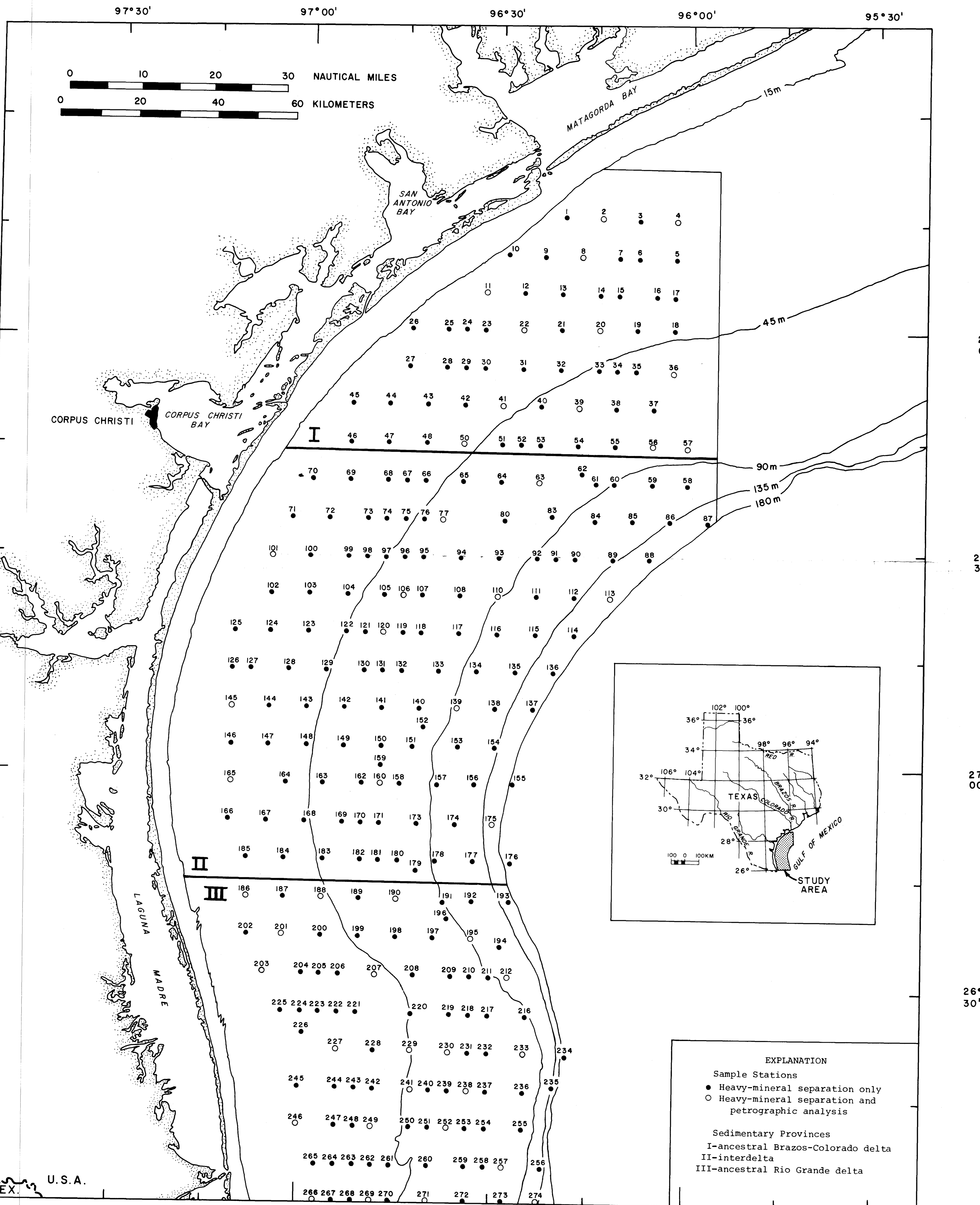

Figure 1. Map showing sedimentary provinces and sample locations on the South Texas OCS.

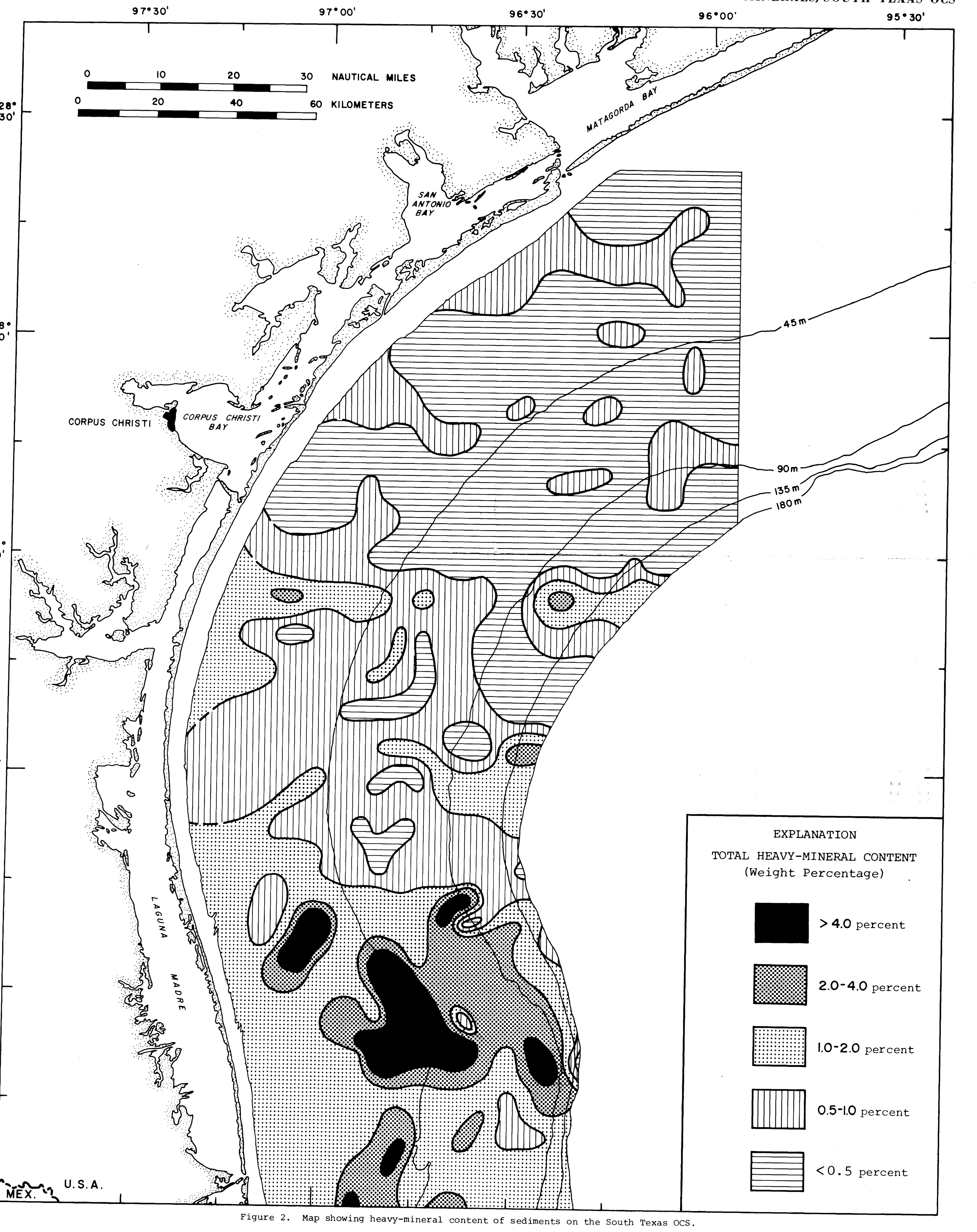

Figure 2. Map showing heavy-mineral content of sediments on the South Texas OCS.

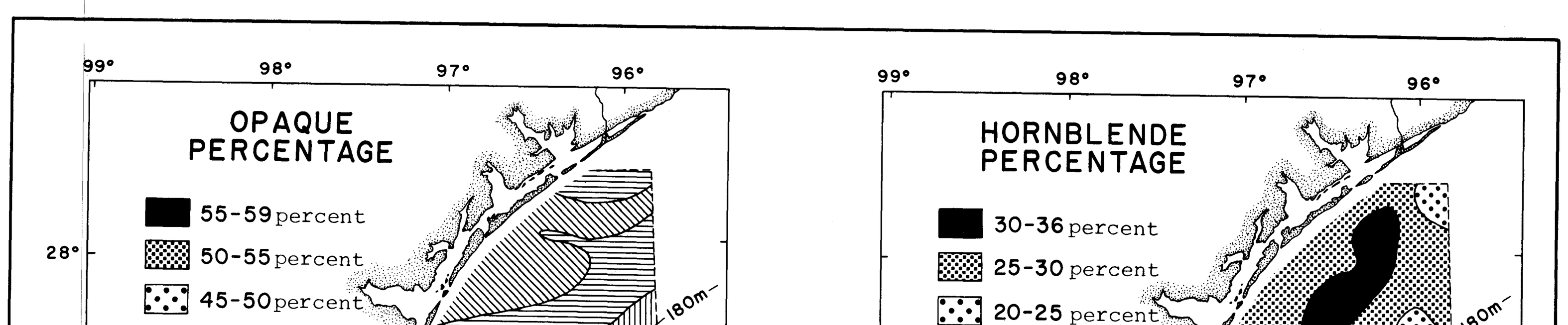

Figure 3. Maps showing regional distribution of prevalent heavy minerals. Opaque minerals are expressed as a percentage of all heavy minerals; other minerals are expressed as percentages of translucent heavy minerals. ZRT, zircon + rutile + tourmaline; PH, pyroxene + hornblende.

INTRODUCTION

Heavy minerals constitute a natural resource which, under proper conditions, could have potential economic significance. The purpose of this report is to describe the heavy-mineral distribution in sea-floor sediments on the South Texas Outer Continental Shelf (OCS) within the northwestern Gulf of Mexico. The South Texas OCS encompasses approximately 24,500 sq km extending southward from Matagorda Bay to the U.S.-Mexico border (fig. 1). In a shoreward direction, the OCS extends from the 180-m isobath to the Federal-State water boundary (16.6 km offshore); however, the mineral distribution patterns presented in these maps have been extrapolated slightly shoreward of the 15-m isobath. This work was part of a regional environmental studies program in the South Texas OCS that was conducted in conjunction with the offshore petroleum-lease sales, under the auspices of the U.S. Bureau of Land Management. Some previous work on heavy minerals within the OCS had been done by van Andel and Poole (1960) and van Andel (1960); the former work was based on relatively few OCS samples and was part of a broader regional study of the northern Gulf of Mexico.

METHODS

Samples of surficial sea-floor sediments were taken at 260 locations within the OCS study area during a two-month field period, between late October and late December, 1974. Shipboard grab samples were obtained with a Smith-MacIntyre sampler over a rectangular sample grid that was keyed to lease-block locations (fig. 1). For reference purposes, the OCS region was divided into three geographic sectors: 1) a southern sector (ancestral Rio Grande delta province) extending from the U.S.-Mexico border to approximately lat. 26°45' N.; 2) a northern sector (ancestral Brazos-Colorado delta province) located north of approximately lat. 27°45' N.; and 3) a central sector (interdelta province) between lat. 26°45' N. and 27°45' N. At each station, a representative subsample was extracted for heavy-mineral analysis by inserting a plastic tube (16 cm length x 3.5 cm diameter) vertically into the grab sample. Therefore, the heavy-mineral analyses reflect the composite characteristics of the uppermost 16 cm of sea-floor sediment. Sample-station locations were determined by a combination of shipboard navigation systems; the primary system was precision Hi Fix, although Loran A and satellite were occasionally used during adverse atmospheric conditions.

In the laboratory, heavy-mineral separations (specific gravity greater than 2.8) were performed on 276 grab samples to determine their total heavy-mineral contents by weight percent. Separations were performed on the 260 station samples, as well as 16 selected replicate samples for evaluating "within station" variability. Prior to heavy-mineral separation, the 63 µm to 250 µm (2-4 ∅) sand fraction from each sample was obtained by sieving. This sand fraction was then treated with a dilute hydrochloric acid solution (10 percent) to remove carbonate minerals and to clean iron oxide stains from heavy minerals. The restricted sand-size range was used for all heavy-mineral separations in order to minimize compositional variations induced by grain size. Separations were performed by the centrifuge-frozen bromoform method (for example, Carver, 1971), using liquid nitrogen as a freezing agent. Separation efficiency was standardized by maintaining a constant centrifuging time (20 sec) and speed (1200 rpm); a sample size (<2 g) and a standard bromoform volume (15 ml) also were maintained. After separation total heavy-mineral contents were determined, and their areal variability illustrated by a percentage isopleth map. Replicate separations on 16 samples distributed throughout the OCS indicated a mean "within station" variability of 27 percent. The "within station" variability reflects the total composite variation resulting from sampling techniques, analytical procedures, and natural *in situ* differences. Consequently, relatively broad isopleth intervals were used in constructing the isopleth map of total heavy-mineral contents (fig. 2).

In order to evaluate heavy-mineral composition, petrographic analyses were performed on 48 representative heavy-mineral fractions distributed throughout the OCS. The separated heavy minerals were mounted in a Lakeside 70 medium (RI = 1.54) and were point counted along random-line traverses. Two hundred translucent heavy-mineral grains were counted to determine the frequency percent of the following: pyroxene, hornblende, epidote, garnet, zircon, tourmaline, rutile, and others (kyanite, staurolite, micas). An additional 100 grains were counted to determine the ratio of opaque minerals to translucent minerals. All point counts were performed by the same person to minimize operator error. The mineral-percentage data of the most prevalent species were used to construct maps illustrating regional variations in composition (fig. 3). The isopleth intervals in these maps generally were selected to exceed the probable maximum point-counting error for each individual mineral species at the 95.4 percent confidence level, as determined by the formula presented by Galehouse (1971, p. 395).

DISCUSSION OF RESULTS

Total heavy-mineral content

The total heavy-mineral contents of South Texas OCS sea-floor sediments range from a trace to a maximum of 32 percent among the individual 260 sample stations (fig. 2). The highest percentages occur at the following stations shown in figure 1: #201 (32 percent), #228 (24 percent), #207 (9 percent), #220 (9 percent), #191 (6 percent), and #230 (5 percent). The regional distribution pattern illustrated by the total heavy-mineral isopleth map (fig. 2) shows a prominent regional trend consisting of a general increase in heavy-mineral content southward along the shelf. The OCS sediments contain less than one percent heavy minerals throughout most of the northern (ancestral Brazos-Colorado delta province) and central (interdelta province) sectors. Heavy-mineral concentrations exceeding two percent are mainly localized within the southern sector (ancestral Rio Grande delta province). The absence of a well-defined coast-normal or seaward gradient is noteworthy. The regional coastwise trend shows substantial local variability. In the northern and central sectors, the most conspicuous local variations are three seaward-trending and three shoreward-trending salients of relatively higher heavy-mineral content.

The highest concentrations of heavy minerals (greater than 4 percent) are in six isolated areas, all of which are localized south of lat. 26°45' N. on the ancestral Rio Grande delta. Bathymetrically, these high concentrations range from the shallowest at 32 m (centered on station 267), to the deepest at 98 m (centered on station 191). The most extensive area containing more than four percent heavy minerals is located along the 45-m isobath; it is centered near station 220.

The regional pattern of heavy-mineral distribution does not show a well-defined systematic correlation with regional sediment-textural patterns, as described elsewhere (Shideler, 1976a). Consequently, textural parameters do not appear to significantly influence the total heavy-mineral distribution. Similarly, the absence of a regional seaward trend indicates an absence of depth control. The existent southward trend is essentially transverse to regional isobaths. Since zones of shoreward-increasing "significant wave surge" are largely parallel to regional isobaths (Curray, 1960), the discordance of the heavy-mineral trend with isobaths indicates that hydraulic fractionation by regional wave surge is not a major factor controlling the heavy-mineral distribution. The same inference can be made for coast-normal currents which do not appear to be very influential on a regional basis; however, the conspicuous salient pattern of the central and northern sectors does suggest that onshore-offshore current components may be effective in locally concentrating heavy minerals by fractionation. Seasonal variations in onshore-offshore drift components have been noted by Hunter and others (1974).

The southward regional trend of heavy-mineral enrichment is interpreted as mainly reflecting the net southward transport by coastwise shelf currents of heavy-mineral-deficient sediments derived from the flank of the northern ancestral Brazos-Colorado delta; these sediments grade into sediments of the southern ancestral Rio Grande delta that are relatively enriched in heavy minerals. Net southward transport on the South Texas OCS is supported by regional sediment-textural gradients (Shideler, 1976b). In essence, the trend may largely reflect differences in provenance, with relict littoral and nearshore deposits of the ancestral Rio Grande delta having intrinsically higher heavy-mineral contents. The higher contents probably reflect relatively higher heavy-mineral concentrations in source rocks of the ancestral Rio Grande drainage basin, which include substantial quantities of volcanic rocks that are absent from the ancestral Brazos-Colorado drainage basin. Qualitative differences between the Rio Grande and Brazos-Colorado heavy-mineral assemblages have been previously documented (for example, van Andel and Poole, 1960; van Andel, 1960), and they are generally supported by the mineral-composition data presented here.

Heavy-mineral composition

Distribution--The heavy minerals in sea-floor sediments of the South Texas OCS consist of both opaque and translucent-mineral groups. The opaque minerals include abundant magnetite, hematite, and ilmenite, as well as a minor proportion of leucoxene as an alteration product. The opaque percentages (fig. 3a) vary from 31 to 59 percent among the 48 analyzed samples. The highest concentration of opaques occurs within the ancestral Rio Grande delta sediments. The opaques exhibit a general decrease regionally toward the ancestral Brazos-Colorado delta sediments which have contents as low as 31 percent. The sediments of the interdelta province have an intermediate amount of opaques, ranging from 38 to 47 percent at individual stations.

Translucent minerals generally comprise the bulk of the heavy-mineral assemblages; they include the following: hornblende, pyroxene, tourmaline, garnet, epidote, zircon, rutile, and others (kyanite, staurolite, micas). Hornblende and pyroxene are most abundant in all samples, individually constituting between 4 and 36 percent of the translucent-mineral fraction (fig. 3). Moderate quantities of tourmaline, garnet, epidote, and zircon are present, individually ranging from 0.3 to 11 percent of the translucent-mineral fractions. Rutile, which varies from a trace to 1 percent, and the other identified translucent minerals are too rare to be of quantitative significance.

Hornblende is the most abundant translucent mineral, comprising from 6 to 36 percent of the translucent fraction; both green and brown varieties were distinguished. In addition, blue-green and reddish-brown varieties were observed in several samples, and they were respectively grouped with the green and brown varieties. Some of the hornblende grains exhibit weathering characteristics such as ragged or hacksaw terminations and iron oxide aureoles. Hornblende percentages are relatively high within the ancestral Brazos-Colorado delta province, intermediate within the interdelta sediments, and relatively low within the ancestral Rio Grande delta sediments where they reach a minimum value of 6 percent (fig. 3b). Although a gradual southward reduction in total hornblende occurs, a more abrupt reduction occurs in the individual percentages of the green-hornblende variety (from 22 to 3 percent).

Pyroxene is the second most abundant translucent heavy mineral, constituting from 4 to 20 percent of the translucent fraction. Varieties of brownish-gray, gray-green, and pink pyroxenes were noted. Grains show some effects of weathering such as occasional dentate or ragged terminations and, very often, iron oxide aureoles. The majority of pyroxene is augite, although very minor amounts of hypersthene and enstatite were identified in some samples. The percentage isopleth map (fig. 3c) shows relatively high pyroxene contents (12 to 20 percent) throughout most of the ancestral Rio Grande delta province, as well as within a second smaller area near the boundary of the interdelta and ancestral Brazos-Colorado delta provinces. Regionally, the pyroxene content exhibits a general southward increase toward the ancestral Rio Grande delta.

Tourmaline is present in moderate quantities, constituting from 2 to 11 percent of the translucent fraction. It occurs mainly as a brown variety, although a rare blue variety (indicolite) is present in some samples. With few exceptions, tourmaline percentages are uniformly in the 5 to 10 percent range within the ancestral Brazos-Colorado delta and interdelta sediments (fig. 3d). In contrast, the ancestral Rio Grande delta sediments are characterized by greater variability and a generally lower tourmaline content. Regionally, a general southward reduction in tourmaline is suggested.

Another mineral present in moderate quantity is garnet, which comprises from 0.3 to 9 percent of the translucent fraction. It occurs in both pale-pink and colorless varieties. The garnet percentage isopleth map (fig. 3e) shows a regional distribution pattern that is the opposite of the tourmaline pattern. Relatively high contents of garnet (greater than 4 percent) mainly occur within the ancestral Rio Grande delta sediments and generally decrease northward. The only exceptions are two locally high concentrations within the ancestral Brazos-Colorado delta province.

In contrast to tourmaline and garnet, epidote and zircon show uniform distributions throughout the OCS region; consequently, distribution maps were not prepared for these two mineral species. Epidote occurs as green to yellowish-green grains and comprises from 3 to 10 percent of the translucent fraction. Zircon occurs as colorless grains and constitutes from 3 to 7 percent of the translucent fraction; most of the zircon grains show pyramidal terminations. The rare rutile mineral exhibits a red-brown to yellow-brown coloration.

As a general stability index for the OCS heavy-mineral assemblages, the ratio of zircon + rutile + tourmaline to pyroxene + hornblende (ZRT/PH) was determined, and its regional variability is illustrated by a ratio isopleth map (fig. 3f). The highest ZRT/PH ratios (0.60-0.72) occur locally within the ancestral Rio Grande delta province; they indicate the local areas of greatest mineral stability. Lowest ZRT/PH ratios (0.15-0.20) occur near the boundary of the interdelta and ancestral Brazos-Colorado delta provinces; they indicate the local area of lowest mineral stability. The absence of a well-defined regional gradient suggests an absence of significant variations in mineral stability between the three geographic provinces.

Provenance--The heavy minerals of the South Texas OCS sediments appear to exhibit a regional variability pattern that is induced mainly by provenance, an inference also made by van Andel and Poole (1960) and van Andel (1960). The heavy minerals of the ancestral Rio Grande delta sediments are characterized by an opaque-pyroxene-garnet suite. In contrast, the ancestral Brazos-Colorado delta heavy minerals are characterized by a tourmaline-hornblende (mainly green variety) suite. The sediments of the interdelta province contain a heavy-mineral assemblage with closer affinities to the Brazos-Colorado suite, as suggested by similarly high percentages of both hornblende and tourmaline minerals. In addition, the interdelta province generally exhibits more gradual percentage gradients with the northern Brazos-Colorado delta, as compared to more abrupt gradients with the southern ancestral Rio Grande delta. Therefore, the interdelta heavy-mineral suite appears to have been derived mainly from the Brazos-Colorado delta sediments; however, some mixing of sediments derived from the southern ancestral Rio Grande delta is also indicated.

A combination of igneous, metamorphic, and recycled sedimentary rocks appears to have been the source of the ancestral Rio Grande delta sediments. The presence of red-brown hornblende (basaltic variety) and abundant pyroxene (mainly augite variety) suggests that the igneous source rocks were primarily volcanic. In addition, the abundance of garnet in the Rio Grande sediments suggests derivation from high-rank metamorphic rocks. An igneous-metamorphic crystalline source complex occurs within the west Texas region and recycled sedimentary source rocks are present within the Gulf Coastal Plain. The tourmaline-hornblende suite of the ancestral Brazos-Colorado delta sediments also suggests the presence of igneous or metamorphic source rocks. However, the absence of the red-brown-hornblende variety in this suite indicates an absence of volcanics, in contrast with the sourceland of the ancestral Rio Grande delta sediments. Additionally, the occurrence of garnet in association with the tourmaline (including indicolite variety) further suggests that metamorphic units were dominant source rocks, probably similar to rocks exposed within the Llano uplift region of central Texas. However, the paucity of green hornblende in rocks of the Llano uplift suggests that this mineral species in the ancestral Brazos-Colorado delta sediments probably was derived from source rocks exposed south of the uplift--namely, from recycled sedimentary units of the Gulf Coastal Plain.

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MAPS SHOWING DISTRIBUTION OF HEAVY MINERALS ON THE SOUTH TEXAS OUTER CONTINENTAL SHELF

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