DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
THE DEPARTMENT OF NATURAL RESOURCES OF
THE COMMONWEALTH OF PUERTO RICO

MISCELLANEOUS FIELD STUDIES
MAP MF-1258
SHIDELER—COMPOSITION OF SURFICIAL SEDIMENTS ON
INSULAR SHELF, SOUTHWESTERN PUERTO RICO

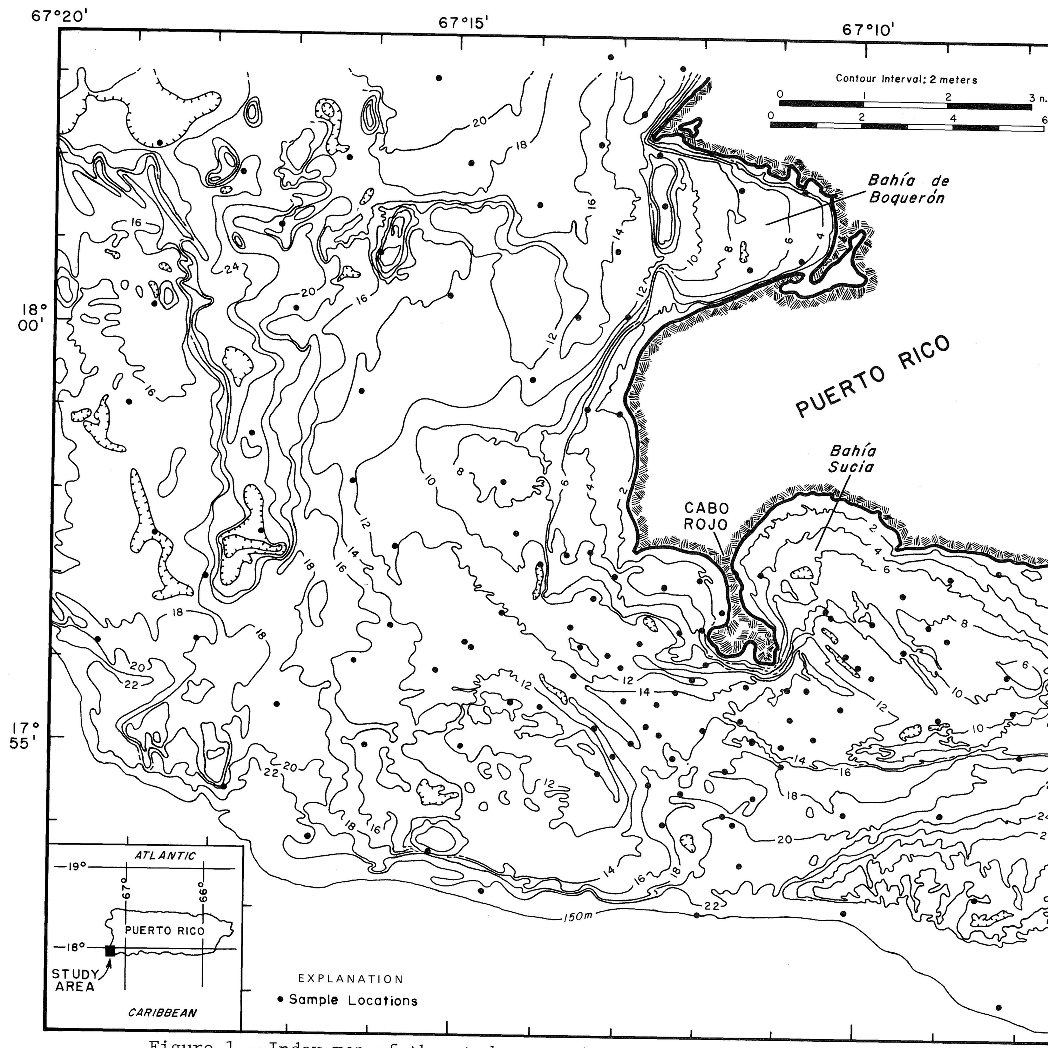


Figure 1.--Index map of the study area showing bathymetry and sample locations. Bathymetry modified from Trumbull, unpublished data.

## INTRODUCTION

The limited availability of onshore sand deposits for use in construction appears to be a future major problem in Puerto Rico (U.S. Bureau of Mines, 1972; Committee on Puerto Rico and the Sea, 1974). Consequently, the mining of offshore sand deposits as supplemental sources of construction aggregate may become necessary. For this reason, the U.S. Geological Survey and the Department of Natural Resources of the Commonwealth of Puerto Rico have conducted investigations of potential offshore sand deposits on the Puerto Rico insular shelf. This report provides information on the composition of surficial sediments on the southwestern Puerto Rico shelf (fig. 1), an area that may be one of the more favorable potential sites for offshore sand resources.

Water depths over most of the study area are less than 22 meters (m). The sea floor is composed of live and dead patch and fringing reefs, areas of rock exposures, and sediment-covered areas. The adjacent coastline includes prominent embayments and a conspicuous rock promontory (Cabo Rojo) connected by a tombolo to the mainland of Puerto Rico. The study area is in the belt of northeast trade winds. Waves approach the coast predominantly from the southeast, resulting in a predominantly westward littoral drift along the south coast (Grove and Trumbull, 1978). Local sand movement on the southern shelf is shown by an active sand wave field south of Bahía Sucia in which the sand wave crests have migrated toward the southwest (Grove and Trumbull, 1978). The presence of the sand wave field suggests that large volumes of sand having potential for mining are locally present in the study area.

## METHODS

Field work consisted of sampling surficial sea-floor sediment at 129 localities (fig. 1) using a Shipek grab sampler from the research vessel *Jean A.* Navigation was by precision radar distances from coastline inflection points, with a probable accuracy of approximately 0.1 nautical mile (nmi).

The sediment samples were desalinized in the laboratory by initial soaking in de-ionized water; the samples were then wet-sieved to determine weight percentages of the gravel (>2 mm), sand (2 mm-63 $\mu$m), and mud (<63 $\mu$m) fractions. The sand fractions were then split into three subsamples for further analyses. One subsample was used for textural analysis. Grain-size distributions of the sand fractions were determined at a 0.5-$\phi$ interval ($\phi = -\log_2 D$, where D = diameter in mm) using a rapid sediment analyzer settling tube similar to the instrument described by Schlee (1966). The mean grain size and standard deviation of the sand fractions were then calculated using a computer program. All size terminology is in accordance with the Udden-Wentworth grade scale, and the statistical parameters are expressed in terms of Krumbein's (1934) phi equivalents. The second sand subsample was analyzed for total noncarbonate content by digesting it in a 10 percent HCl solution and determining the weight percent of acid-insoluble residue. The third sand subsample was dry-sieved, and the proportions of skeletal constituents in the very coarse (1 mm-2 mm) fraction were determined by means of a random point count of 200 grains using a binocular microscope. For consistency, all point counting was done by the same person. For each sample, the skeletal constituents were divided into 10 biogenic groups and the percentage in each group was determined. The results of the laboratory analyses were used to prepare maps (figs. 2-10) illustrating the areal variability of the following sediment characteristics: general sediment type, percentages of gravel and mud, sand texture (mean grain size and sorting), and sand constituents (percentages of insoluble residue and dominant skeletal groups).

## GENERAL SEDIMENT CHARACTERISTICS

Unconsolidated sediments of variable thickness cover most of the shoreward two-thirds of the southwestern shelf. In contrast, the seaward third of the shelf is largely a sediment-deficient, hard-bottom area where no surficial sediments were obtainable during sampling.

The surficial sediments on the southwestern shelf can be divided into textural classes using a classification system based on weight percentages of thin gravel, sand, and mud components (fig. 2). The class boundaries used in the report are based on the percentages used in the sand-silt-clay classification system proposed by Shepard (1954). The sediments that occur in the study area represent six textural classes. The most widespread class is sand, which contains less than 25 percent gravel and mud combined. Sand covers most of the southern shelf and much of the western shelf. This sediment class would provide the optimum quality of clean sand-size aggregate. Coarser gravelly sand is locally present along the southern coastal zone east of Cabo Rojo, along a reef structure at the mouth of Bahía de Boquerón, and in several isolated mid-shelf localities. Two small isolated areas of sandy gravel are present on the southern shelf. Surficial sediments become progressively finer grained northward along the western shelf. Mud is localized within the headward portion of Bahía de Boquerón and in a south-trending salient west of the baymouth reef structure.

The amounts of gravel-size (>2 mm) and mud-size (<63 $\mu$m) material in the aggregate are significant in selecting potential offshore mining sites for construction sand. These materials affect the engineering properties of the aggregate and are important considerations in treatment and processing. Gravel percentages at individual stations on the southwestern shelf range from zero to 55 percent (fig. 3). Regionally, surficial sediments on most of the shelf contain less than 20 percent gravel and most commonly contain less than 10 percent. Areas totally devoid of gravel are restricted to a few small isolated localities, largely along an east-west trending belt on the southern shelf. Except for a high gravel concentration on the bay-mouth reef shoal of Bahía de Boquerón, no systematic relationship appears to exist between gravel concentrations and bathymetry.

Mud percentages in samples from localities on the southwestern shelf range from less than 1 percent to a maximum of 89 percent (fig. 4). Regionally, most mud is concentrated on the western shelf which exhibits a progressive northward-increasing mud gradient. The highest concentrations of mud (>80 percent) occur within Bahía de Boquerón, and in a south-trending salient just west of the bay; the salient occurs along a bathymetric depression that may be an effective mud depocenter. The northern part of the western shelf appears to be the least desirable area for mining a clean sand aggregate. In contrast, mud is a relatively minor component throughout the remainder of the region where, except for a few local areas, it generally constitutes less than 10 percent of the sediment.

## SAND CHARACTERISTICS

Because sand-size (63 $\mu$m-2 mm) sediment is of primary interest in the offshore mining of construction aggregate, a more detailed discussion of the sand characteristics is warranted. The texture and constituent composition of a sand aggregate can influence its mass properties such as bulk density and bearing capacity, which, in turn, can determine the sand's suitability for particular engineering applications.

### Texture

Mean diameter of the sand samples collected for this study on the southwestern shelf locally range from -0.33$\phi$ to 3.52$\phi$ showing a complete range of grain size from very coarse sand to very fine sand. The distribution pattern of sand mean diameters (fig. 5) shows that fine- to coarse-grained sands are the most widespread varieties. Very coarse sand occurs only in small isolated patches located mainly on the southern shelf, and very fine sand occurs only along a south-trending salient on the western shelf. The distribution pattern of sand grain size also shows some prominent regional trends. On the southern shelf, the sand shows a general shoreward reduction in grain size. In contrast, the western shelf sand, which is generally finer grained than the southern shelf sand, shows a general grain-size reduction toward the central mid-shelf area. The sand grain-size pattern is generally consistent with the sediment-class and mud-distribution patterns (figs. 2 and 4). The areas of finer sand are also generally the areas of higher mud content. The regional grain-size distribution pattern illustrates substantial variability in the coarseness of potential sand aggregate.

The regional variability of sand sorting characteristics on the southwestern shelf is illustrated by the distribution pattern of the standard deviations of particle diameters (fig. 6). Standard deviations for the samples used in this study locally range from 0.45$\phi$ to a maximum of 1.38$\phi$. Using Folk's (1965) classification scale, the shelf sand ranges from well-sorted to poorly sorted. Figure 6 illustrates that moderately sorted sand (0.50$\phi$ - 1.00$\phi$) is the most widespread type. It also illustrates two regional trends: a general shoreward improvement in sorting along the southern shelf and an improvement toward the central part of the western shelf. The cause of the regional sorting pattern is unknown; it may be related to sand grain size, with the finer sands exhibiting a higher degree of sorting. This possible relationship is suggested by similarities in the regional trends of grain size and sorting. Empirical relationships between sand size and sorting characteristics have been previously established; as noted by Moss (1963), finer sands tend to be better sorted than coarser sands.

### Constituent Composition

The sand on the southwestern shelf is composed predominantly of carbonate grains that consist mainly of skeletal material and a few calcareous rock fragments. In addition to the dominant carbonate fraction, the sand also generally contains variable amounts of noncarbonate grains.

#### Noncarbonate Fraction

The total noncarbonate fraction of the sand is reflected by its content of acid-insoluble residue. Except for very minor amounts of siliceous plant and animal skeletal matter, the noncarbonate acid-insoluble residues consist mainly of inorganic grains eroded from the land surface (terrigenous sediments). The dominant constituents are quartz grains, clay minerals, and a variety of rock fragments; small amounts of feldspar and heavy minerals also are frequently present.

The amount of noncarbonate grains in sea-floor sand samples collected for this study ranges locally from zero to a maximum of 33 percent. The distribution pattern (fig. 7) illustrates a regional trend of noncarbonate grains increasing shoreward along the western shelf. Highest local concentrations (>16 percent) occur in the Bahía de Boquerón area and in the embayment immediately west of Cabo Rojo. Portions of the sea floor that are completely devoid of noncarbonate grains are restricted to a narrow belt immediately adjacent to the sediment-deficient area along the outer shelf and to a few isolated mid-shelf localities. The regional insoluble-residue pattern appears to reflect a progressively increasing proportion of noncarbonate grains with increasing proximity to coastal sources. The substantial influence of coastal terrigenous sources on sediment composition also has been observed locally throughout other portions of the insular shelf, especially along the northern coast where stream outflow is most pronounced (Ehlman, 1968; Schneidermann and others, 1976; Pilkey and others, 1978).

#### Carbonate Fraction

Except for occasional rock fragments, the dominant carbonate fraction of sand on the southwestern shelf is composed of skeletal debris derived from various biogenic groups; the three major groups are molluscs, the calcareous alga *Halimeda*, and foraminifera. In terms of mean frequency percentages based on the entire sample suite skeletal fragments from these three groups collectively account for 94 percent of all biogenic sand grains in the 1- to 2-mm size range. Mollusc shell fragments are the most abundant grains, representing 51.55 percent; *Halimeda* fragments are second in abundance at 37.66 percent; and foraminifera are third at 4.93 percent. All other biogenic groups contribute skeletal debris in only minor or trace quantities; these groups include calcareous algae (excluding *Halimeda*), coral, echinoderms, serpulids, and sponges. The importance of molluscs, *Halimeda* and foraminifera as major sources of carbonate sand in other parts of the Puerto Rico Shelf has been noted by Schneidermann and others (1976), Pilkey and others (1978), and Grove and Trumbull (1978). Although the percentages of skeletal constituents are important in characterizing the composition of sand on the southwestern shelf, they do not necessarily reflect the proportions of organisms in modern sea-floor communities. The skeletal composition of a sediment is determined not only by the proportions of organisms but also by their relative life spans and skeletal growth rates, and by the differential breakdown of the various skeletal constituents (Bathurst, 1979). Furthermore, skeletal sand on the southwestern shelf appears to be a mixture of both modern and older relict debris (Schneiderman and others, 1976).

Sand of different skeletal compositions may exhibit different engineering properties, which could be relevant in determining its quality as a construction aggregate. Consequently, the frequency-percentage distribution patterns of the three major skeletal constituents composing the carbonate fraction were determined and are illustrated in figures 8-10. Mollusc shell fragments are the dominant skeletal sand component; locally, they constitute 2-94 percent of the biogenic fraction. The regional distribution pattern for mollusc fragments (fig. 8) shows a progressive seaward increase along the southern shelf. In contrast, the western shelf is characterized by a south-trending salient of high mollusc fragment concentrations, which is spearated from a high concentration area in Bahía de Boquerón by the bay-mouth reef.

Fragments of the calcareous alga *Halimeda* are the second most abundant skeletal sand component, locally constituting 0-97 percent of the biogenic fraction. The regional *Halimeda* fragment distribution pattern (fig. 9) is, to a large degree, the inverse of the mollusc pattern. It shows a general seaward reduction in *Halimeda* fragment concentrations along the western shelf. Locally, areas of high Halimeda fragment concentrations occur in nearshore sections of both the southern and western shelves, and along the bay-mouth reef of Bahía de Boquerón. Water depth appears to have been a major factor in establishing the present *Halimeda* fragment distribution pattern; greater concentrations occur in shallow waters which have high light intensity. In addition, because *Halimeda* and mollusc fragments are the two most abundant constituents, the *Halimeda* distribution pattern also could have had a substantial inverse numerical influence in establishing the mollusc pattern. In essence, reductions in mollusc fragment percentages may be largely a result of an increase in the amount of *Halimeda* fragments.

Foraminiferal tests, which are primarily benthonic forms, constitute the third most abundant skeletal sand component; locally the tests compose 0-46 percent of the biogenic fraction. The regional distribution pattern of foraminifera (fig. 10) shows no apparent depth control. Relatively high test concentrations (>8 percent) tend to occur in isolated areas, whereas zones devoid of foraminifera occur both adjacent to the outer sediment-deficient area and along the southern inner shelf. The highest concentration of foraminiferal tests (46 percent) occurs within Bahía de Boquerón. There appears to be a direct relationship between areas of both high percentages of foraminiferal tests and high percentages of *Halimeda* fragments on the western shelf. This suggests that *Halimeda*-rich areas may provide a favorable habitat for the foraminiferal population, possibly because they provide good anchorage conditions.

## CONCLUSIONS

Clean surficial sand-size aggregate is widespread on much of the southwestern insular shelf south of Bahía de Boquerón, whereas muddy sediments occur in the bay itself and further north. The shelf sand is a mixture of two distinct sediment populations: dominantly carbonate grains derived from the skeletal remains of local sea-floor organisms, and subordinate quantities of terrigenous noncarbonate grains derived from erosion of the adjacent landmass. No systematic relationship appears to exist between sand texture and the type of skeletal constituents composing the carbonate fraction.

This study has demonstrated substantial areal variations in the composition of surficial sediments on the southwestern shelf. This variability could have a significant influence on both the engineering properties and the processing of aggregate mined for construction purposes. Consequently, these observations could be used to assist in the selection of potential mining sites for construction aggregate having a specific texture and constituent composition.

## ACKNOWLEDGMENTS

Gratitude is expressed to the Department of Natural Resources of the Commonwealth of Puerto Rico for logistical support and participation in the field operations. Appreciation is also expressed to P. Cotter who did the point-counting phase of the laboratory work.

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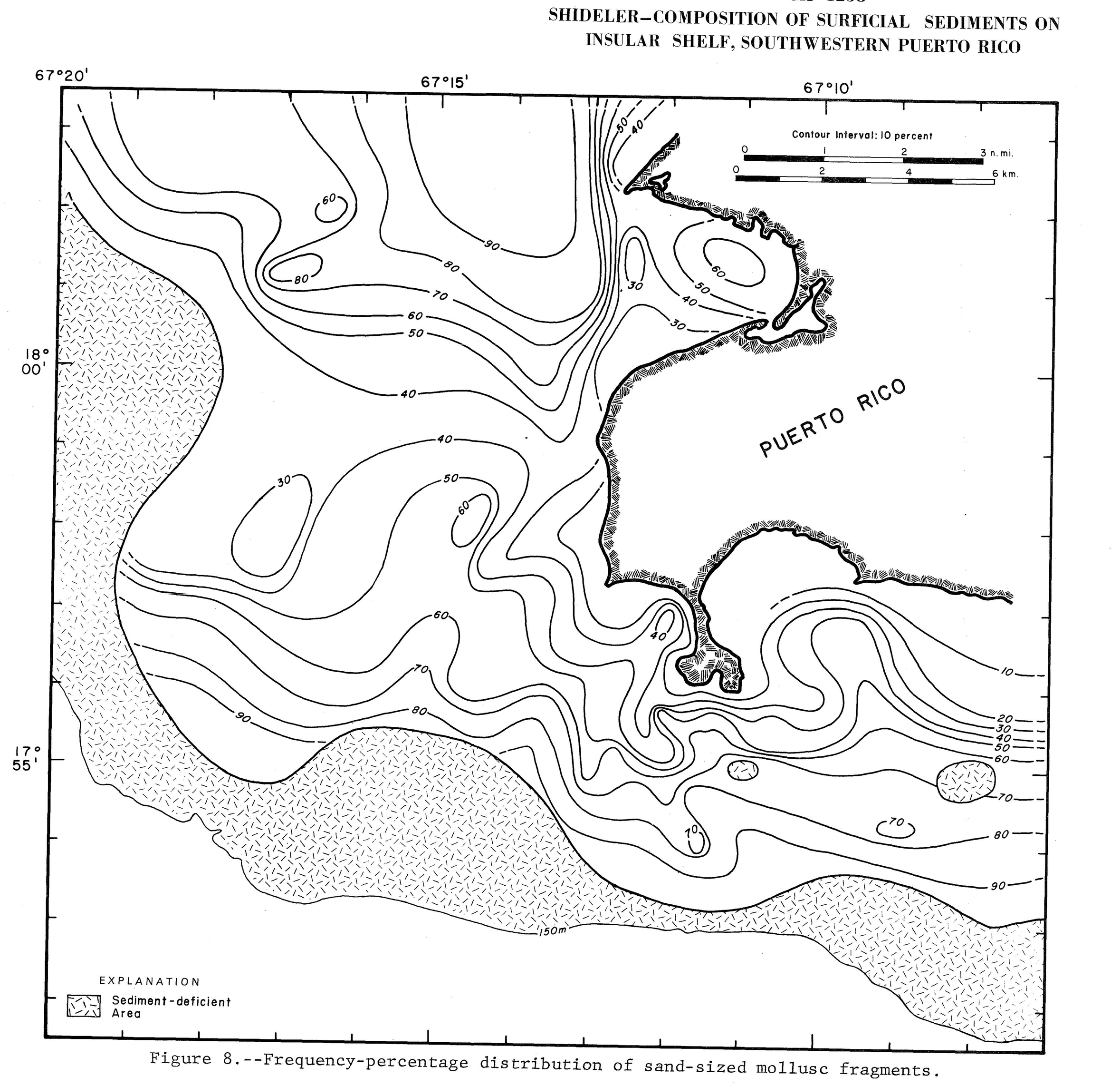


Figure 8.--Frequency-percentage distribution of sand-sized mollusc fragments.

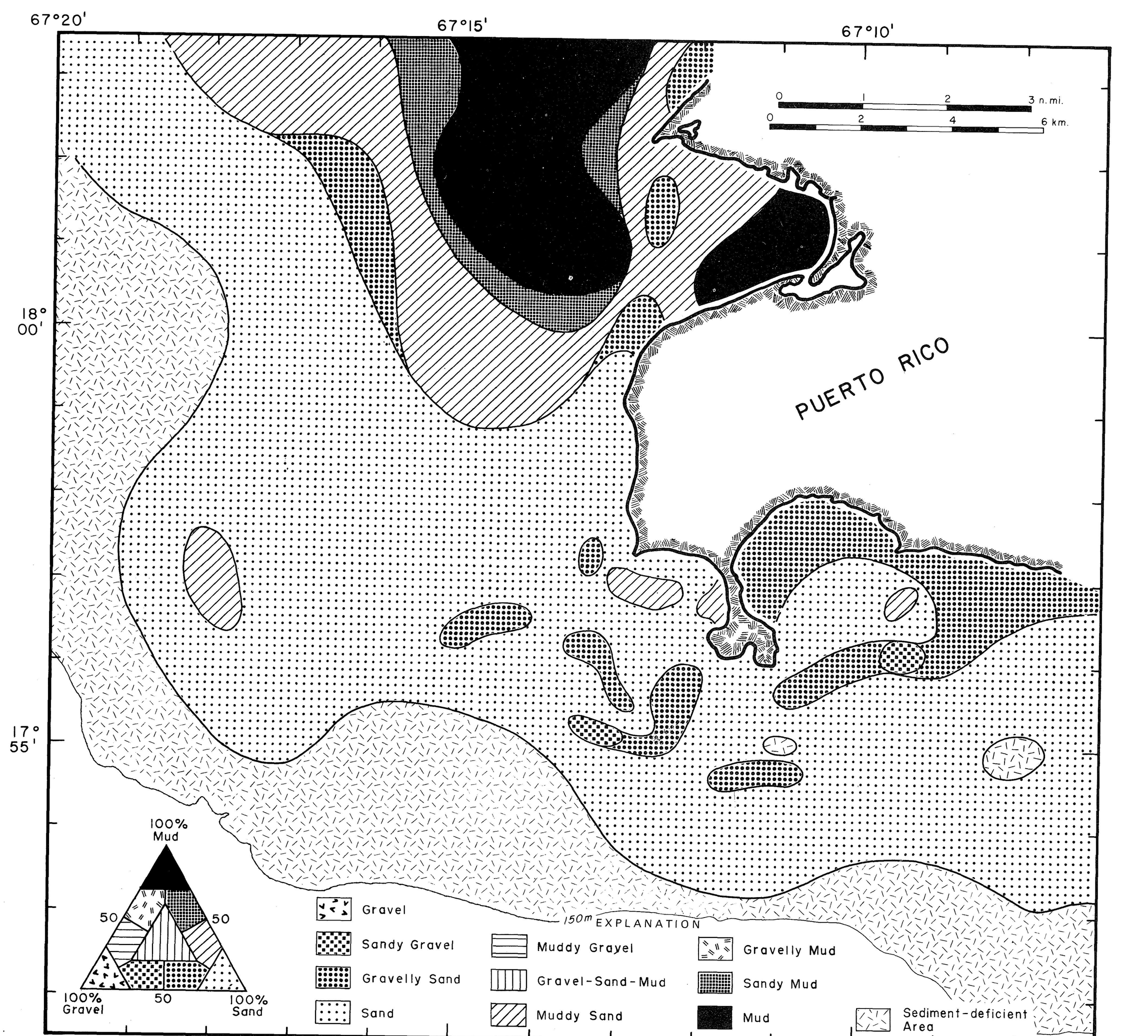


Figure 2.--Distribution of sediment textural classes based on proportions of gravel (>2 mm), sand (2 mm-63μm), and mud (<63 μm).

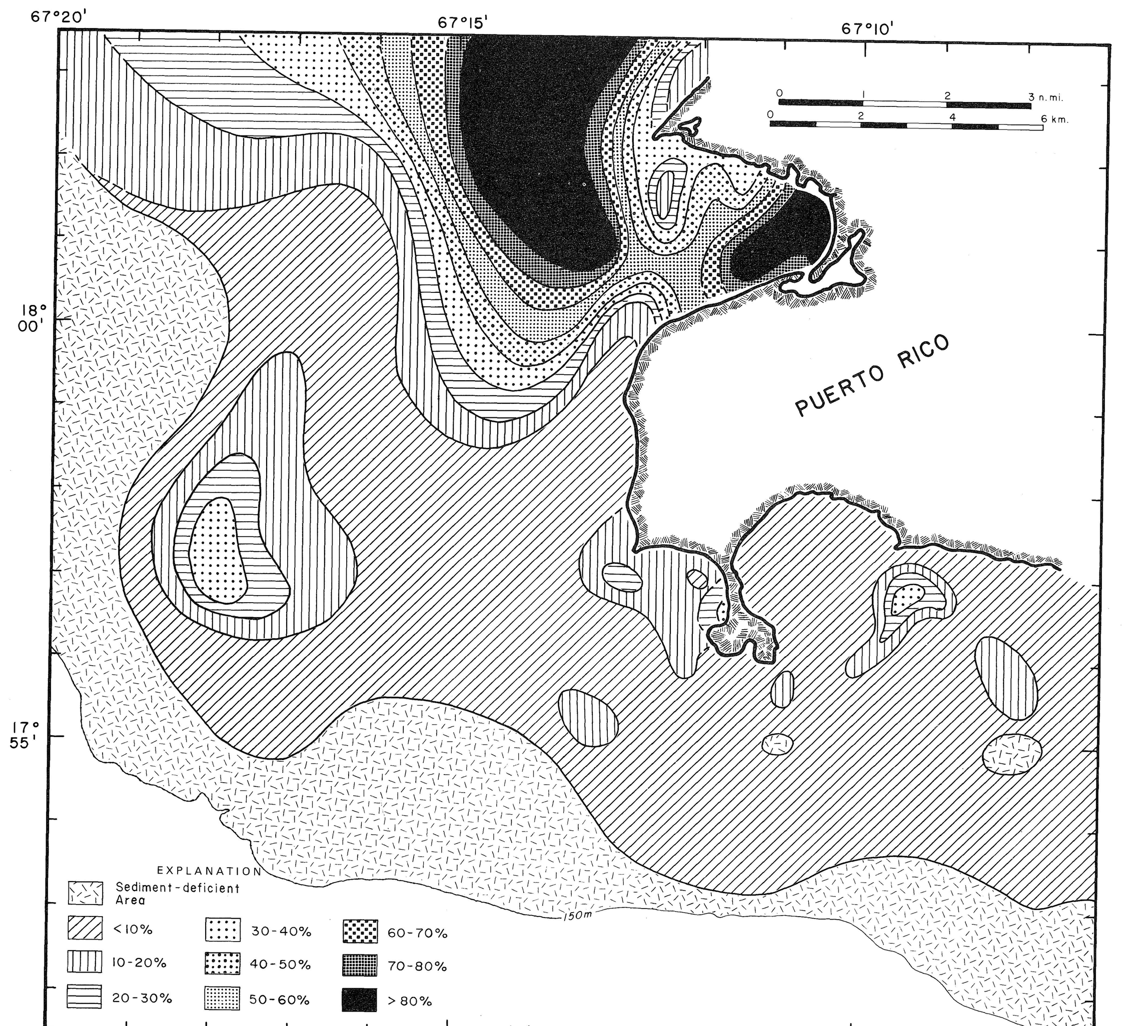


Figure 4.--Weight-percentage distribution of mud-size (<63 μm) detritus.

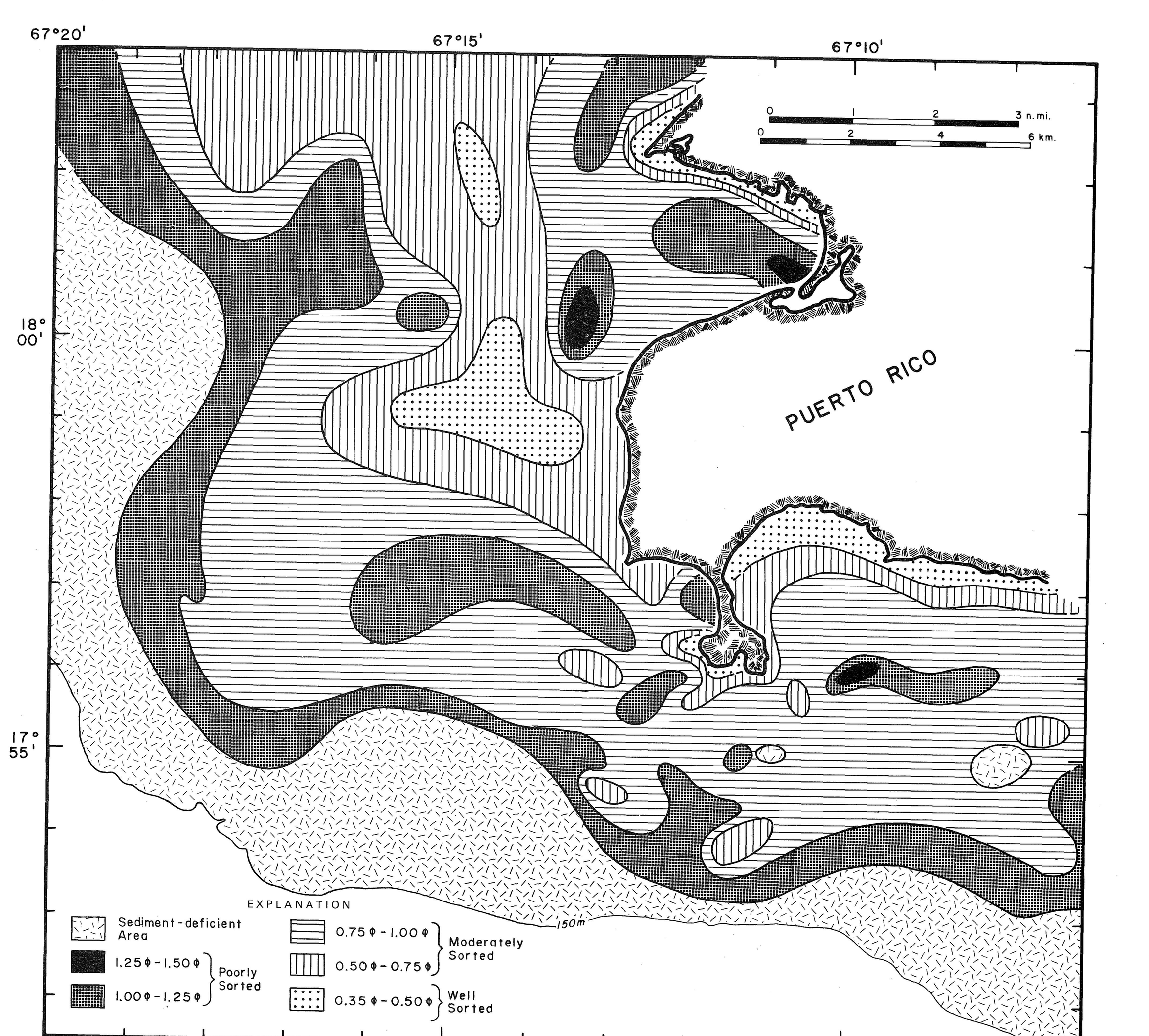


Figure 6.--Distribution of grain-size standard deviation values (ϕ) of sand-size (2 mm-63 μm) detritus.

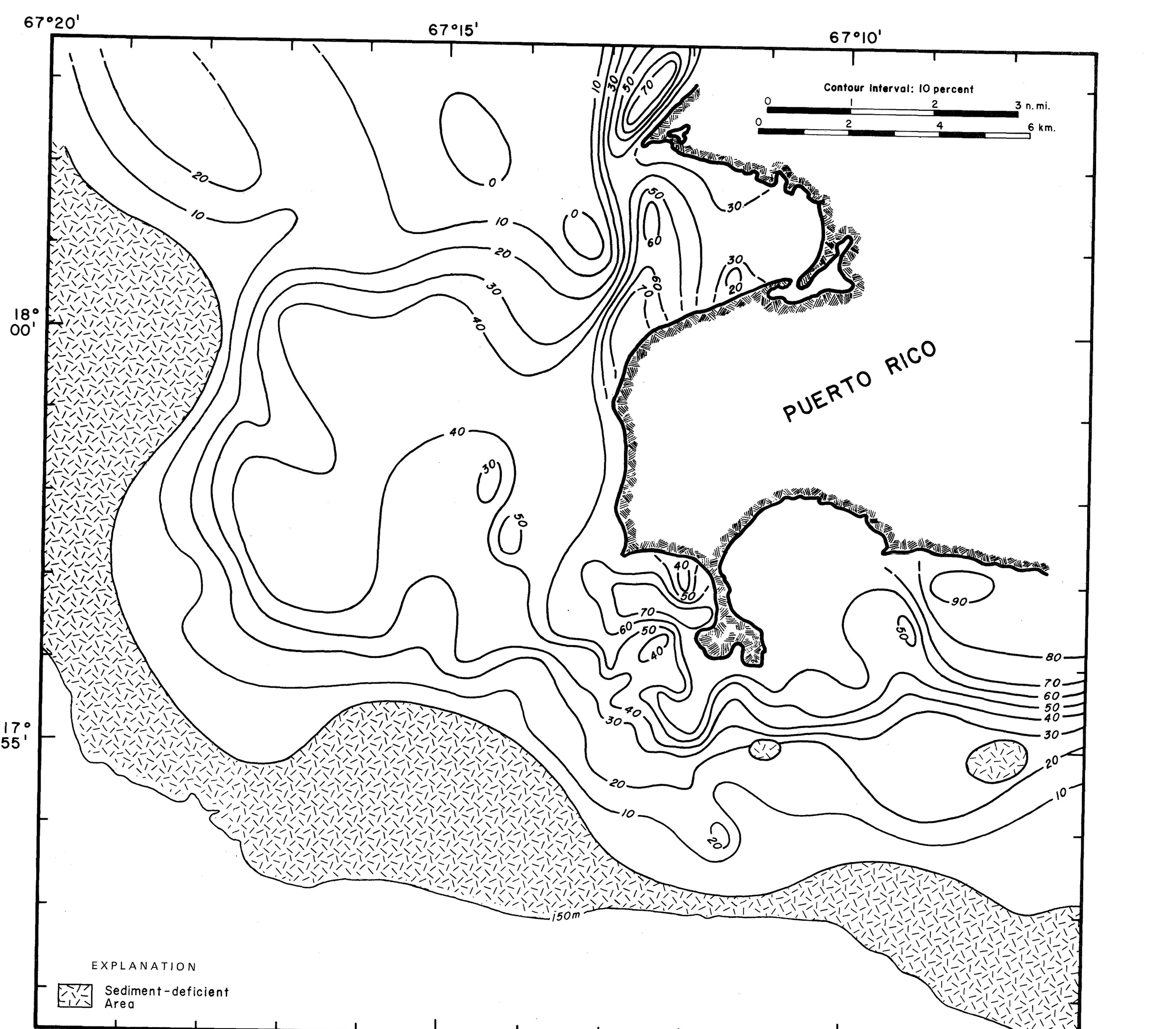


Figure 9.--Frequency-percentage distribution of sand-sized *Halimeda* fragments.

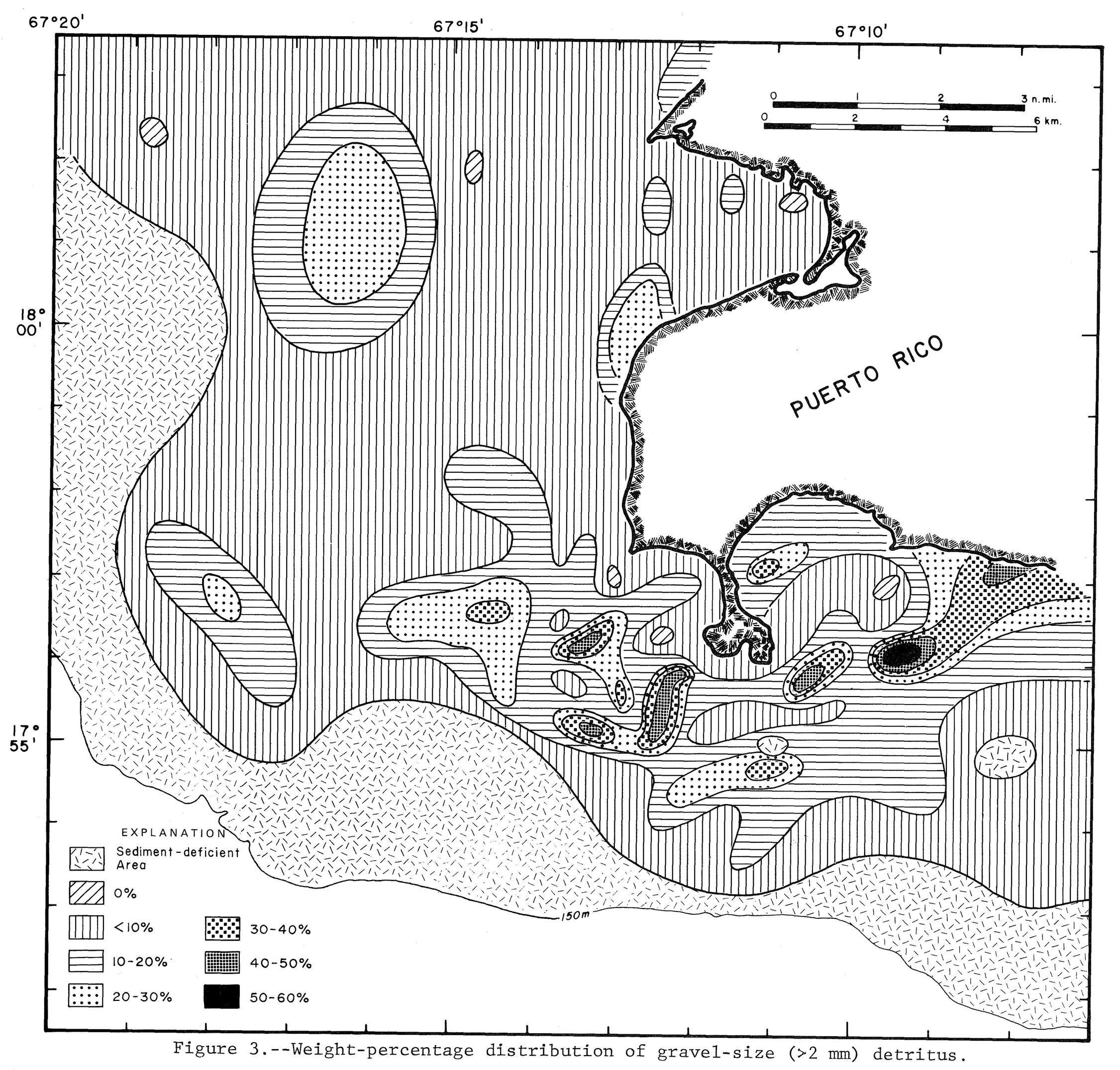


Figure 3.--Weight-percentage distribution of gravel-size (>2 mm) detritus.

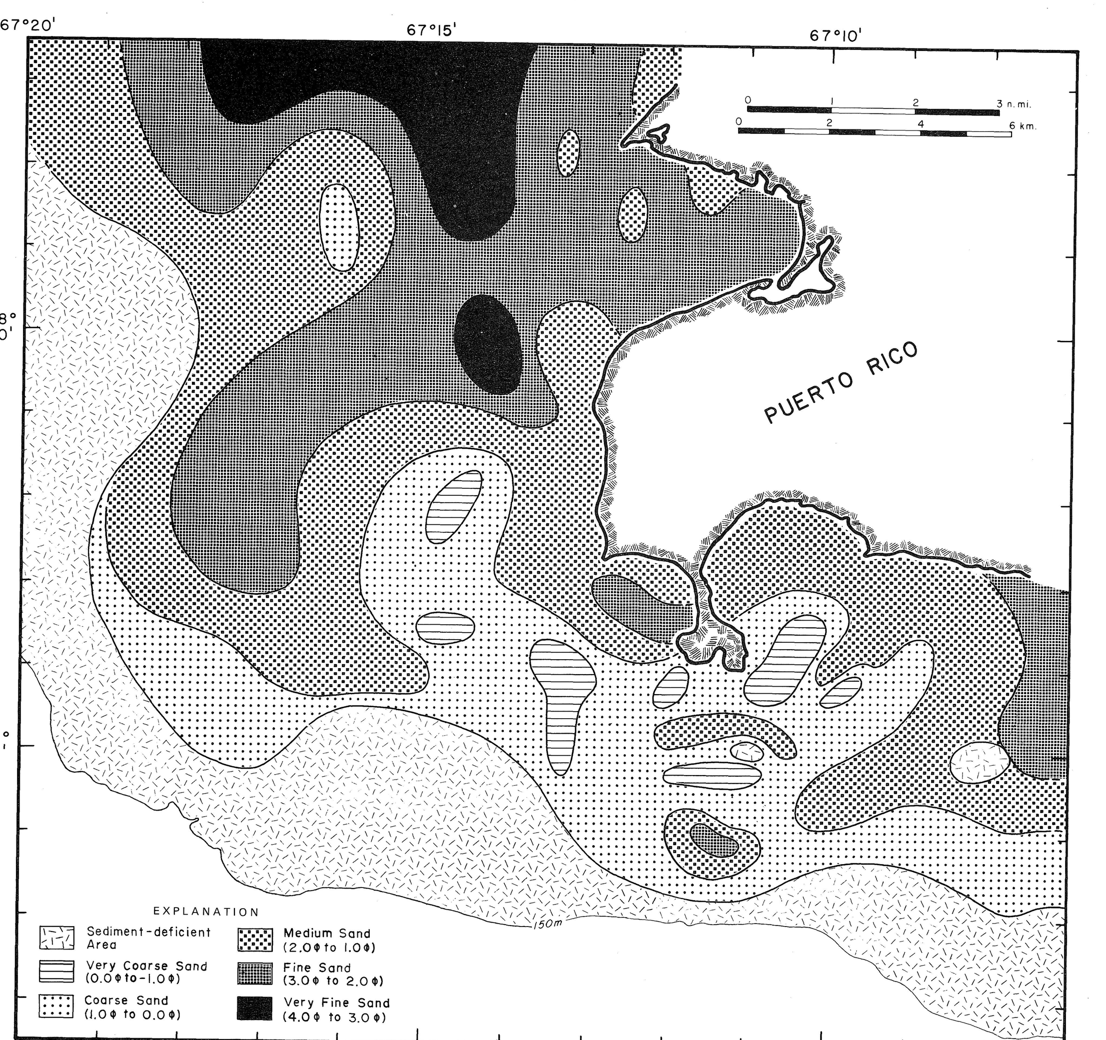


Figure 5.--Distribution of mean diameters (ϕ) of sand-size (2 mm-63 μm) detritus.

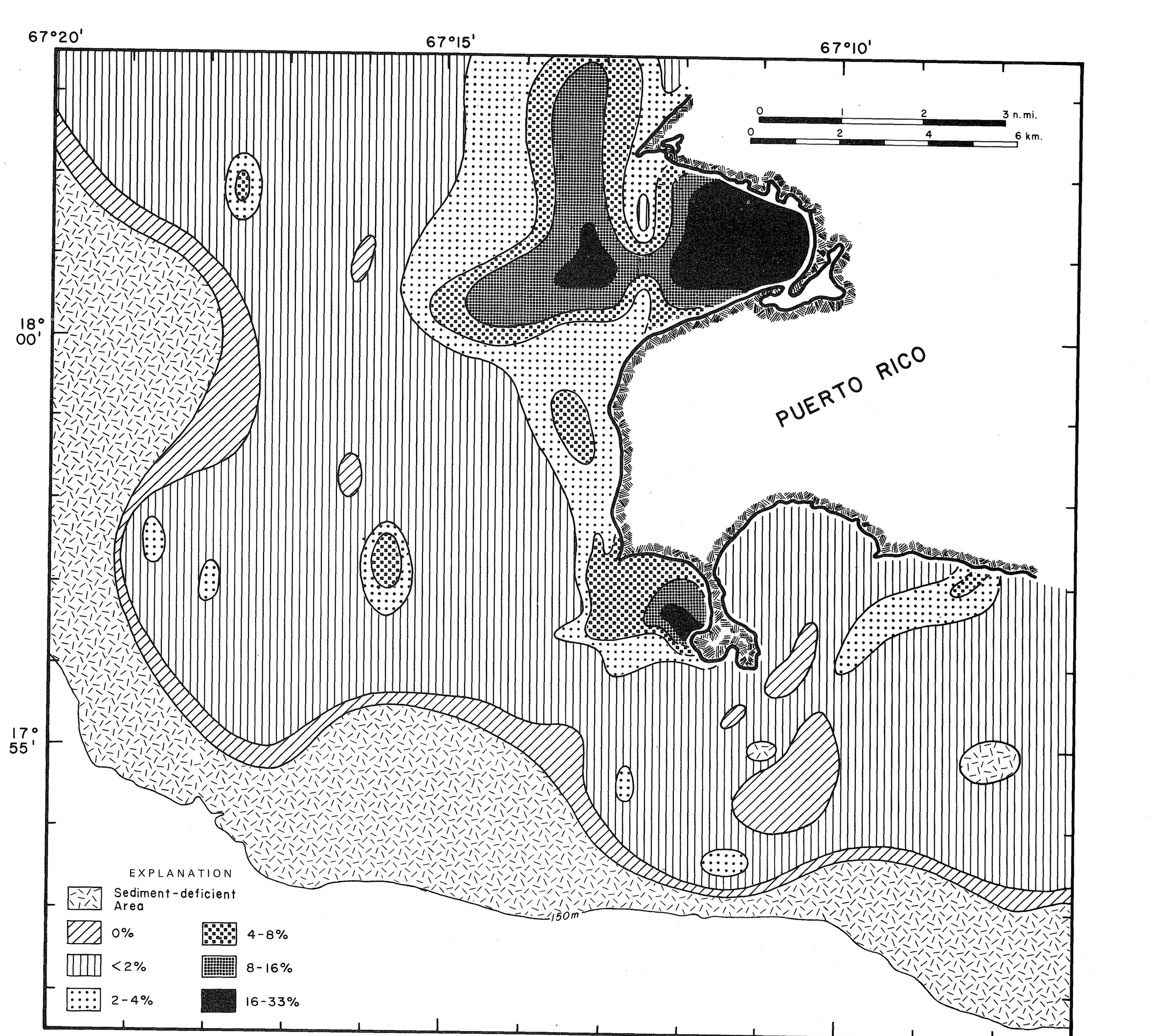


Figure 7.--Weight-percentage distribution of the total sand-sized noncarbonate sediment (acid-insoluble residue).

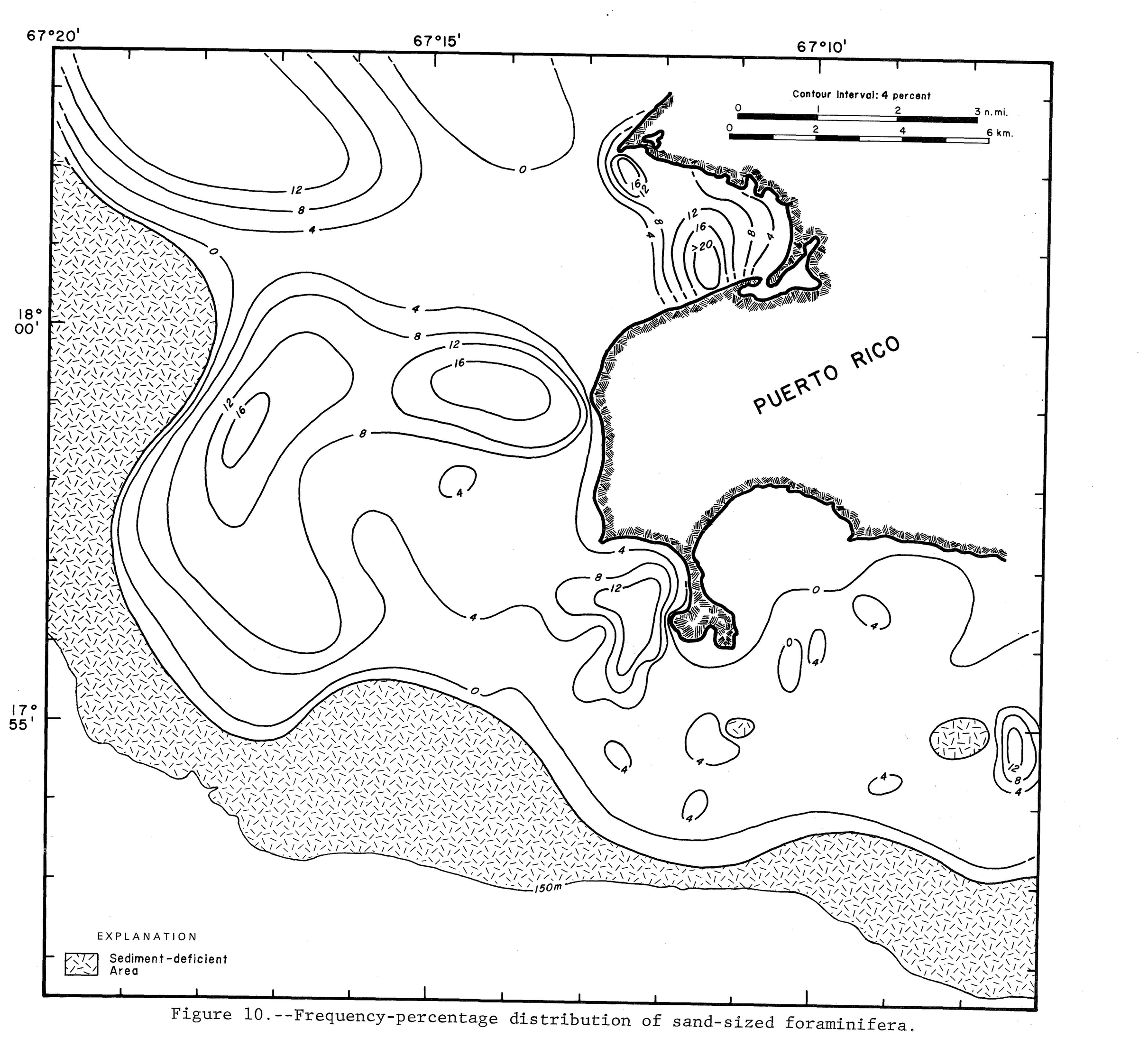


Figure 10.--Frequency-percentage distribution of sand-sized foraminifera.

# MAPS SHOWING COMPOSITION OF SURFICIAL SEDIMENTS ON THE INSULAR SHELF OF SOUTHWESTERN PUERTO RICO

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