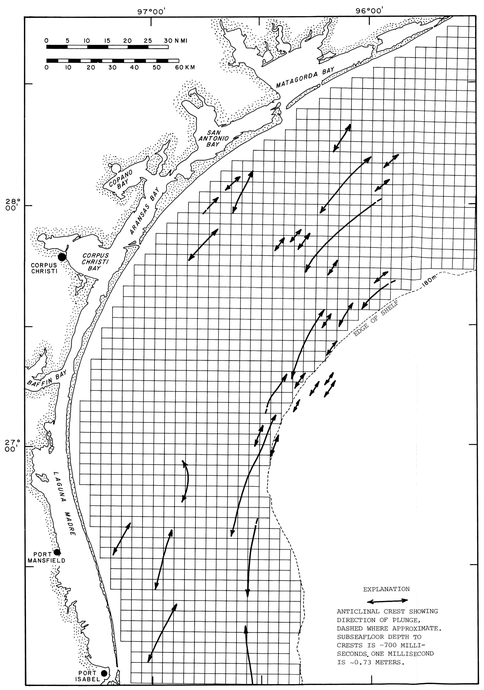



Figure 8.--Map showing folds within the continental terrace.

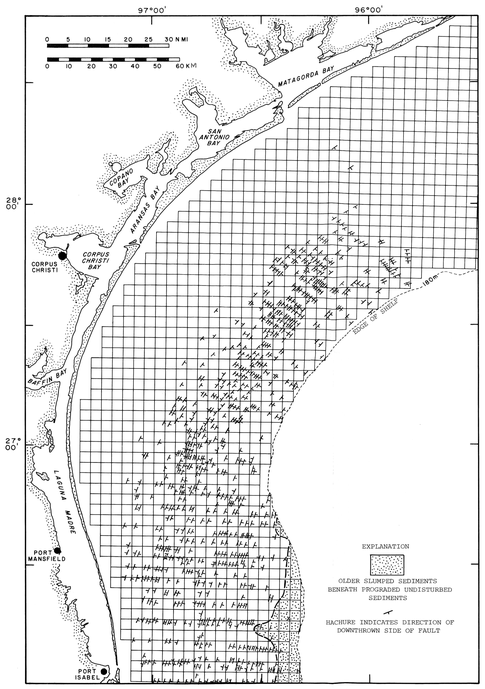



Figure 9.--Map showing faults that offset reflector D but terminate below reflectors A and B.

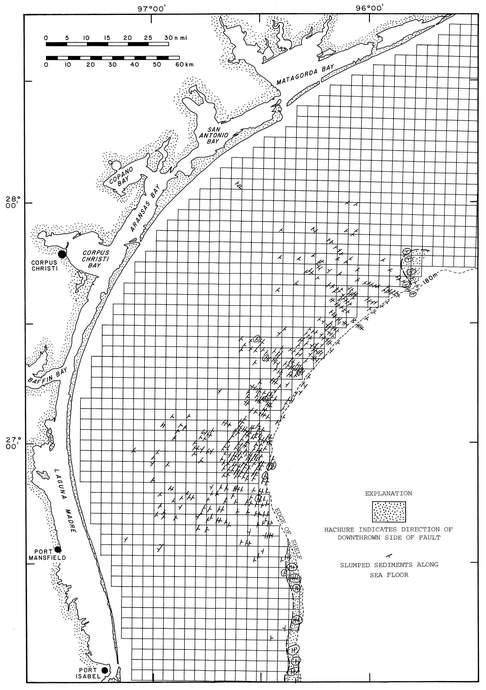
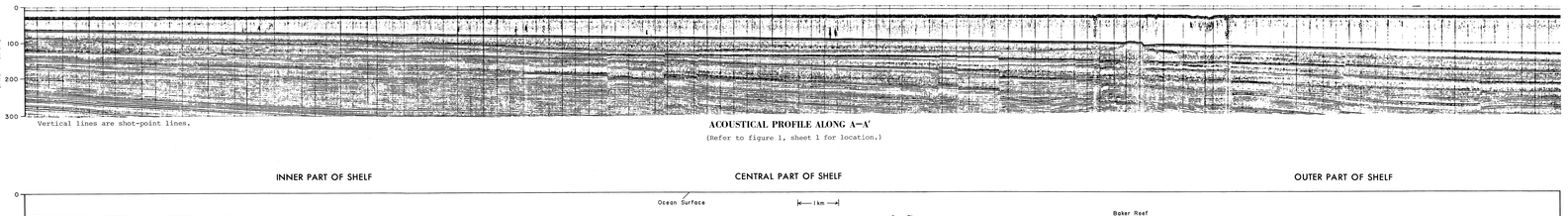


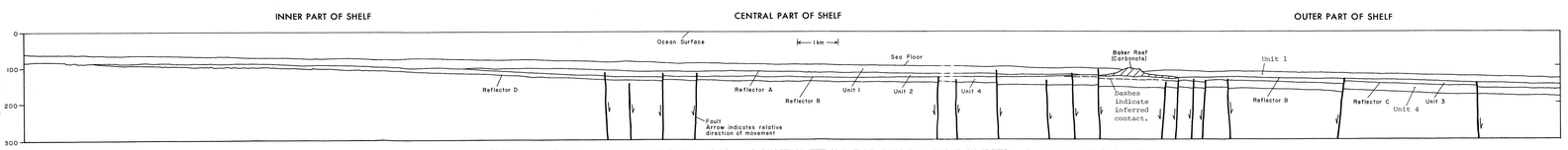

Figure 10.--Map showing faults that offset reflectors A, B, and D as well as the overlying sediments. Faults extending to the sea floor are circled.

**NOTE: FIGURES 8 THROUGH 10 SHOW STRUCTURES AFFECTING LATE PLEISTOCENE AND HOLOCENE DEPOSITION**



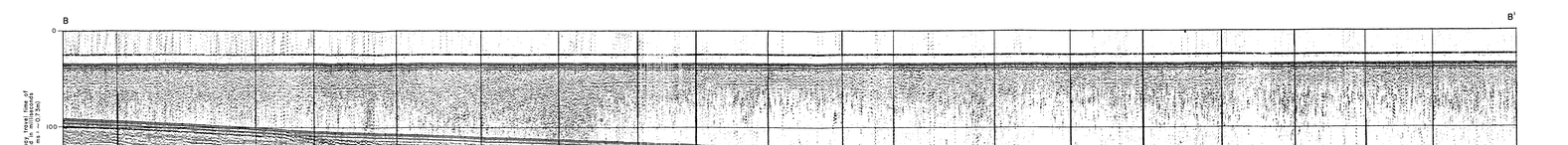

ACOUSTICAL PROFILE ALONG A–A'

(Refer to figure 1, sheet 1 for location.)



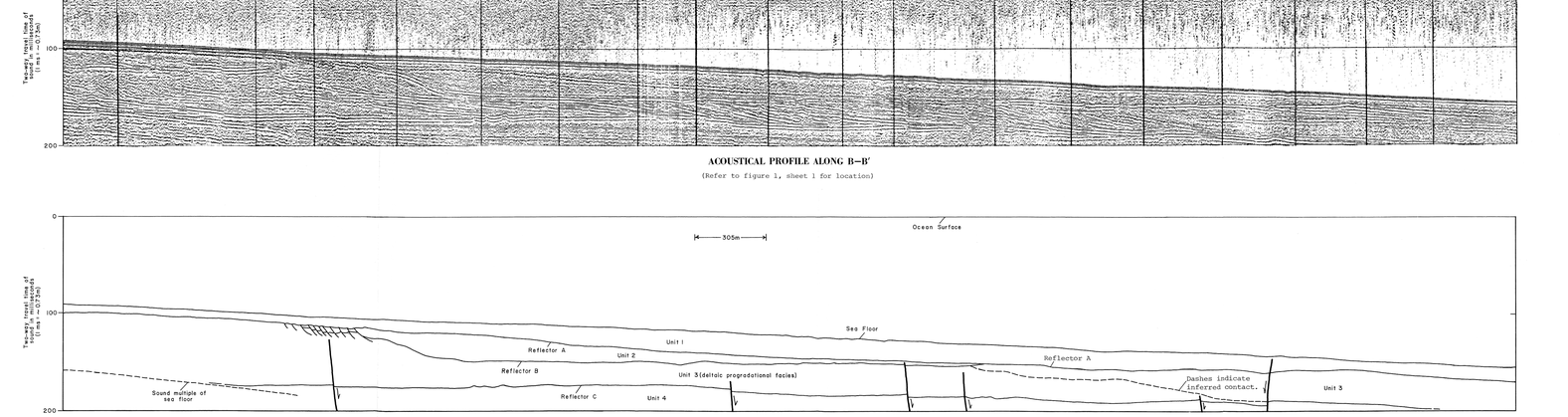

INTERPRETIVE DRAWING OF THE ACOUSTICAL PROFILE ALONG A–A' SHOWING THE STRATIGRAPHIC RELATIONS OF UNITS 1–4 AND REFLECTORS A–D

(Note the strong reflectors on the acoustical profile stratigraphically below D that probably indicate older oscillations of sea level.)




ACOUSTICAL PROFILE ALONG B–B'

(Refer to figure 1, sheet 1 for location)




INTERPRETIVE DRAWING OF THE ACOUSTICAL PROFILE ALONG B–B' SHOWING THE STRATIGRAPHIC RELATIONS OF UNITS 1–4 AND REFLECTORS A–C

## INTRODUCTION

Interpretation of acoustical profiles has provided insight into the late Quaternary geologic history of the Continental Shelf off South Texas. (See the geographic index map on sheet 1 for location of the area studied.) The profiles reveal the interplay of tectonism, sedimentation, and cyclic fluctuations of sea level in the building and geologic evolution of the continental terrace. The sequence of sediments studied extends to about 200 meters (m) beneath the sea-floor surface. Four seismic-stratigraphic units underlain by four prominent sound reflectors were identified and mapped.

This geologic synthesis, for which the research was funded by the U.S. Bureau of Land Management (BLM), is but one aspect of a coordinated, multidisciplinary environmental study of the South Texas Outer Continental Shelf sponsored by BLM (Berryhill, 1976, 1977). The environmental studies are keyed to the leasing of Federal Outer Continental Shelf (OCS) lands for petroleum exploration and production. Their purpose is to provide the data necessary to make sound management decisions regarding the development of petroleum resources on the OCS, as well as to provide the basis for predicting the impact of oil and gas exploration and production on the marine environment. Of primary concern is the recognition of geologic conditions that might be hazardous to structures placed on the sea floor. Geologic hazards relate directly to the potential for significant movement of the sea floor in the future. Judging sea-floor stability and recognizing geologic features that are potentially hazardous require an understanding of the recent geologic history of the area, which, in turn, entails determining the relative rates and interactions of sedimentation and tectonism through time.

In addition to the primary objective, the synthesis provides knowledge about the magnitude and extent of sea-level fluctuations in the western Gulf of Mexico, and it provides a depositional facies model of possible use in appraising the resource potential of the more deeply buried sediments.

## DATA COLLECTION

The data used consist of about 13,000 kilometers (km) of high-resolution seismic-reflection profiles. (See the index map on sheet 1 showing the location of the geophysical track lines.) Approximately 4,170 km of these profiles were recorded aboard the R/V *TAY* by the U.S. Geological Survey (USGS) at a 1.0-second (s) sweep speed, providing sound penetration to about 400 m below the sea floor with resolution under optimum conditions as fine as 4.5 m. The additional 8,860 km were obtained by the USGS and were recorded at a 0.25-s sweep speed, resulting in maximum penetration of only about 75 m below the sea floor, but giving resolution of sedimentary units as thin as 1.5 m. Navigation used aboard ship during collection of the geophysical data was accomplished by radio positioning, providing an accuracy of ±15 m. Fix marks were recorded on the records at 305-m intervals for both surveys. About 52,000 navigational fixes were used to identify and plot the geologic features during data interpretation and synthesis.

## SEISMIC STRATIGRAPHY

The four major sound-reflecting surfaces used to delineate the four youngest stratigraphic units deposited on the Continental Shelf off South Texas were designated by the letters A, B, C, and D; and the sedimentary units themselves were designated by the numbers 1, 2, 3, and 4. The stratigraphic alternation of the unconformable reflecting surfaces and the intervening sediments is the marine record of the cyclic repetition of glacial and interglacial epochs.

The sedimentary units are made up primarily of sediments deposited during interglacial epochs, when sea level rose and the shoreline was near its present location. The units also include some prograded deltaic deposits laid down during glacial epochs when sea level fell. The uneven or unconformable reflecting surfaces that serve as boundaries between the sedimentary units are interpreted to be paleoland surfaces that reveal the extent of erosion across the Continental Shelf during glacial epochs, when sea level fell approximately 150 m and the shoreline was about 65 km east of its present location.

During the glacial epochs, the courses of streams were lengthened and the streams became incised, regressional deltas built by the major streams migrated seaward across the shelf as sea level fell. During the interglacial epochs, as the sea transgressed landward across the shelf, open ocean sediments accumulated over the eroded paleoland surface and the regressional deltaic deposits. The geographic extent and the thickness of the sedimentary units are shown in figures 1 through 4 on sheet 1; the configurations of the ancient topographic surfaces at the bases of the sedimentary units are shown in figures 5 through 7. The stratigraphic relationships between the sedimentary units and the paleoland surfaces that separate them are shown by the acoustical profiles A-A' and B-B' on sheet 2. Profile A-A', located in the northern part of the area studied, is typical of that segment of the shelf lying between the ancestral Rio Grande delta to the south and the ancestral Brazos-Colorado delta to the north (see fig. 3 on sheet 1). Profile B-B' shows the interfingering relationship of the regressional deltaic deposits and the transgressive open-ocean deposits along the northern edge of the Rio Grande delta. The contours on the thickness and structural maps, figures 1 through 7, have been omitted in parts of the southernmost Texas OCS, where the stratigraphic relations of the Rio Grande are geometrically complex and where correlations are as yet uncertain.

### Unit 1

The uppermost unit includes all sediments above reflector A. Both on the inner and outer parts of the shelf, reflector A merges with reflector B, so that the base of unit 1 in those areas is defined by reflector B (see profile A-A'). The sediments in unit 1 have a typically transparent reflecting pattern in most areas, and reflections from within unit 1 are parallel and onlapping on the central and inner parts of the shelf.

The reflection character of unit 1 suggests sediments of generally fine grain size, but the grain size apparently varies both geographically and with increased depth. The sediments in the upper half of the unit probably are similar in texture; the predominant grain size is within the range of silt. The surficial sands over much of the southern part of the South Texas OCS are relict sediments not yet completely covered by the more recent, finer grained transgressive deposits; they represent a combination of deltaic and ancient shoreline deposits (Curray, 1960; Berryhill, 1976). Cores to depths of 1 to 2 m show an increase in fine sand on the inner shelf compared to the amount of fine sand on the outer shelf. The sand is distributed principally as thin discrete layers within the silty sediments, except in parts of the southern sector where shelly, hard sand is continuous to the depth cored (Berryhill, 1976, 1977). Where sampled by coring, the sediments of unit 1 generally are soft; in the southern sector firmness of the sediments varies considerably, depending on the amount of sand.

The reflection characteristics of the basal part of unit 1 indicate sediments of a different nature from those making up the upper half. The basal sediments are believed to be largely material reworked by the transgressing Holocene sea. The reflections suggest these sediments are coarser in general, and less evenly bedded, than the sediments above.

### Reflector A

The structure-contour map for the base of unit 1 (reflector A) indicates a relatively gentle gradient seaward to the geographic position of the 120-millisecond (ms) contour, where the gradient increases (fig. 5). Reflector A is indiscrete and was identified over much of the area on the basis of its correlative relationship to subsurface erosional benches or terraces on the buried flanks of some of the reefs that lie along the outer part of the shelf. (See profile A-A'.) The landward merger of reflector A with the older surface, reflector B, coincides with a change in gradient along reflector B, which is interpreted to be a buried erosional surface. (See profiles A-A' and B-B'.) Reflector A represents a stratigraphic horizon that connects erosional features, yet the acoustical reflection patterns above and below reflector A are largely parallel. (See profiles A-A' and B-B'.) Reflector A probably represents a static sea level that produced both a wave-planed surface on reflector B along the shoreline and benches on the topographically high reefs offshore.

### Unit 2

The sediments of unit 2 are restricted mainly to the central part of the shelf (fig. 2). Where unit 2 is thickest, the acoustical reflection pattern is made up of widely spaced, high-amplitude parallel peaks that become more thinly spaced and lower in amplitude outward along the shelf. Unit 2 is not easily separated from the overlying unit 1 either in the northern part of the South Texas OCS or seaward of the reefs, because the reflecting surfaces there are less discordant. (Compare on profiles A-A' and B-B'.)

Comparison of the thickness map for unit 2 (fig. 2) with profiles A-A' and B-B' shows that the unit filled an erosional and locally structural swale that had been cut into the Continental Shelf. No samples of the sediments from unit 2 are available, but the geographic position of the deposit relative to the underlying swale, as well as the intensity of the reflection pattern from within the unit (profile A-A'), suggest sandier sediments in the landward part of the unit and progressively finer grained sediments seaward, except near the reefs, where carbonate rubble probably accumulated.

### Reflector B

Reflector B is easily recognized both by its characteristically high amplitude and by the discordance of the sound signatures above and below it (profiles A-A' and B-B'). The unconformable nature of the reflector, its high acoustical amplitude, and its stratigraphic position strongly suggest that it represents an ancient eroded surface. The most prominent feature of this surface is the broad swale outlined by the 110 and 120 ms contours in figure 6. The swale in vertical perspective is shown by profile A-A'. Carbonate reefs lie along the seaward edge of the swale, indicating a low stand of sea level coincident in time with reflector B (profile A-A', fig. 1).

### Unit 3

Unit 3 includes those sediments between reflectors B and C. The extent and thickness of the unit are shown in figure 3. The configuration and stratigraphic relationships of the surfaces represented by reflectors B and C indicate that the thickness of sediments originally deposited above reflector C was modified by sea level withdrawal and subsequent erosion. Reflector B is the erosional surface carved onto the upper part of unit 3.

Unit 3 is thickest in the southern part of the South Texas OCS, but the thickness varies considerably. Variations in the reflection characteristics of the sediments in unit 3 suggest that two depositional environments are represented (fig. 3). The more significant deposits, in terms of extent and thickness, are those of the southern and northern parts of the area where the relatively high-angle reflection peaks have the appearance of foreset bedding common to prograded sediments (profile B-B'). The numerous truncated surfaces within the facies, along with the inclined bedding, leave little doubt that the sediments are deltaic. These relatively thick deposits represent outbuilding of the ancestral deltas of the Rio Grande and the Brazos-Colorado in response to a major lowering of sea level. The sediments making up the deltas probably are typical of most deltaic deposits: they are characterized by a relatively greater content of sand-sized sediments, as well as by a large variability of grain size over short distances, because of the complexly interbedded individual deposits within the sequences. The thinner part of unit 3 along the edge of the shelf in the central sector between the two deltas (see fig. 3) has low amplitude, closely spaced, offlapping reflections, which suggest fine-grained sediments.

### Reflector C

Reflector C, which represents the surface across which the ancestral deltas prograded, separates the deltaic facies of unit 3 from the distinctly different underlying transgressive deposits of unit 4 (profile B-B'). Reflector C is truncated by reflector B over most of the central sector of the shelf (profile A-A'). Because of the limited areal extent of reflector C, no structural contour map was made for this surface.

### Unit 4

The sediments between reflectors C and D make up unit 4. The reflections of this unit consist of widely spaced, low-amplitude peaks on the outer part of the shelf, becoming progressively more transparent landward (profile A-A'). The acoustical nature of these sediments suggests generally fine grain size. The thickest part of unit 4 (fig. 4) lies in the southern part of the South Texas OCS, slightly landward of the thickest part of unit 3. The original thickness of unit 4 has been modified locally by subsequent erosion; the zero thickness isopach represents an erosional pinchout. Because the base of unit 4 seems to be marked by an erosional surface (reflector D), and because unit 4 is overlain by a progradational sequence (unit 3), unit 4 is interpreted to be the deposits of a transgressing sea between two periods of regression.

### Reflector D

The base of unit 4 is marked by reflector D, which has a very distinctive, high-amplitude reflection pattern (profile A-A'). The configuration of the base of the unit is shown in figure 7. In the northern part of the South Texas OCS, reflector D is truncated by younger reflectors (profile A-A'). The configuration of reflector D indicates that an angular unconformity over the central part of the shelf grades into a conformable surface along the outer edge of the shelf (profile A-A').

Mound-shaped features, interpreted as ancient carbonate reefs, occur on reflectors C and D in the southern part of the area (fig. 7). If they are indeed carbonate reefs, their subsurface position indicates a relatively high rate of shelf subsidence in the area of the ancestral Rio Grande delta during late Pleistocene to early Holocene time.

## STRUCTURAL CONTROL OF DEPOSITIONAL PATTERNS

Major elements of the structural framework of the continental terrace, interpreted from the acoustical profiles, are shown in figure 8. The series of anticlinal folds within the terrace trend generally northeastward. Consequently, the axes of the folds are roughly parallel to the present shoreline in the northern half of the South Texas OCS, but they are oriented obliquely to the shoreline in the southern part.

Comparison of the thickness maps for each unit to the structure map of the continental terrace (fig. 8) demonstrates some structural influence on the pattern of thickness for each unit. The relationship is not absolutely coincident because the tectonic movements have not affected the same folds at the same time. All faults that affect the four sedimentary units studied were plotted chronologically as a means of determining the relative ages of the tectonic movements. Those faults that offset only reflector D but not A and B are shown by figure 9, and those that offset reflectors A and B in addition to D are shown by figure 10.

The thickest part of unit 4 (see fig. 4) is beneath the northeastern part of the ancient Rio Grande delta; apparently deposition was localized along the edge of the delta at that time (see fig. 3). The increased thickness of sediments indicates the filling of a localized southeastward-trending depression that probably was created by structural movement within the continental terrace. Although the trend of the depression indicated by the lobe of thicker sediments in unit 4 is perpendicular to the trend of the anticlinal axes within the terrace, the depression lies mainly seaward of the anticlines or within the lows between the anticlines. Furthermore, the several large and apparently still active diapiric masses that underlie the Continental Slope, just to the east of the area in question, suggest that the depression, which became the repository for the thicker sediments in unit 4, may have been caused by lateral migration of diapiric material (salt) from beneath the shelf edge. If the deeply buried mounds (fig. 7) are indeed shallow-water reefs, the structural depression must have formed after the "reefs" were established. The form of these mounds on the profiles is very similar to that of reefs that lie on reflector B and now crop out on the outer shelf (see profile A-A').

The thickness of unit 3 has been modified extensively by subsequent erosion. The increased thickness of sediments at the outer edge of the shelf in the south indicates both that deposition of the unit contributed considerably to shelf outbuilding, and that the structural depression created prior to deposition of unit 4 continued to be the primary center of deposition on the shelf during the accumulation of unit 3.

Structural activity during the deposition of units 1 and 2 appears to have been restricted largely to the outer edge of the shelf. The anticlines beneath the shelf edge in the central and northeastern parts of the South Texas OCS appear to have acted as sediment dams, because unit 1 thins over them.

All four depositional units become progressively thinner toward the inner shelf. The pattern of thinning indicates that during the span of time represented by the four sedimentary units, the shelf has subsided progressively seaward along a line located several kilometers to the west of the zero contour on the thickness map for unit 4 (fig. 4); the subsidence has been countered to some degree by the rising anticlines along the northeastern edge of the shelf. The southeastward-trending depression outlined by the sediment lobe in the southern part of the South Texas OCS has been the factor of greatest control on sediment thickness. During low stands of sea level, this structural sag caused the streams crossing the Coastal Plain at least as far north as Corpus Christi Bay to be diverted southward. In essence, the drainage for what is now South Texas and areas farther west appears to have converged at the structural depression during the low stands of sea level.

## AGES OF THE SEDIMENTARY UNITS

The geologic ages of the sedimentary units studied were determined on a tentative basis by correlation of the seismic-stratigraphic units, with foraminiferal zones reported by Poag and Valentine (1976). Poag and Valentine studied samples from the Phillips COST No. 1 stratigraphic test well, which was drilled in 1975 at midshelf in the area of the ancestral Rio Grande delta. (See fig. 1 for location.)

Reflector D, the oldest stratigraphic feature studied, represents the base of unit 4, a major transgressive sequence. The base of the unit lies within the *Globorotalia flemingo* zone of Poag and Valentine, a zone that encompasses the period from 130,000 to 90,000 years B.P. and is closely associated with their *Amphistegina gibbosa* II zone, which is apparently characterized by transgressive sands. Regardless of whether reflector D actually marks the base of this transgressive sequence or marks a sea-level fluctuation within the interval, the depositional interpretation is not affected and only the absolute age of the reflector is unknown.

The sediments of unit 3 are in the *Turborotalita inflata* I zone of Poag and Valentine and are interpreted to be colder water deposits laid down during the regressive stage that lasted from about 90,000 to 30,000 years B.P. Reflector C marks the surface onto which the progradational deltaic sediments were deposited, and this surface is correlative to the unconformity in the *Turborotalita inflata* I zone as shown by Poag and Valentine (1976, p. 215). The age of the unconformity is not stated specifically by Poag and Valentine; however, a study of the several figures on which they show the stratigraphic position of the unconformity within the *Turborotalita inflata* I zone, made in comparison with their figure 13, which includes a radiometric dating scale, suggests an age of about 50,000 years B.P.

The paleontological data suggest that a transitional climate (*Globorotalita crassaformis* zone of Poag and Valentine) existed from about 30,000 to 10,000 years B.P., preceding the Holocene transgression. The base of the transgressive sequence is marked by the erosional surface, reflector B. The seismic data indicate at least two distinct stillstands in sea level within the period of transgression. The first is indicated by the broad terrace represented by the 110- and 120-ms contours on figure 6. The offshore reefs began to grow on the outer edge of the terrace at this time and continued to grow until the second stillstand. The position of the shoreline formed by the second stillstand is approximated by the updip limit of unit 2 (fig. 2). During the second stillstand, benches were formed on the flanks of the reefs, either by wave planation or by predominantly lateral spreading of the reefs.

The broad terrace formed by the first stillstand lies at 80 to 88 m (110-120 ms) below present sea level and corresponds reasonably well with the upper level of the terrace that is 78 to 91 m below sea level, reported by previous investigators. As shown in figure 13 below, Frazier (1974) dated a submerged terrace on the Texas shelf at 17,000 years B.P. at this depth, and his sea-level curve shows a stillstand dated from 16,000 to 19,000 years at -88 m. McFarlan's (1961) curve also shows a major stillstand, dated from 36,000 to 18,000 years B.P. A sample of coralline material from Southern Reef, which rests on the terrace formed by the first stillstand, has been dated at 18,000 years B.P. (Berryhill, 1976).

A second stillstand, at a depth of 50 to 60 m (70 to 80 ms) below present sea level, is marked by reflector A. This stillstand appears to have produced the benches on the reefs, thus approximating very closely the base of the last major transgression of sea level. The ancient shoreline of the second stillstand closely approximates the -52 to -64 m zone of terracing reported by previous investigators, as shown on the following graphs (figs. 12 and 13).

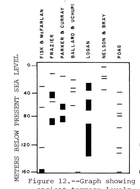



Figure 12.--Graph showing ancient terrace levels (geomorphic data).

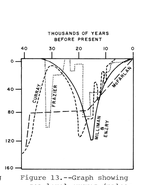



Figure 13.--Graph showing sea level curves (paleoenvironmental data).

Comparison of the published dates indicates that previous investigators have placed the onset of the Holocene transgression somewhere within the range of 10,000 to 13,000 years B.P. (Poag and Valentine, 1976; Curray, 1960). During the resumed rise of sea level to its present position, the Rio Grande delta and the Brazos-Colorado delta (see fig. 3) were inundated and the sediments of unit 1 were deposited, completing the filling of the bathymetric low related to the -50 to -60 m terrace.

## SEA-FLOOR STABILITY

The history of mobility of the continental terrace off South Texas during approximately the last 120,000 years indicates the following characteristics:

1. The South Texas OCS is not a seismically active area. However, the pattern of folds and faults and the chronology of movement of the faults within the continental terrace indicate relatively low-level, but nevertheless long-term and progressive, movements that are caused by the interaction of rapid sediment accumulation and burial of the dense sediments. All faults shown on the maps are the growth type. Stratigraphic throw increases with depth. Displacements at depths of approximately 300-400 m below the sea floor range from a few meters to as much as 65 m.
2. Deep-seated slippage of the sediments by faulting has been most prevalent during Holocene time along the outer part of the Continental Shelf. The pattern of faulting and, in particular, its concentration along the rising anticlines, suggest the probability of continued faulting in the future. Seepage of natural gas appears to be extensive along the outer edge of the shelf where faulting has been most prevalent (Berryhill, 1977).
3. Disturbance of the sea-floor sediments by slumping is restricted to the outer periphery of the ancestral deltas (figs. 9 and 10). Two types of slumped sediments are present: older slumps now covered by undisturbed prograded sediments (fig. 9), and the most recent slumps at the very edge of the shelf along the leading edges of the deltas (fig. 10). The area of slumping shown on figure 10 continues down the Continental Slope adjacent to the shelf edge.
4. Sediment strength, or cohesion, is variable. To the depth observed, the sediments over much of the area are fine grained and are relatively soft and incoherent rather than compact. The discrete sand layers are thinner than the mud layers separating them, except over parts of the ancestral Rio Grande delta where pavements of hard relict sand containing large numbers of shells are indicated. Shallow cores taken in the area of the relict delta indicate that the bearing strength of the sediments can vary considerably over relatively short distances, because mud has filled topographic depressions within the harder sand (Berryhill, 1976). Within the overall sediment sequence encompassed by units 1 through 4, the acoustical reflectors B, C, and D, which are interpreted to be ancient land surfaces, are probably hard and compact, as indicated by the high sound-reflective quality of these surfaces.
5. Slumping of sea-floor sediments at the juncture of the shelf and the Continental Slope and down the slope itself probably has been most active during low stands of sea level, when deposition of sediments was concentrated along the edge of the shelf and on the steep upper slope.

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# MAPS SHOWING LATE PLEISTOCENE AND HOLOCENE EVOLUTION OF THE SOUTH TEXAS CONTINENTAL SHELF

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1979

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