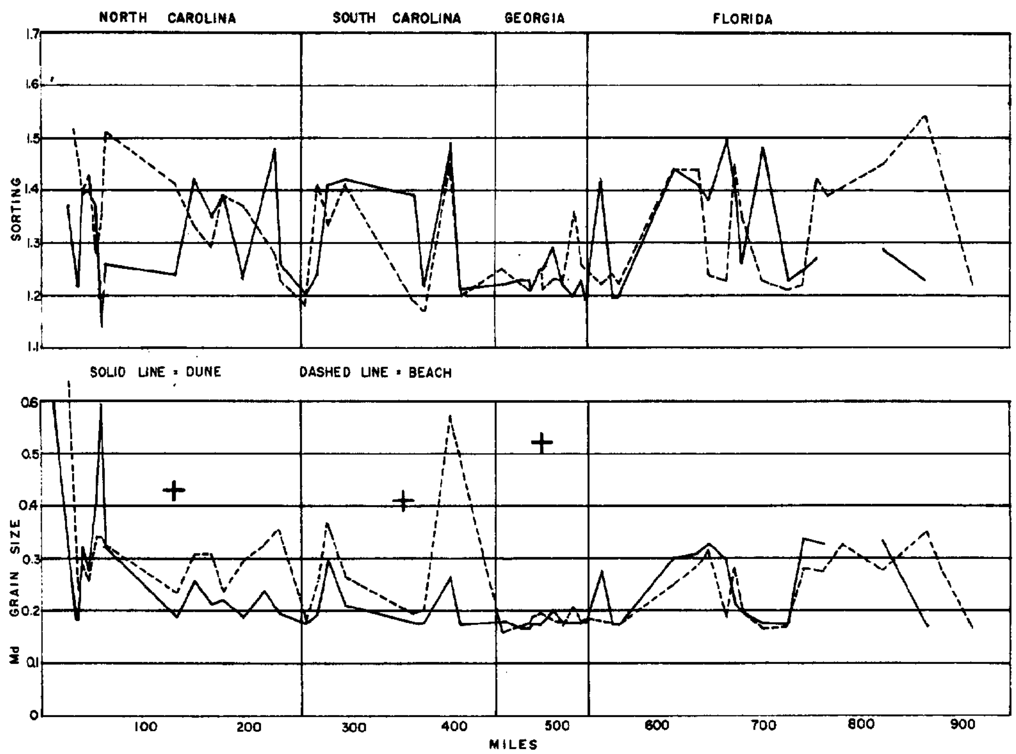

FIG. 2.—Plot of the median grain size and sorting of beach and dune samples versus shoreline distance. Samples are acid insoluble residues. The first two samples (at 0 and 14 miles) are too coarse and poorly sorted to be plotted on this scale. The crosses on the median grain size scale represent the average median grain sizes of all the river sands studied in the particular state.

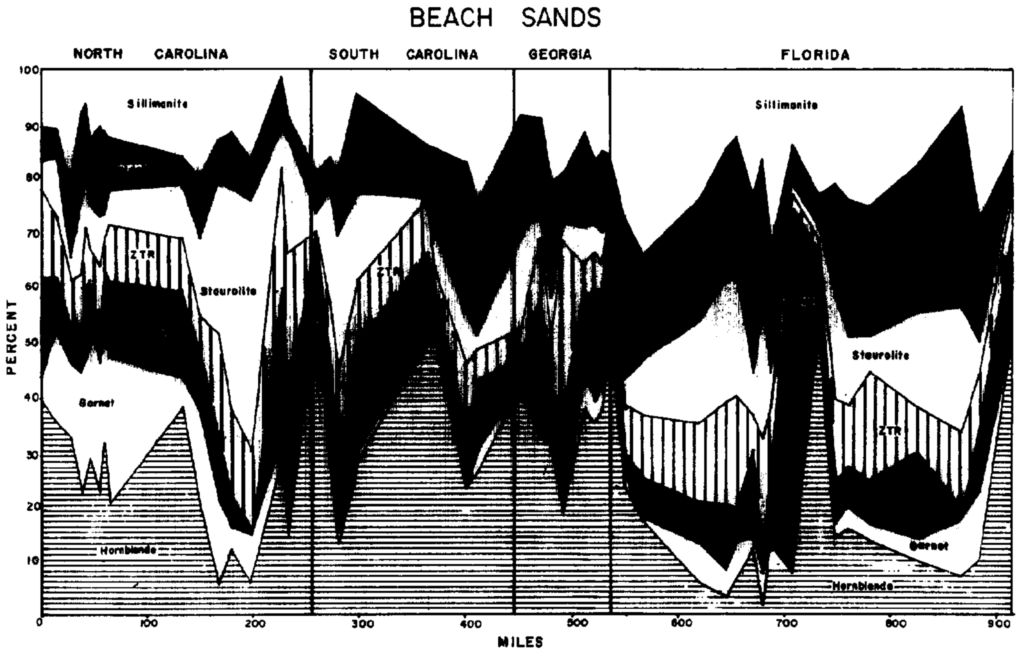

FIG. 3.—Plot of beach sand fine sand size, heavy mineralogy calculated on a non-opaque basis.

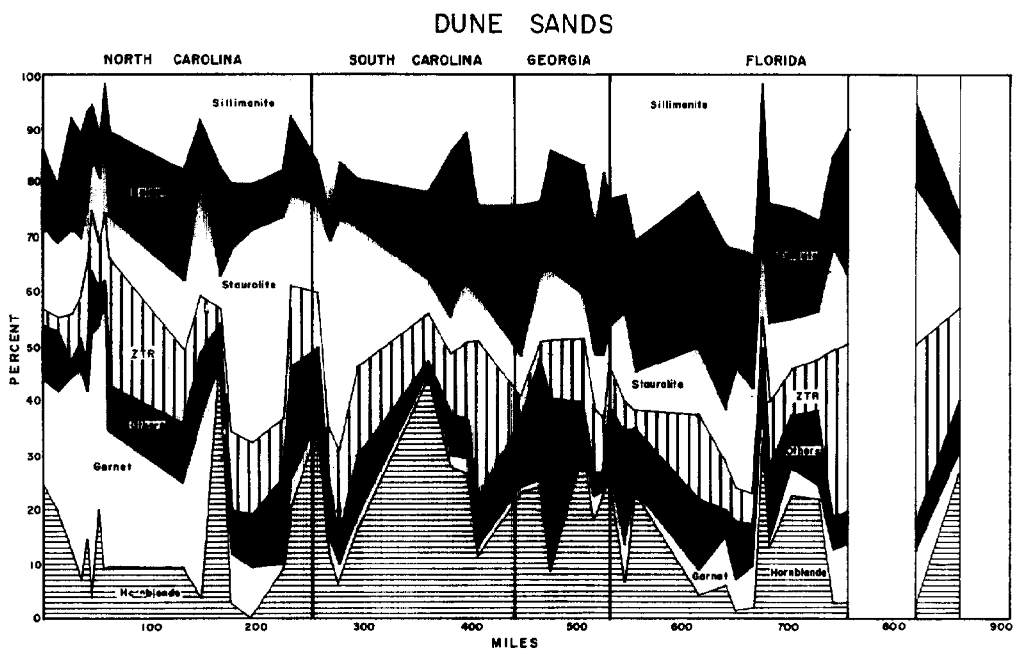

FIG. 4.—Plot of dune sand, fine sand size heavy mineralogy calculated on a non-opaque basis.

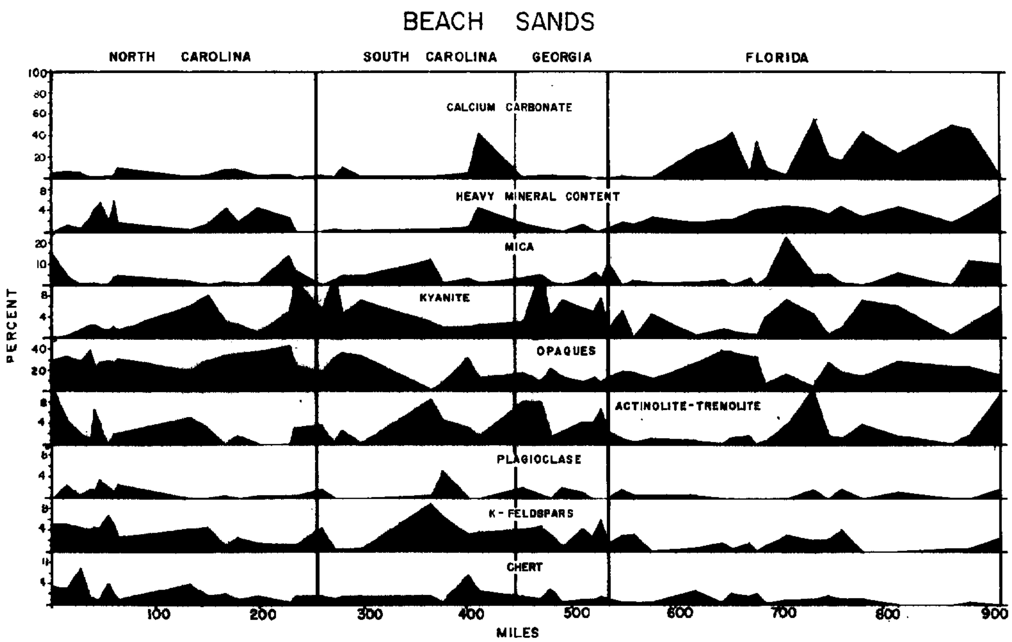

FIG. 5.—Plot of the total carbonate content, total heavy mineral content, and mineralogy of beach sands. Mica includes both muscovite and biotite. Percentages of K-feldspars, plagioclase and chert are percentage of carbonate-free, heavy mineral-free light fraction.

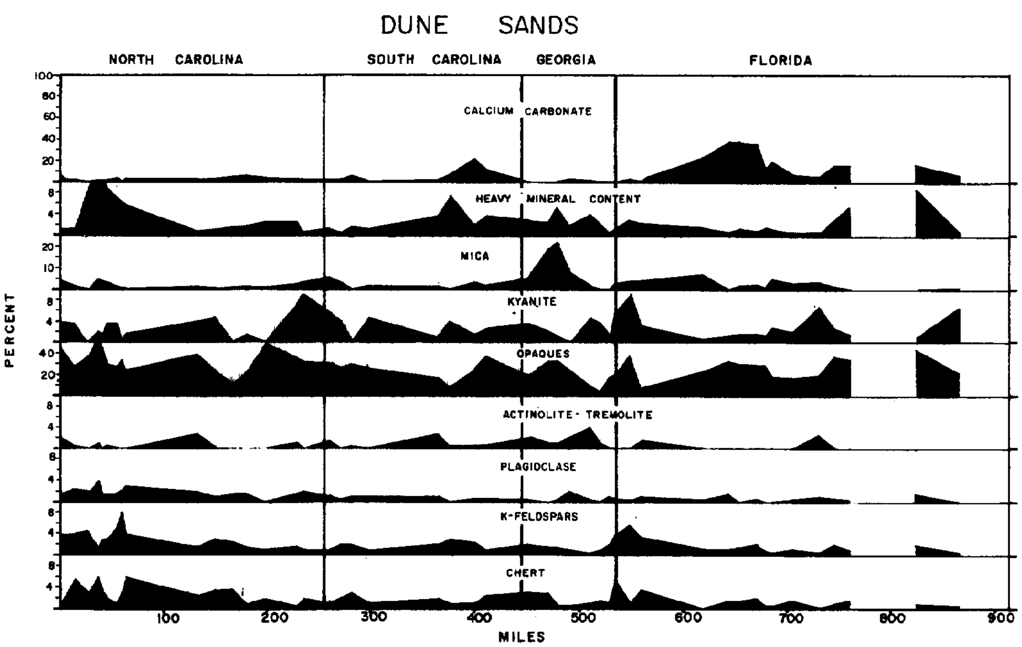

FIG. 6.—See FIG. 5.

content and the percentages of certain heavy minerals in beach and dune sediments respectively. Figures 5 and 6 illustrate the heavy mineral abundances of the major species. Distance plotted on the abscissa of these figures is an approximate shoreline distance taking into account irregularities in outline. Four Georgia locations were not plotted on figures 3 thru 6 in the interest of clarity of presentation. However, the removal of these data does not affect the conclusions in any way.

Table 1 is a summary of all the data. For convenience, state boundaries were used for tabulation. The Savannah River on the South Carolina-Georgia boundary is considered to be a Georgia river for the sake of computations. With the exception of median grain size, sorting and percent calcium carbonate, all figures refer only to the fine sand size fraction.

Mineralogy

Quartz most commonly composes more than 90 percent of the light fraction of beach and dune sands. Of the three other non-carbonate light minerals of importance, K-feldspars are most abundant, followed by chert and plagioclase.

The heavy mineral content of the fine grain size fraction of beach and dune sand ranges from 40 percent to less than 1 percent. Typically heavy mineral percentages (after acid treatment) fall below 5 percent. It is important to again emphasize that these figures do not represent the total heavy mineral content of the sediments. Opaque minerals are an important constituent of all heavy mineral suites and in beaches and dunes the most important opaque mineral is ilmenite. "Others" include pyroxenes, topaz, anatase, xenotime, corrundum and unidentified grains. No olivine was observed.

Over the 913 mile shoreline covered by this study, no fundamental mineralogical differences were observed. Variations in the abundance of mineral species occur but no major new species are introduced and even varieties of minerals such as tourmaline, hornblende and garnet remain in fairly constant proportion to one another.

Rivers

River sands, which range in median grain size from medium to coarse sand are typically coarser than beach and dune sands. Sorting is also generally poorest in river sands. The amount of heavy minerals is about the same for river, beach, and dune sand, but mineral suites from river sands differ from beach and dune sand suites in several respects. First, highly weathered minerals, primarily ferromagnesians, appear to be more common in river sands. Secondly the opaque mineral content of river sands is higher (which may be due to the presence of highly weathered ferromagnesians). A third consistent difference between river and other sands is the high mica content of river sands.

There is considerable more overall variation in mineralogical composition in the fine grained sand of river sediments as compared to beach and dune sands because some of the rivers drain piedmont and coastal plain rocks and others drain only the sediments of the coastal plain. A significant difference exists between the two types of rivers (table 1). Heavy minerals of the piedmont rivers include more biotite, muscovite, epidote and actinolite-tremolite which are unstable minerals and fewer minerals which are considered stable (Pettijohn, 1954). Based on the differences between piedmont and coastal plain rivers a stability series can be calculated for the particular weathering and transport conditions encountered in this area, as shown in table 2. This stability series is reasonably close to the expected order except perhaps for the position of rutile. Of course, this series is based on the fine sand size only and hence may not be entirely comparable to previous work.

Grain Size

The coarsest median grain size observed on untreated beach samples is 2.43 mm and the coarsest dune or beach ridge sample is 1.84 mm (both from the vicinity of Nags Head, North Carolina). After treatment with acid these samples yielded median grain sizes of 2.46 and 1.76 respectively. The finest untreated beach sample median grain size is .162 mm and the finest dune sample is .166 mm (both from Ossabaw Island, Georgia). After treatment with acid these samples yielded median grain sizes of .168 and .166 mm respectively.

According to Trask's (1932) sorting classification, all the beach and dune sands are well sorted. Treatment with acid resulted in only slight changes in the values of median grain sizes and sorting coefficients. Most commonly sorting was improved slightly after removal of the carbonate fraction and grain size decreased slightly.

Percent Calcium Carbonate

It is apparent that calcium carbonate is an important constituent of upper beach and dune sediments only in Florida. Georgia sands contain the least amount of calcium carbonate. The maximum observed carbonate content of beach sands is 55 percent (weight percent) at Cocoa Beach, Florida. Several other Florida Beach samples contained more than 40 percent calcium

TABLE 1

	Grand Average—Rivers (40)	Grand Average—Dunes (50)	Grand Average—Beaches (53)	Piedmont Rivers (27)	Coastal Plain Rivers (13)	Virginia Rivers (3)	North Carolina Rivers (12)	South Carolina Rivers (17)	Georgia Rivers (8)	North Carolina Dunes (17)	North Carolina Beaches (17)	South Carolina Dunes (7)	South Carolina Beaches (7)	Georgia Dunes (11)	Georgia Beaches (11)	Florida Dunes (15)	Florida Beaches (18)
Median Size (Untreated)	0.66	0.27	0.34	0.76	0.44	3.39	0.43	0.41	0.52	0.36	0.50	0.22	0.29	0.18	0.23	0.27	0.28
Sorting (Untreated)	1.49	1.34	1.40	1.51	1.45	1.77	1.43	1.45	1.53	1.41	1.53	1.32	1.34	1.22	1.29	1.35	1.37
Median Size (Treated)		0.27	0.31							0.37	0.52	0.21	0.29	0.18	0.18	0.25	0.24
Sorting (Treated)		1.32	1.36							1.37	1.49	1.34	1.31	1.23	1.24	1.33	1.34
Percent Carbonate		7	11							3	4	7	9	0	2	15	23
Percent Heavies	3.7	4.0	2.1	4.4	2.3	3.7	3.0	4.2	10.3	8.4	2.0	2.0	1.1	3.5	0.8	2.6	3.3
Opaques	44.5	28	23	41.5	50.5	29.5	51	45	39	32.5	29.5	23.5	22	24	15	27	21.5
Chert	3	2	1.5	3	3	5.5	3	3	2.5	3	2	2	2	2	1	1.5	1
K Feldspar	5.5	2	2.5	7	2	13	6	4	4	3	3.5	2	3.5	1.5	3	1.5	1.5
Plagioclase	1	1	1	1.5	0.5	0.5	0.5	1	2.5	1.5	1	0.5	1	0.5	0.5	0.5	0.5
Green Hornblende	11.5	14	21.5	15.5	2	28.5	9.5	7.5	18	13.5	20	19.5	27	18	31	9	15
Brown Hornblende	0.5	1	1.5	0.5	0	0	0.5	0.5	0.5	1	2.5	1	2	0.5	1.5	2.5	1
Sillimanite	11	17.5	17	8	18.5	6	5.5	15.5	13.5	12.5	12.5	19	15.5	20	17	21.5	21
Zircon	6.5	4	2.5	5	9.5	0.5	6.5	8	4.5	4	2	4.5	2	2.5	2.5	5	3
Rutile	3.5	3.5	2.5	3.5	4	1	5.5	3	3	3	2.5	4	2	3.5	1.5	5.5	3.5
Staurolite	14.5	15	12	12	19.5	11.5	18.5	16	4.5	17.5	14.5	19.5	11.5	9	8	14.5	12
Garnet	2	10	6	2	2	5	3	1.5	2	22	14	2	2	1.5	1	5	3
Kyanite	4	3	3.5	3.5	5.5	0.5	6	4.5	2	3	3.5	2.5	5	3	4.5	3	3.5
Epidote	11	18.5	15.5	12.5	7.5	10	10.5	8	17	13.5	9.5	16	16	23.5	14.5	21.5	22
Brown Tourmaline	5	3.5	4.5	3.5	8	0	6	5.5	3	3	6	4.5	3.5	3.5	3.5	3	4.5
Green Tourmaline	1	0.5	1	0.5	1	0	0.5	1	0	0.5	1.5	1	2	1	1	0.5	0.5
Biotite	8	2.5	3	9.5	5	11.5	5.5	9.5	8.5	1	2.5	1	3	6.5	4	1.5	4
Muscovite	15	0.5	1	17.5	11.5	15.5	17	15	12.5	0	0.5	0.5	1	0	1.5	0.5	1
Actinolite-Tremolite	0.5	0.5	2.5	0.5	0	0.5	1	0.5	1	0.5	2.5	1	3	1.5	3.5	0.5	2

carbonate. The highest values observed in dune sands is 37 percent which occurred at both Flagler and Ormond Beach, Florida. Ten out of eleven dune samples from Georgia contained essentially no carbonate materials.

Regional Sorting

Figures 3 through 6 show the trends of various sediment properties with shoreline distance. Figure 2 illustrates regional trends in grain size and sorting.

The median grain size of beaches and dunes in Georgia are finer than those of beaches both to the north and south (see both figure 2 and table 1). Although figure 2 illustrates only the acid insoluble residue grain size, the same regional trend exists for total sample median grain sizes. If beach and dune grain sizes were controlled by sorting processes alone, it would be expected that Florida beaches would be finer than those of Georgia and would become progressively finer with distance to the south. This is because the ultimate sources of sand (the Piedmont and Appalachian provinces) are to the north. Instead, median grain size appears to be more closely related to wave energies; high wave energies, coarse sand; low wave energies, fine sand.

Mineralogical sorting, if due to a simple sorting through transport process (assuming dominant southward drift), would be expected to be most pronounced in sediments from the Florida Peninsula. Elsewhere in the study area, the numerous small rivers emptying into coastal waters could very likely confuse the picture. It is apparent from figures 3 through 6 that no strong regional sorting effect has taken place on the Florida coast. Another conceivable expectation is that Florida sands should be more stable mineralogically than more northerly areas because during the time required for transport of the sand southward, progressive removal of the unstable heavy and light minerals should have occurred. Hornblende and Feldspar seem to decrease but both the epidote and garnet content are higher in Florida beach and dune sands than many areas to the north. Thus the evidence is not conclusive in this respect but it can be seen that the Florida beach and dune fine sand size heavy mineral fraction is largely an unstable one; certainly not as stable as the coastal plain river suite.

Sources of Beach and Dune Sediments

As mentioned previously, the carbonate content of beach and dune sands is highest in Florida and lowest in Georgia. The high calcium carbonate content of Florida sediments can be largely attributed to the high carbonate productivity of the local warm waters (see Gorsline, 1963). But this does not explain why North Carolina and South Carolina beach and dune sediments contain more calcium carbonate than Gerorgia sediments when the shelf sediments in both areas contain similar amounts of shell material (Gorsline, 1963). It is believed that two factors control the amount of calcareous material in upper beaches and dunes. The most important of these is the availability of carbonate materials. A second and less obvious factor is wave energy. High wave energy causes fragmentation and abrasion of calcium carbonate making it available for widespread incorporation in upper beaches and dunes. Low energies such as those on the Georgia beaches cause little fragmentation and the nearby dunes, in particular, receive essentially no calcareous fragments. Note that the carbonate content refers to the total sample and not just to the fine sand size fraction.

TABLE 2.—*Relative stability of heavy minerals based on the difference in fine sand size heavy minerals of Piedmont and Coastal plain rivers*

Actinolite-tremolite Hornblende Biotite Muscovite	Very unstable
Epidote Garnet	Moderately unstable
Rutile Kyanite Staurolite	Moderately stable
Zircon Tourmaline Sillimanite	Very stable

A comparison of river mineralogy and beach and dune mineralogy indicates that, mineralogically, beaches and dunes most closely resemble piedmont rivers. That is, beaches and dunes contain a predominately unstable heavy mineral suite. On this basis it can be assumed that coastal plain rivers are not important contributors to present-day beach sediments. The next question then is whether the piedmont rivers are actually at present the source of the sediment. Piedmont river and beach-dune heavy mineral suites differ in the relatively minor content of mica in the beach-dune sediments. However, this could simply be due to bypassing by mica flakes of the high energy shore environment and/or to the abrasion of the mica to finer sizes than those observed in this study.

To further delve into the importance of piedmont rivers it is desirable to compare beach mineral concentration anomalies with the concentration of the same mineral in nearby rivers. For example, the concentration of staurolite is

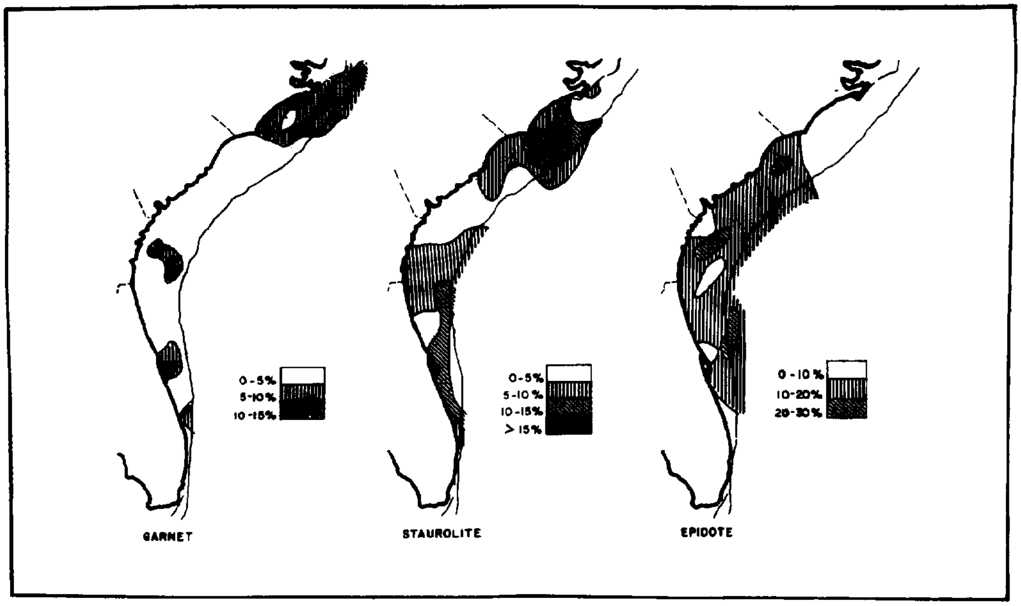

FIG. 7.—Epidote, garnet and staurolite content of Southern United States Atlantic shelf and upper slope sediments. These represent total heavy mineral fractions calculated on a non-opaque basis. Modified after Pilkey (1963).

generally quite high in the beaches and dunes of northern South Carolina and southern North Carolina and rivers in this area also have a high staurolite content. However the anomolously high garnet content of northern North Carolina beaches (figs. 5 and 6) has no counterpart in the North Carolina or nearby Virginia rivers. Another important consideration is the previously discussed observation that river sands are typically coarser than beach-dune sands (fig. 2, table 1).

There appear to be some relationships between adjacent shelf mineralogy and beach-dune mineralogy. Figure 7 shows maps of the aerial distribution of garnet, staurolite and epidote in the shelf and upper continental slope sediments of the study area. These maps of the offshore heavy minerals are based on analyses of several size fractions and although comparison with the beach-dune fine sand size mineralogy can only be approximate, it is interesting to note that the large garnet "high" on the North Carolina shelf roughly corresponds to the garnet high in beach and dune sediment (figures 5 and 6). Similarly, the staurolite high off North and South Carolina may correspond to the adjacent beach dune high; in fact Gorsline (1963) reports staurolite concentrations as high as 60 percent of the total heavy mineral fraction in nearshore sediments just north of Cape Fear, North Carolina.

Pilkey (1963) recognized two heavy mineral provinces on the United States South Atlantic shelf; a low epidote province and a high epidote province (figure 7). The low epidote content of North Carolina beach and dune sands and the higher epidote content of South Carolina, Georgia and Florida sediments (table 1) generally reflects or correlates with the continental shelf epidote provinces.

Although the general uniformity of the heavy mineralogy increases the difficulty of determining regional sediment sources, the evidence based on the high garnet content of North Carolina beaches, dunes, and the adjacent shelf and the corresponding low garnet content of the rivers points strongly to an offshore or shelf source of beach and dune sand. It is possible that the garnet-rich sand was originally transported into the area from the north, perhaps during times of lowered sea level, or is derived from outcropping ancient sediments on the shelf. A third alternative is that the garnet-rich shelf sand was derived from more competent and more deeply eroding rivers during low sea level stands. On the other hand, the staurolite beach and dune "high" can be correlated with river "highs" which indicates that the present day rivers may also be sediment sources. As a further indication of this on a more local level, Gorsline (1963) noted that beach sands show a "marked increase in epidote" near the mouth of the Santee River, South Carolina. Two fine sand

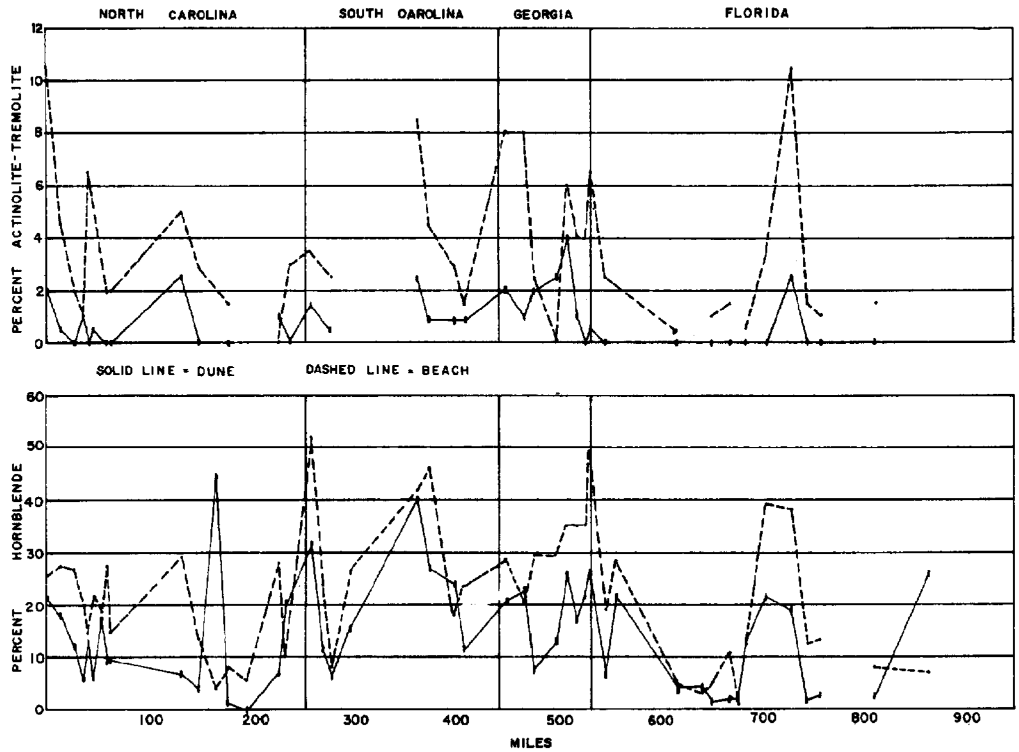

FIG. 8.—Comparison of the hornblende and actinolite-tremolite content of beaches and dunes.

size heavy mineral fractions of samples from the Santee River collected for this study are relatively epidote rich. Neiheisel (1959) also presents evidence that the Santee River is actively contributing sediment to adjacent and "downstream" (to the southwest) beaches.[1]

Beach-Dune Differences

Some idea of beach-dune differences can be obtained from figures 2 through 6, figure 8 and table 1. The average median grain size of the untreated beach samples from each state is coarser than that of the dunes (table 1). Similarly, sorting is generally best in dune samples. However the dune sands from 30 percent of the individual locations were coarser and more poorly sorted than the beach sands. Even less overall consistency of beach-dune differences was noted for the sediment insoluble residues (treated samples). Figure 1 illustrates these differences. Over much of North Carolina and all of South Carolina, the treated beach samples are coarser than the treated dune samples but most often in Florida and Georgia the reverse is the case.

The average carbonate content of dune sands is lower than that of beaches in all four states but in 40 percent of the individual cases the carbonate content of the dune and beach are the same or the dune is higher.

Considering the mineralogical averages for beaches and dunes in each of the four states the following consistent differences are apparent. Dune sands contain less actinolite-tremolite, green hornblende, muscovite, and kyanite; and contain more garnet, staurolite, rutile, zircon and opaque minerals than beach sands. At 91 percent of the locations where actinolite-tremolite occurred (40 locations) the beach sediment contained more of this mineral than the dune. At 83 percent of all the localities, green hornblende is relatively most abundant in beach sands. Garnet and staurolite are both more abundant in dunes than beaches in 79 percent of the locations, and zircon in 70 percent of the cases. The other minerals are less consistent with respect

[1] A study, almost completed, of the phosphorite content of these and other local sediments strongly indicates that a large part of many southern United States Atlantic beach sediments is derived from adjacent continental shelf sediments. This is because rivers are bringing down essentially no phosphorite yet beach and continental shelf sediments commonly contain significant numbers of phosphorite grains.

to beach-dune differences. Figure 8 is a plot of beach-dune differences in hornblende and actinolite-termolite.

Equidimensional minerals apparently are preferentially deposited by wind as opposed to elongate minerals. Shepard and Young (1960) observed that mica is commonly more abundant in beach foreshores than in adjacent dunes, a phenomenon also observed in this study with respect to the fine sand size fraction.

Comparison of the abundance of elongate minerals in restricted size fractions of ancient sands may well be profitable as an aid in distinguishing co-existing beach and dune sands. Certainly the 91 percent and 83 percent consistency figures for actinolite-tremolite and green hornblende, respectively are encouraging in this respect.

CONCLUSIONS

1. Beach-dune median grain sizes are finest on the Georgia coast and coarser to the north and south. Median grain size is primarily controlled by wave energy and secondarily by the nature of and proximity to available source materials.

2. The carbonate content of beach and dune sediments is lowest in Georgia and increases slightly to the north and greatly to the south. The amount of calcareous material is controlled primarily by the availability of carbonate productivity and secondarily by attrition by wave energy.

3. No regional mineralogical sorting effect was detected in beach and dune sands of this area. This includes the Florida coast where essentially all material must have been transported from the north. Heavy mineral suites are unstable over the entire area including Florida.

4. The most consistent difference between beach and dune sands is the relative enrichment in beach sand of elongate heavy minerals and the relative enrichment in dune sands of equidimensional minerals.

5. Rivers deriving their load exclusively from coastal plain sediments are characterized by a stable heavy mineral suite. Sediments of rivers with headwaters extending into the piedmont are characteristically mineralogically unstable.

6. Available evidence indicates that beach and dune sediment in this area is derived, in part, from previously deposited sediments on the adjacent shelf, and in part, also from local rivers.

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