SOUTH TEXAS CONTINENTAL SHELF AND CONTINENTAL SLOPE: LATE PLEISTOCENE/ HOLOCENE EVOLUTION AND SEA-FLOOR STABILITY

(An outline and notes relative to geologic hazards on the sea floor)

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Introduction

In an engineering sense, the geologic aspects of the sea floor are hazardous to man's activities when and where structures cannot be designed to withstand the combined stresses of the marine environment. In the most basic sense, geologic "hazards" relate directly to sea-floor stability, or the potential of the sea floor for significant movement that would be damaging to man-made structures placed on the sea floor. Judging the potential for movement requires descriptive details about the geologic conditions plus a quantitative understanding of the geologic and related oceanographic processes that are operative in the region on both short-term and long-term bases. Recognition and quantification of the geologic processes and their implications regarding potential hazards must stem from an understanding of the geologic history of the area in the recent past, which requires determining the relative rates and interactions of the two basic processes, sedimentation and tectonism, through time.

In an empirical sense certain features on the surface of the sea floor suggest unstable conditions: irregular or hummocky topography caused by the sliding or slumping of surficial sediments or diapiric movement, and offsets of the sea-floor surface caused by vertical slippage or faulting. The movements that created such features were a response or readjustment to some type of instability; the factors that caused the instability may have been localized or they may have been regional in scope. Furthermore, the movements indicated by the observed features may have been a one-time event that reestablished equilibrium for a long time to come, or they may have provided only temporary release of reoccurring stresses that eventually will cause movement again.

Studies at two levels of detail are needed for the identification and assessment of geologic conditions of a potentially hazardous nature in areas where resource production is anticipated: a systematic study of regional scope and in sufficient detail to describe properly the principal geologic and environmental characteristics of the region and to indicate the scope of their interactions; and follow-up studies as needed for those specific sites that are in areas where the regional study indicates geologic conditions are potentially hazardous. Topics of investigation covered by the systematic regional studies should include: 1) the structural or tectonic framework, with emphasis on the pattern and chronology of fault movements since the late Pleistocene, and the identification of tectonically active and structurally complex areas; and 2) aspects of sedimentation such as surficial grain size relations, textural stratigraphy of shallow subsurface sediments, extent, thickness and facies of the late Pleistocene and the Holocene interglacial deposits, rates of sediment deposition during the Holocene, surface expression of depositional features, and delineation of areas where the sediments have moved by sliding and slumping and where significant amounts of gas are indicated at shallow depth beneath the seafloor surface.

The outline and notes that follow describe the geologic aspects of a multidisciplinary systematic regional environmental survey made of the Outer Continental Shelf off South Texas for the Bureau of Land Management that included biology, geochemistry, and physical oceanography. The outline proceeds from a short stability and potential hazards. Emphasis has been placed on illustrations which have been used liberally to document the geologic features discussed. Investigators interested in a summary of the nature and results of the complete environmental study are referred to Berryhill (1977) and Berryhill and others (1977).

Brand names of equipment used are capitalized throughout the text. The use of a brand name does not imply endorsement of the product.

The Study Plan

I. The systematic and integrated approach

A. Rationale

To investigate all components of the geological environment in a unified rather than piecemeal manner so that the geologic features and the processes responsible for them can be better understood and the interactions of the processes quantified to the extent possible in time and space. The planned and integrated study approach is based on the premise that the problem of analyzing and understanding sea-floor stability is best handled by looking at all related components of sea-floor geology simultaneously rather than topically and out of context. Furthermore, in analyzing sea-floor stability in a predictive sense, the past is the best key to the future.

B. Geologic components studied

1. Geologic framework (tectonic history):

a. Identify the internal structures shaped by crustal movements within the continental terrace and determine their relations: folds; faults.

b. Determine the chronology of post middle Pleistocene folding and faulting relative to the depositional sequences identified.

2. Sedimentation

a. Determine the distribution of surficial sediments based on grain size.

b. Determine the distribution of the sand-sized and coarser fractions of the sediments.

c. Determine the stratigraphy of shallow subsurface sediments to a depth of 2-3 m, with emphasis on the distribution of discrete sand layers and the mechanisms of sand dispersal over the shelf.

d. Determine the geochemistry of surficial sediments with emphasis on key trace metals that indicate patterns of sediment transport and the organic carbon content.

e. Relate the types of sediments to the physiographic sub-provinces of the OCS and to localized topographic features.

f. Determine the rates of Holocene sediment deposition and the thickness of Holocene sediments.

g. Delineate to the extent possible areas of natural gas seepage and areas where gas is suggested at shallow depths.

h. Document the post middle Pleistocene depositional history of the region relative to sea level fluctuations caused by glaciation.

II. Methods of study

A. Geologic framework

High resolution acoustical profiling of two types in traverses spaced to cover uniformly all physiographic subprovinces of the South Texas OCS:

1. 3.5 kHz
2. 900 joule sparker

(See figure 1 for the physiographic nature of the region as revealed by the bathymetry of the area and figures 2, 2A, and 2B for the spacing of geophysical track lines used to provide data sufficient to describe the geologic framework.)

B. Sedimentation

Sampling methods and acquisition of data:

1. High resolution acoustic reflection profiles: thickness of late Pleistocene/Holocene sedimentary sequences; and history of sea level fluctuations.
2. Coring: pipe and box coring for determining textural stratigraphy and for identifying discrete sands in the cored sediments.
3. Bottom grab samples: grain size analysis; geochemical analysis. (See figures 3 and 4 for location of bottom sample stations.)

Analytical techniques:

1. X-radiography—an aid in core logging for identification of

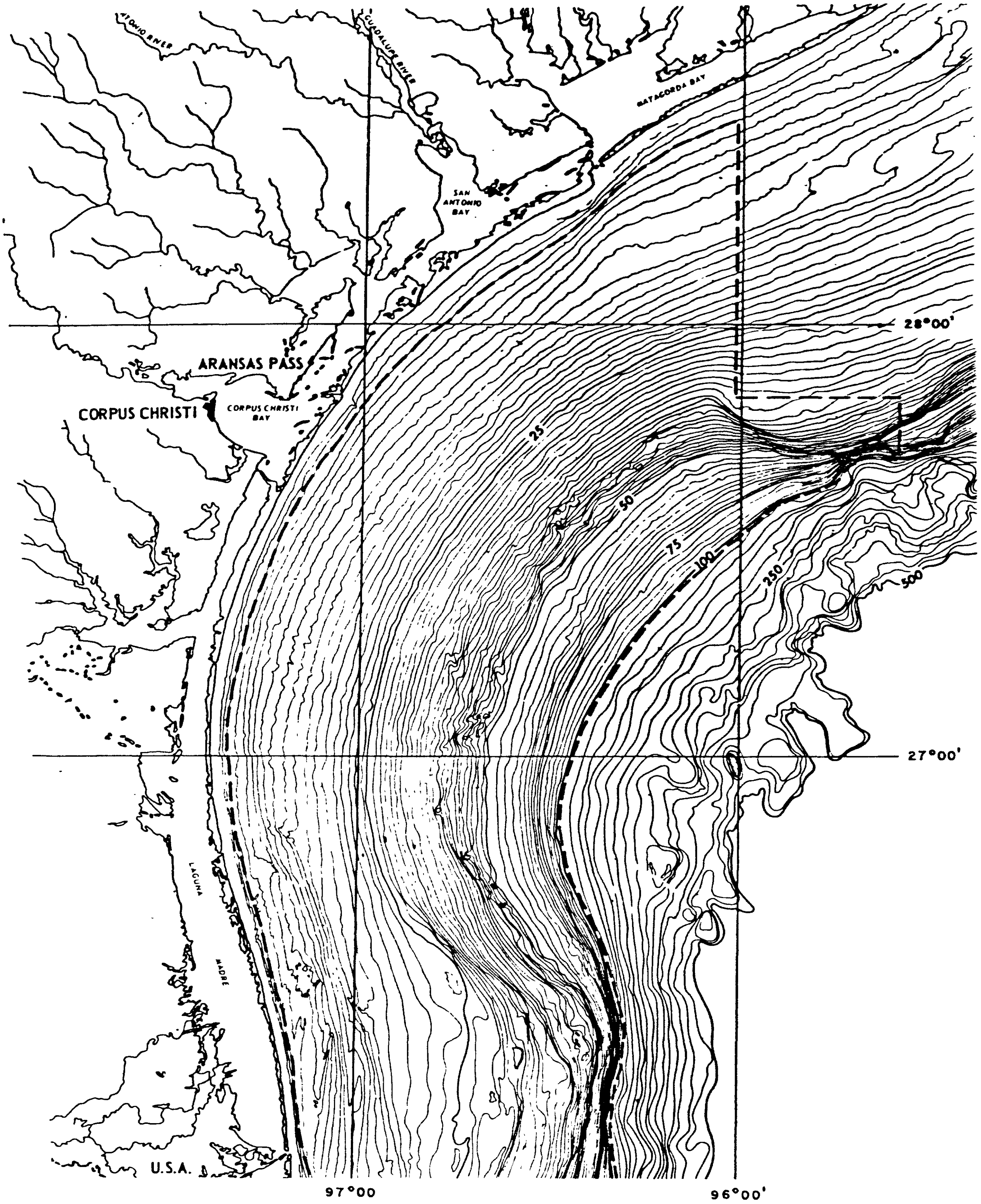


Figure 1. Bathymetry and topography of the South Texas Outer Continental Shelf.

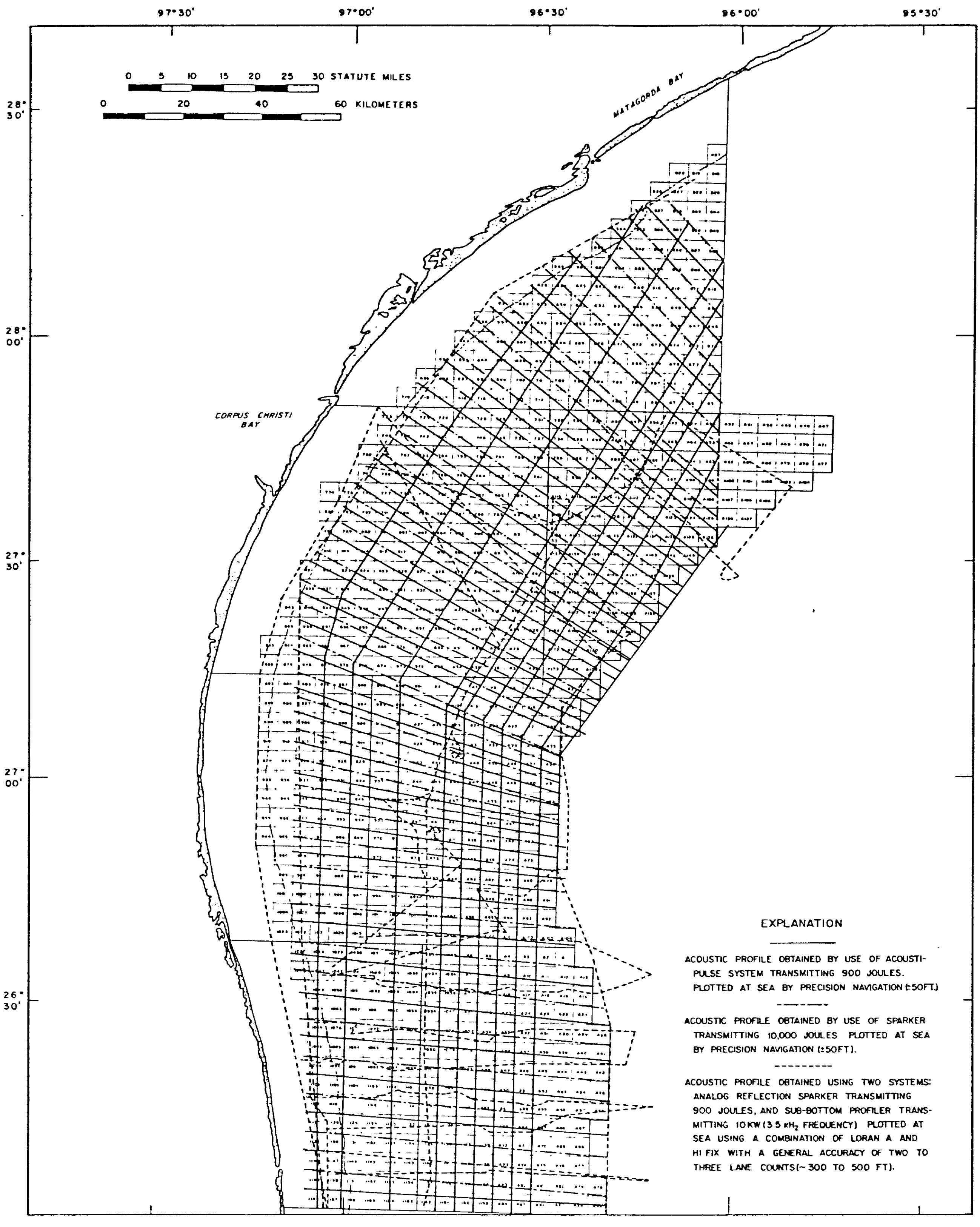


Figure 2. Location of geophysical track lines, continental shelf.

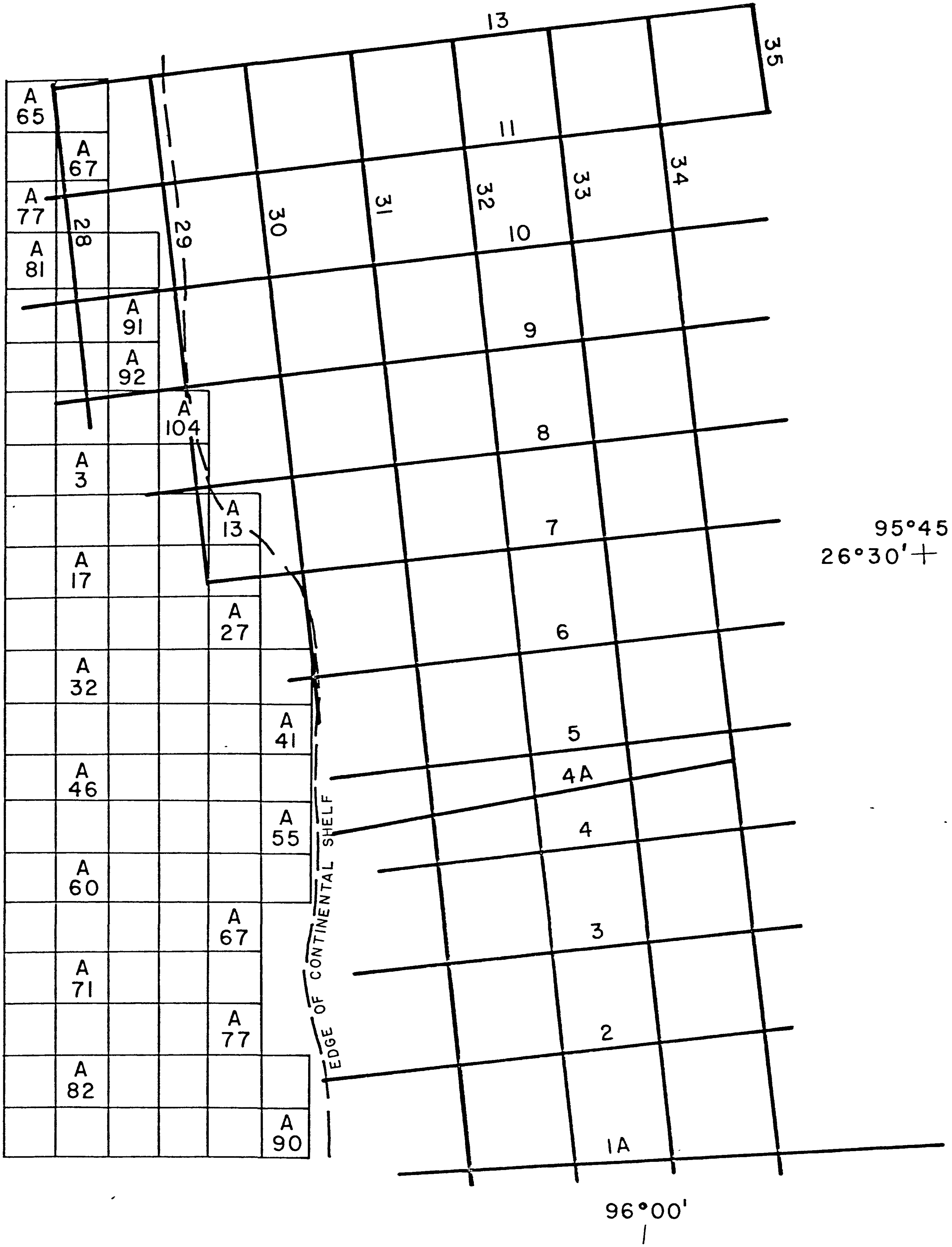


Figure 2A. Location of geophysical track lines, continental slope.

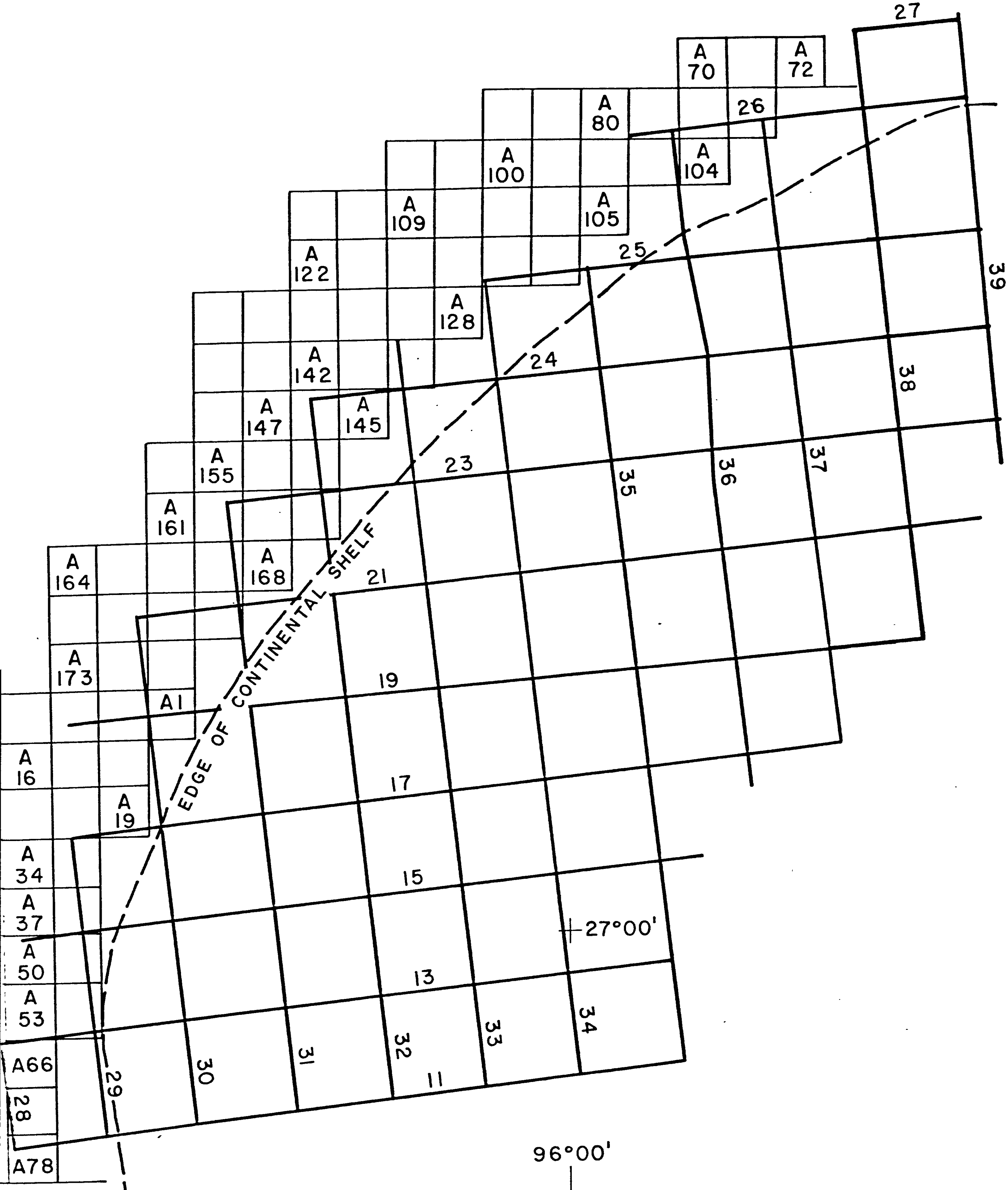


Figure 2B. Location of geophysical track lines, continental slope.

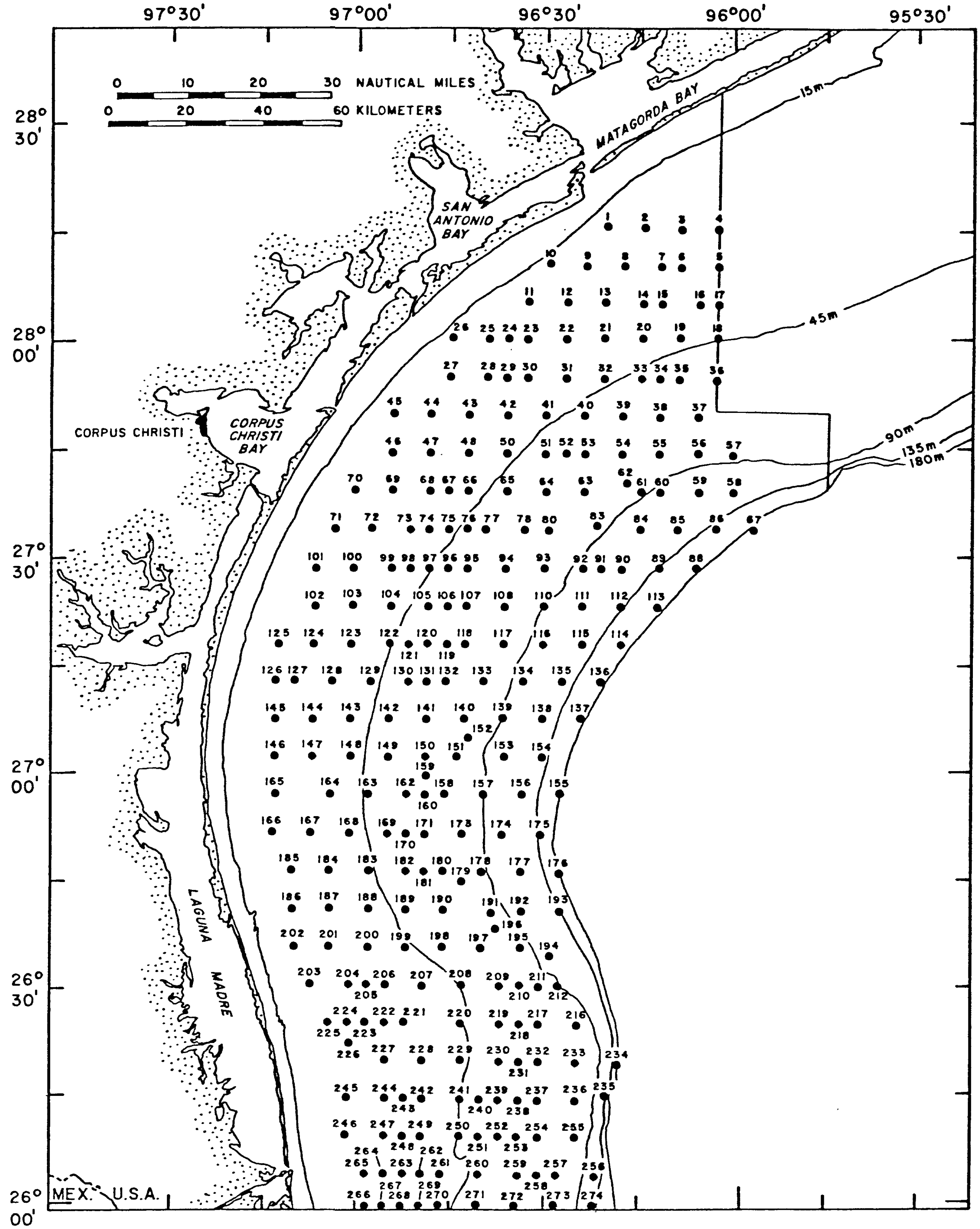


Figure 3. Location of bottom grab sample stations.

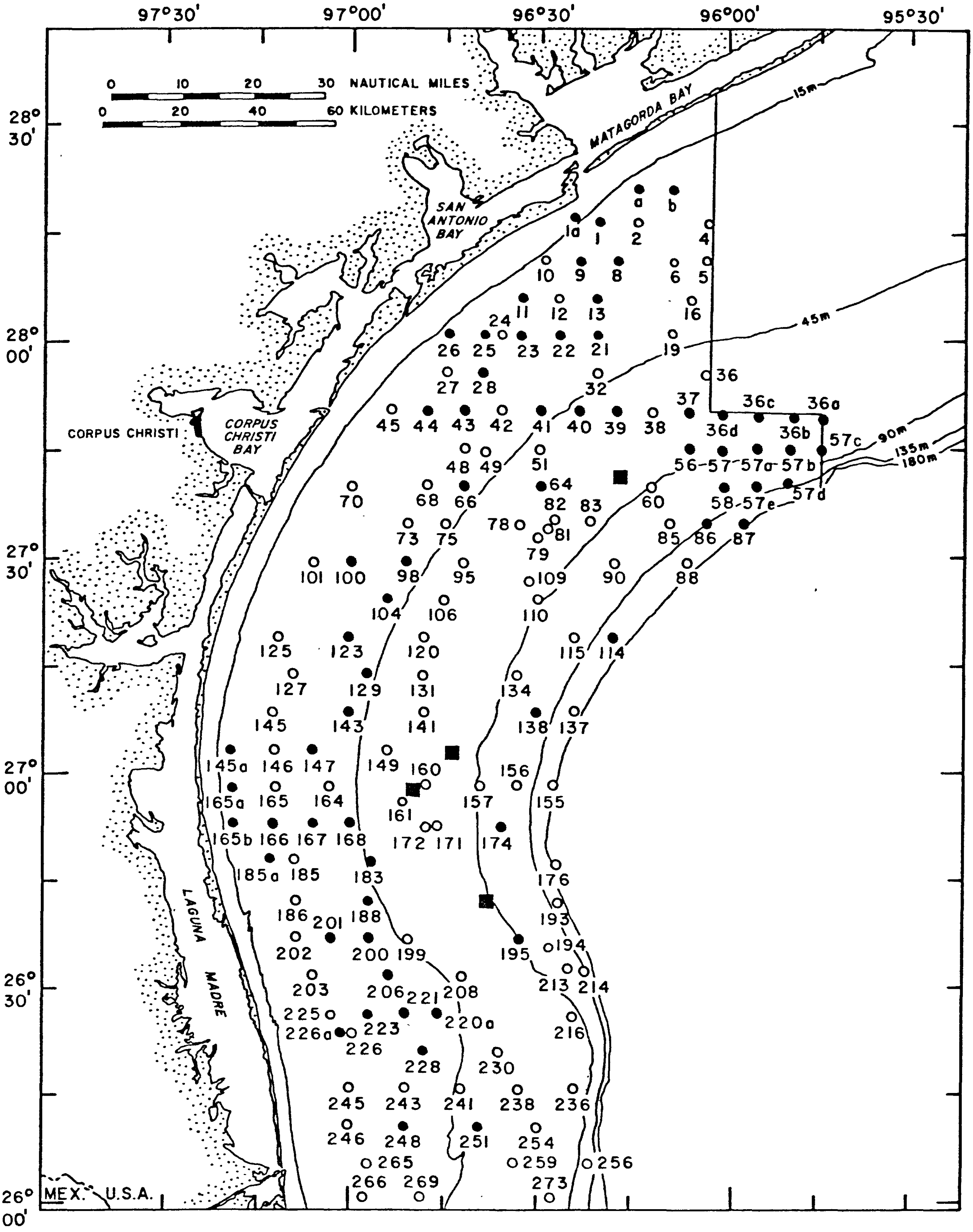


Figure 4. Location of core sample stations: black dot indicates core collected in 1975; circle indicates core collected in 1974; black square indicates closely spaced traverses across reefs.

depositional microstructures in cores and for precise definition of tops and bottoms of discrete sand layers.

2. COULTER COUNTER--for textural analysis of the less than 63 μm grain size component of the sample.
3. Rapid sediment analyzer--for textural analysis of the greater than 63 μm grain size component of the sample.
4. Atomic absorption photospectrometer--for analyzing the trace metals content of the sediments.
5. LECO carbon analyzer--for analyzing the organic carbon content of the sediments.

C. Synthesis of data and reporting

All types of data compiled in map form to indicate spatial relationships; initially prepared on transparent base material so that all types of topical data could be compared in overlay fashion to determine relationships.

III. Geologic characteristics of the region based on synthesis of the analytical and interpretative data

A. Structural framework of the continental terrace

1. Folds--series of northeastward-trending folds identified as primary structures within the continental terrace (see figure 5 for location and trend of folds).

2. Faults--five types recognized:

a. Tensional breaks formed in the strata above the crests of anticlines (elongate structures) (fig. 6).

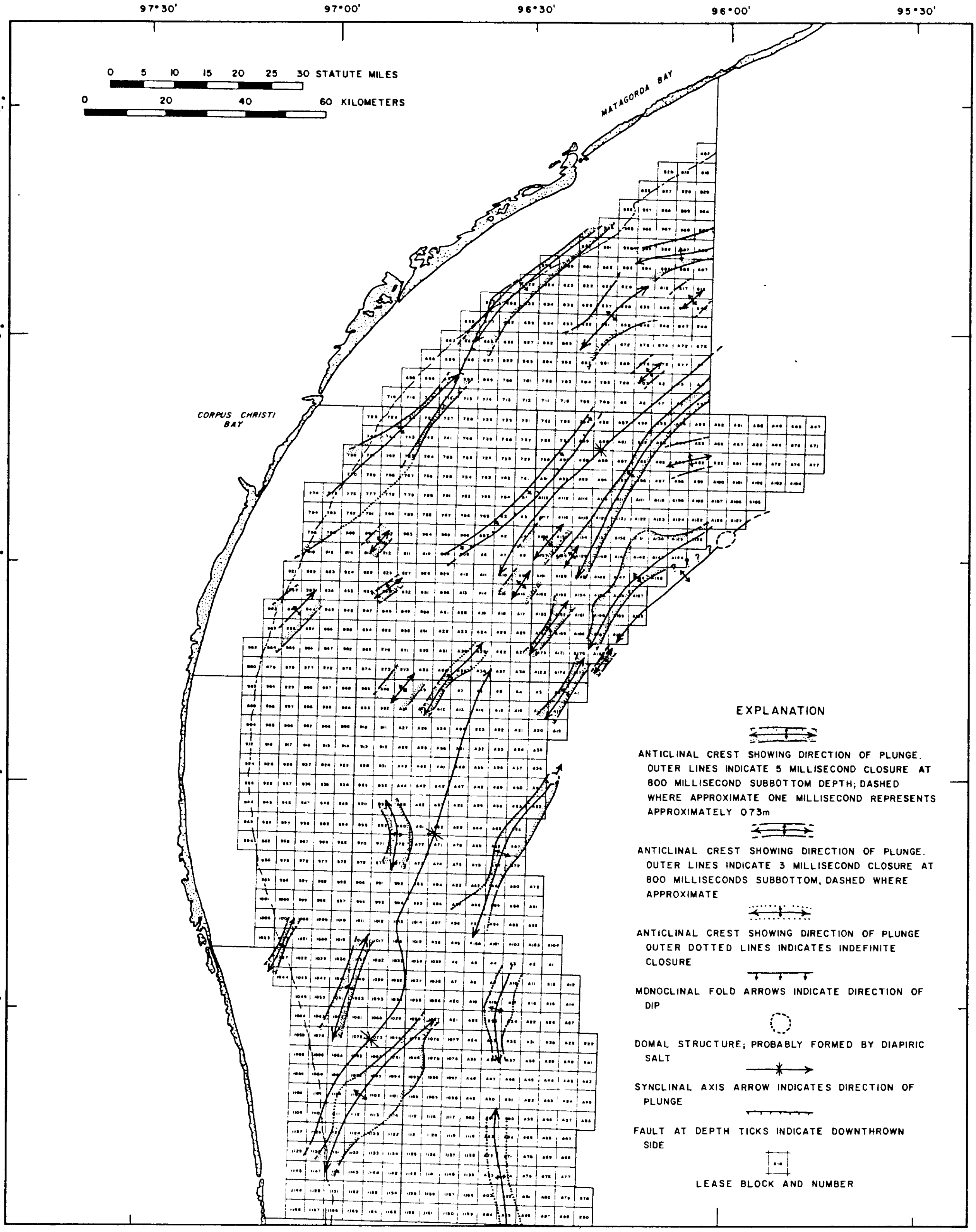


Figure 5. Location of folds within the continental terrace.

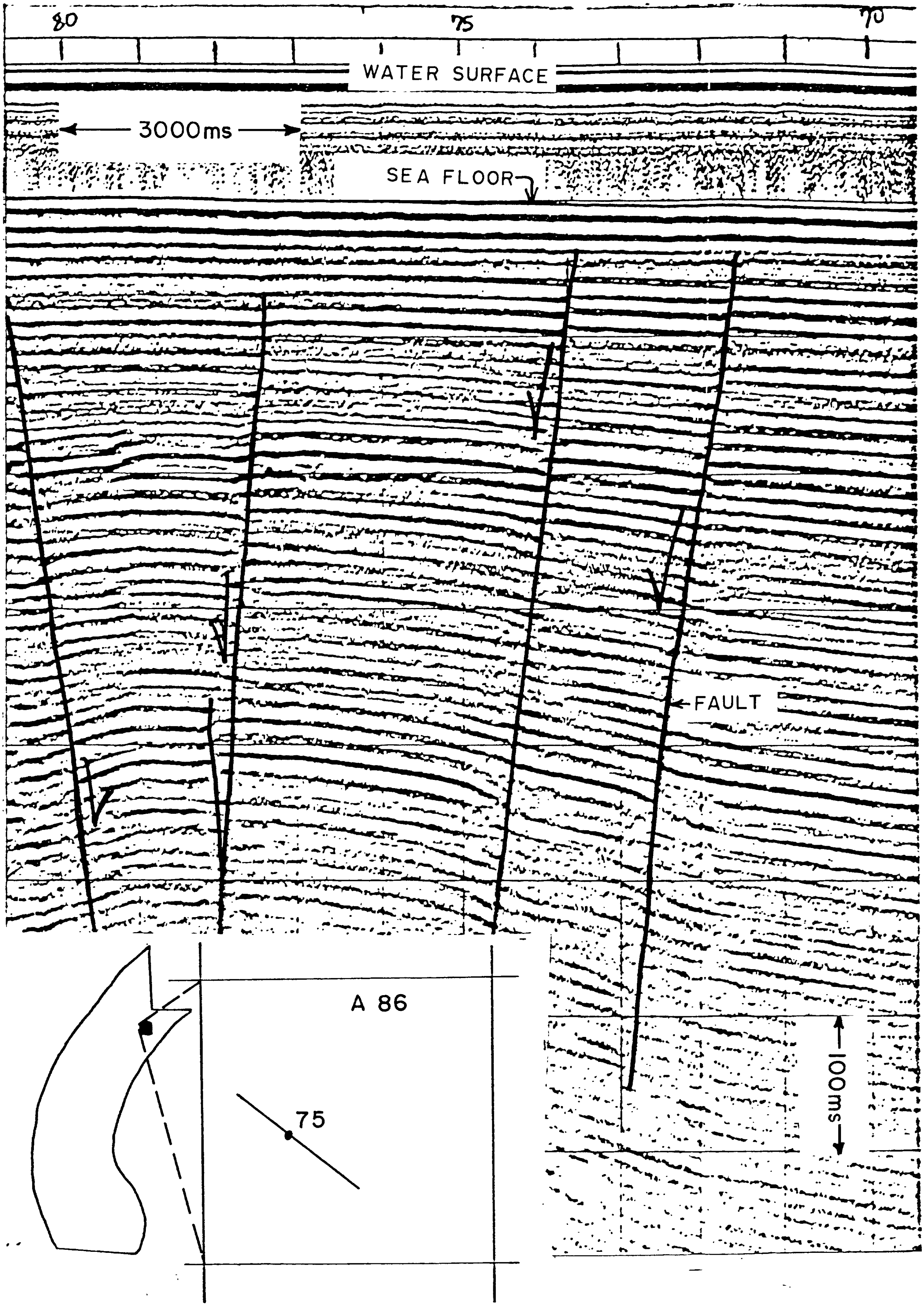


Figure 6. Tensional faults in typical pattern above the crest of an anticline.

b. Tensional breaks above diapirs (domal structures) (fig. 7).

c. Deep seated rotational gravity faults in the outer part of the continental terrace where sediment loading has caused the rim of the continental terrace to sag and slide basinward (fig. 8).

d. Composite tensional and gravity faults, edge of continental terrace and upper slope (fig. 9).

e. Shallow rotational faults associated with sliding and slumping of surficial sediments, continental slope (figs. 9 and 10).

B. Evolution of the continental terrace since middle Pleistocene

General depositional history:

1. Three general environments of deposition are recognized: open shelf, deltaic, and continental slope (fig. 11). Each has distinctly different sedimentary characteristics.

2. In general perspective, the outer edge of the continental terrace has grown progressively seaward as a result of the large influx of clastic sediments. The principal factor that

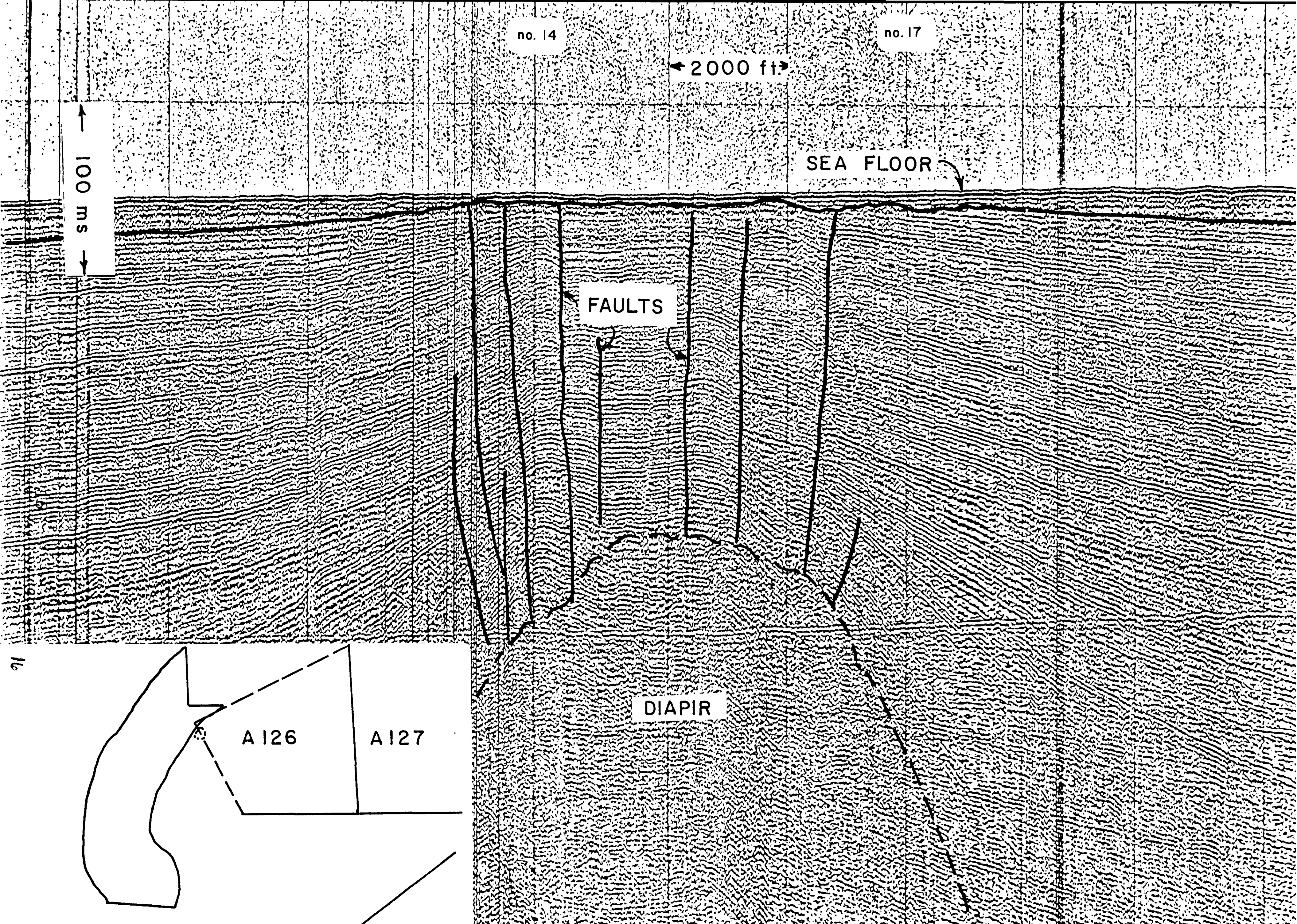
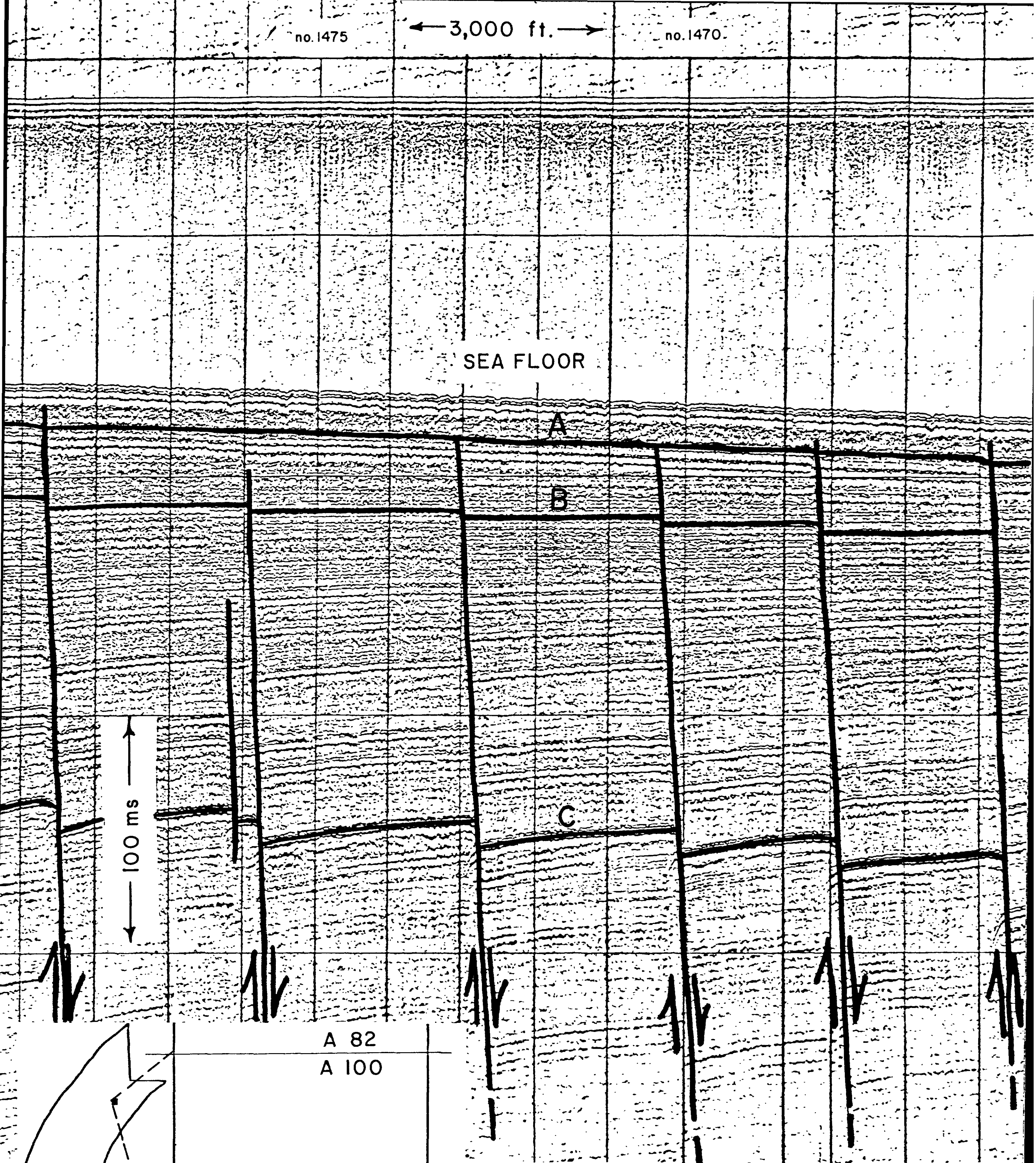


Figure 7. Tensional faults in typical pattern above the crest of a diapir.



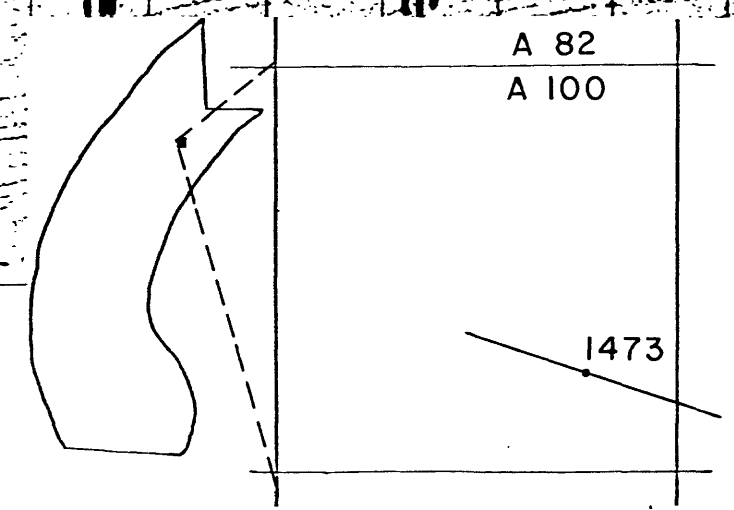


Figure 8. Deep seated rotational gravity faults in typical pattern showing direction of offset of beds, outer part of the continental terrace. Increased offset of beds with depth, as indicated by A, B and C, indicates continued and progressive movement through time.

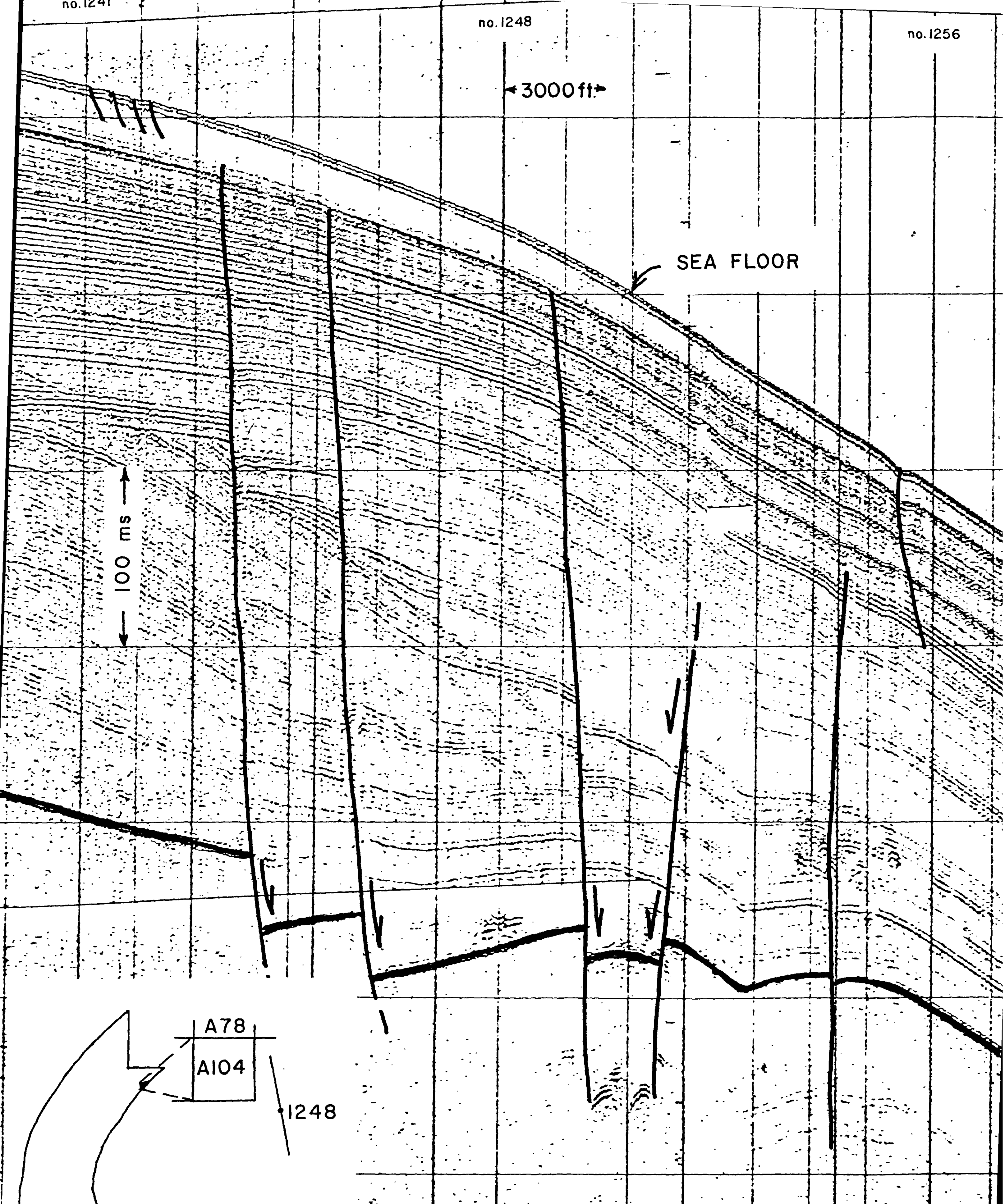


Figure 9. Composite of tensional and gravity faults, upper continental slope.

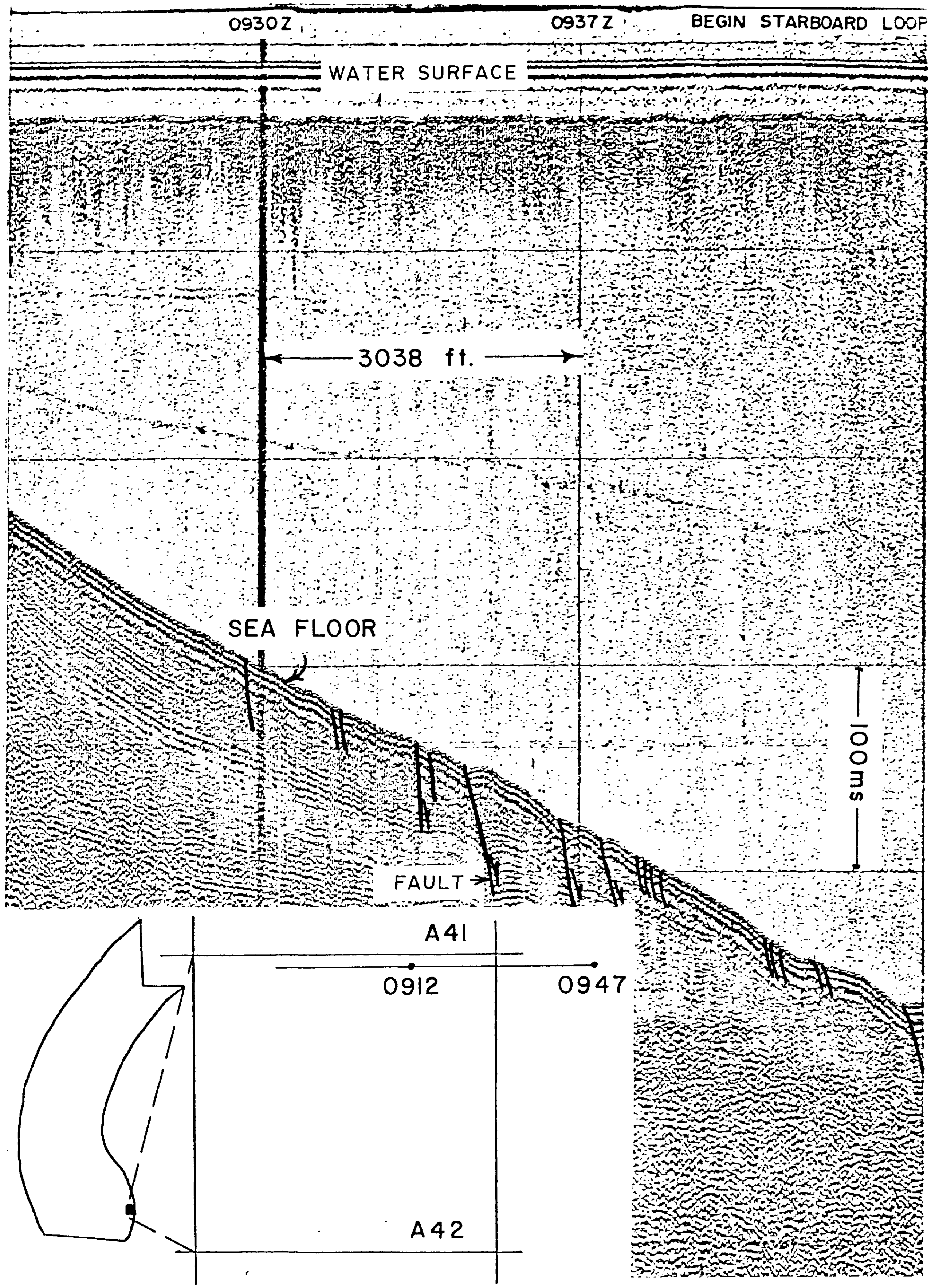


Figure 10. Shallow seated rotational gravity faults associated with slumping of sediments down the continental slope.

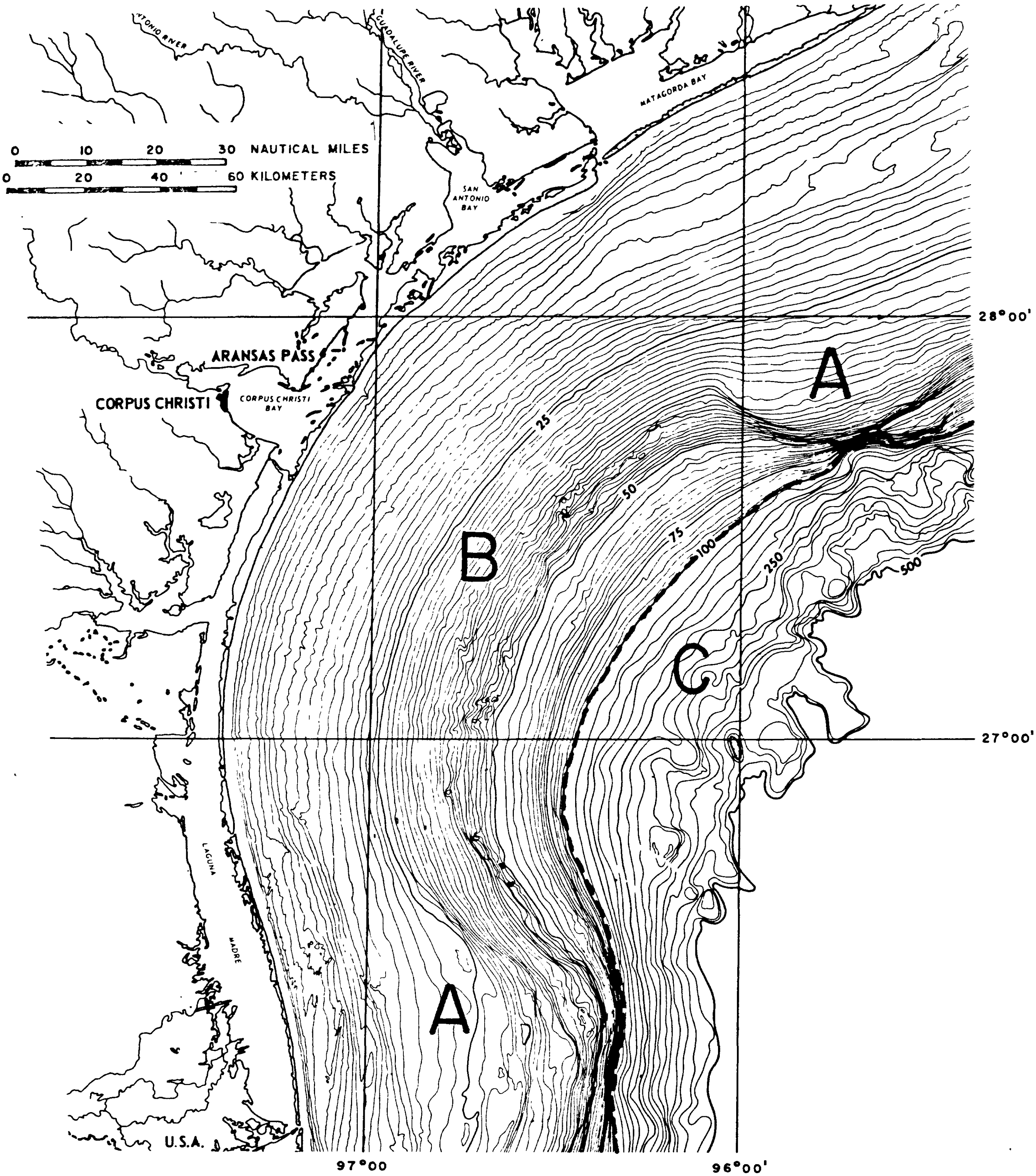


Figure 11. Principal depositional environments, continental terrace off south Texas. (A = ancestral deltaic; B = open shelf; C = continental slope)

has shaped the geomorphic profile of the terrace has been the climatically controlled fluctuations of sea level. Sea level has risen and fallen cyclically over a range of some 100 to 150 m during Pleistocene time. The nature of the general depositional process is shown by figures 12 and 13, which are adjoining sections from an acoustical profile. The development of the continental terrace in the western Gulf has been discussed previously by Lehner (1969), Curray (1960), Moore and Curray (1963), Sidner (1977), Sangree and others (1976), Tatum (1977), and Pyle and Berryhill (1977).

3. The geomorphic extent of open shelf versus deltaic deposition has varied widely because of the changes in sea level: sedimentation has been principally deltaic during the glacial epochs when the shelf was exposed as land surface and open shelf during the interglacial epochs when the sea rose and spread landward across the shelf. Deposition has been continuous over the slope, but the amount and type of sediment deposited there has varied considerably as the result of the migrations of the shoreline.

4. Previous low stands of sea level are represented on the acoustical analog records as strong reflecting surfaces that are irregular and nonconformable to the sediments above and below. Figures 14 and 15 are sections of acoustical profiles from different parts of the shelf showing the nature and

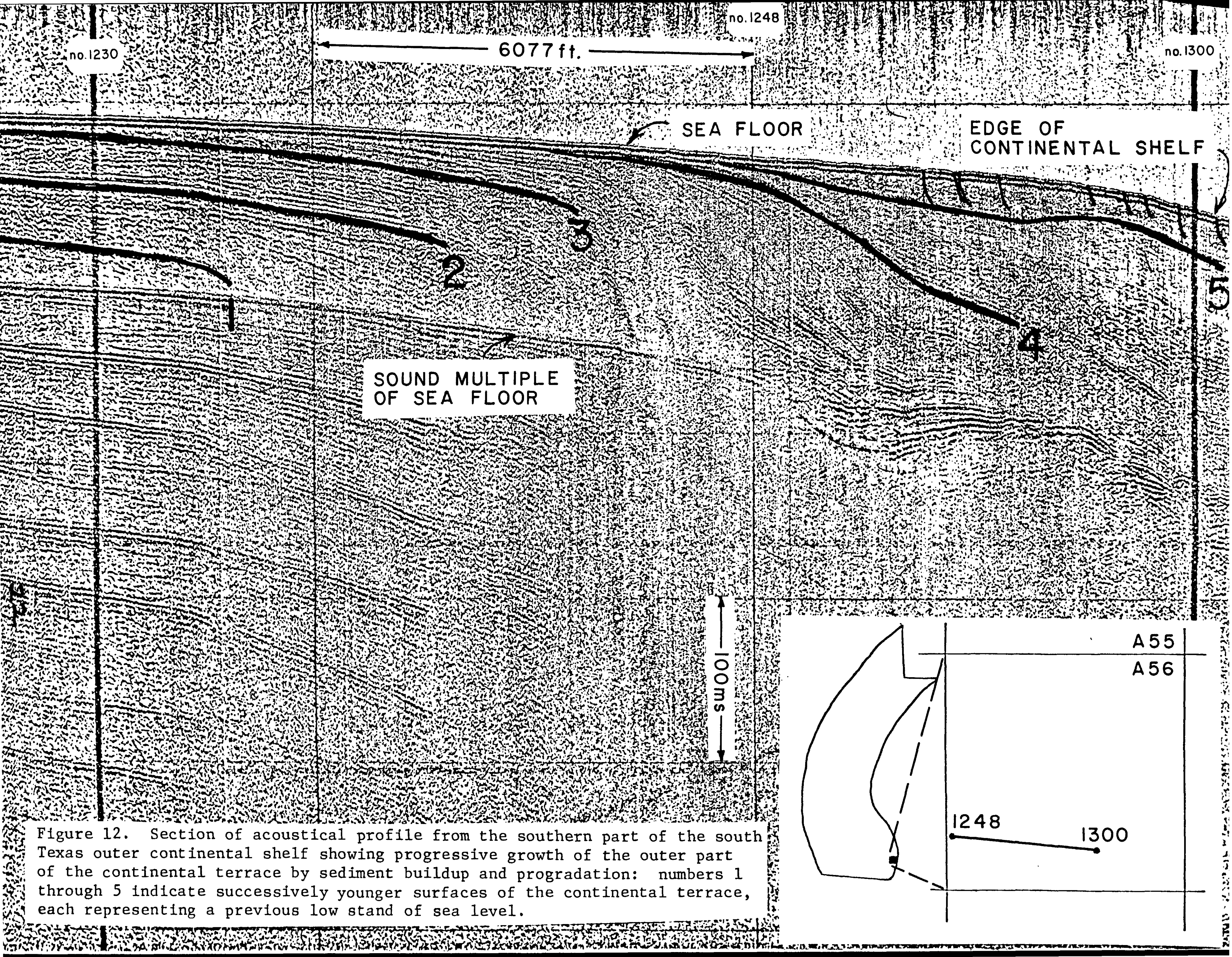


Figure 12. Section of acoustical profile from the southern part of the south Texas outer continental shelf showing progressive growth of the outer part of the continental terrace by sediment buildup and progradation: numbers 1 through 5 indicate successively younger surfaces of the continental terrace, each representing a previous low stand of sea level.

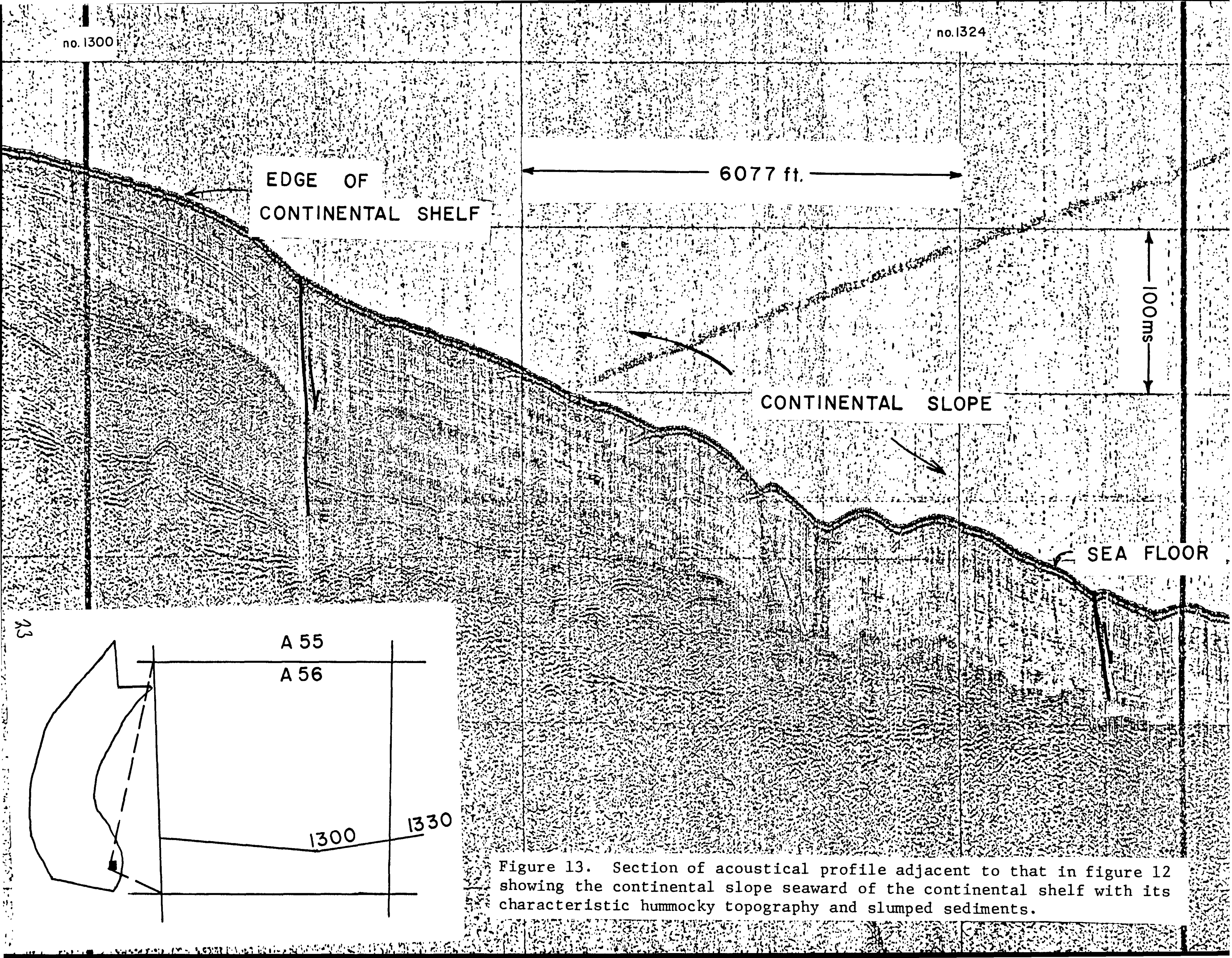


Figure 13. Section of acoustical profile adjacent to that in figure 12 showing the continental slope seaward of the continental shelf with its characteristic hummocky topography and slumped sediments.

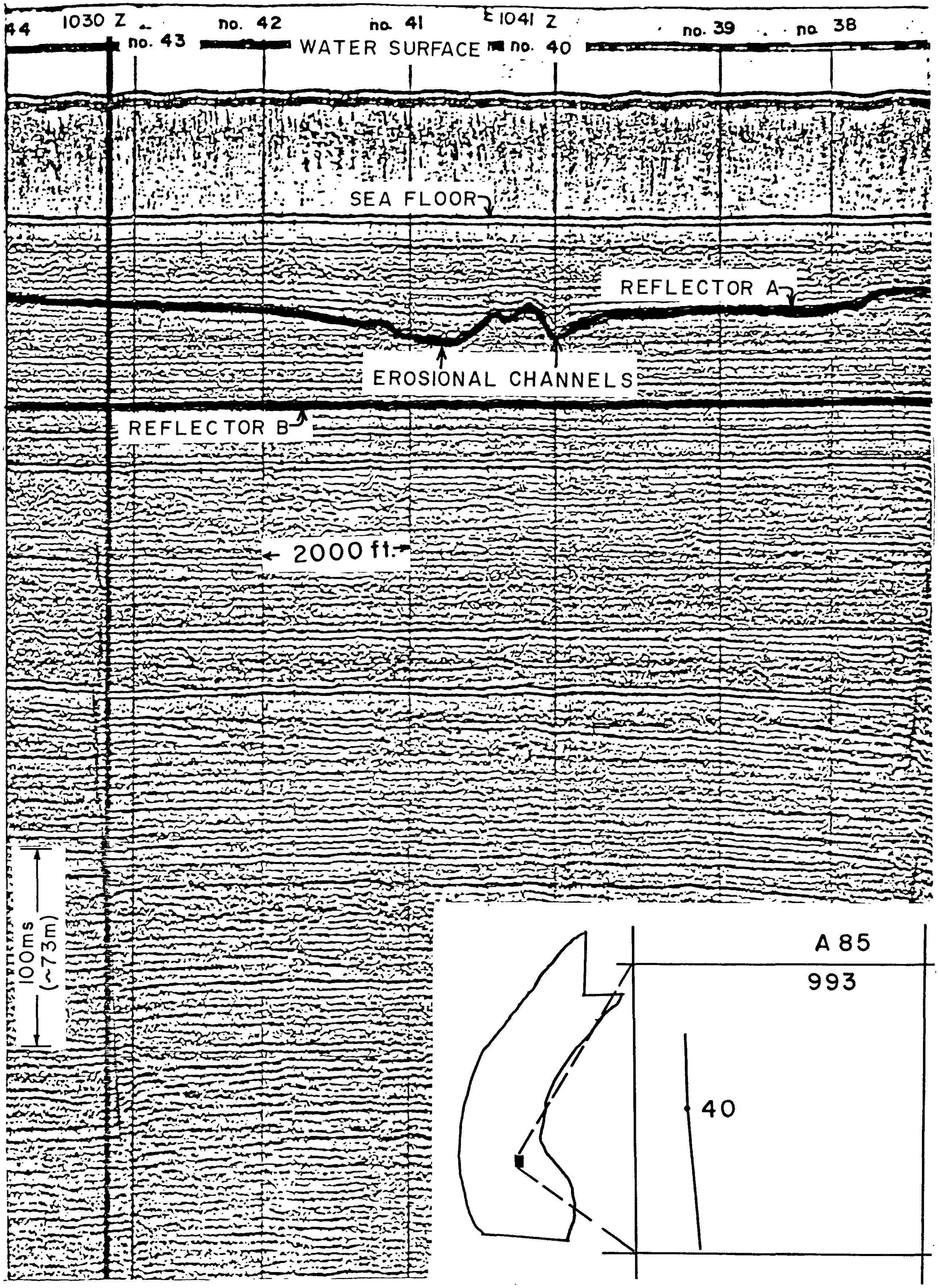


Figure 14. Section of an acoustical profile, southern part of the south Texas continental shelf, showing the nature and subsurface positions of two paleo surfaces that represent previous low stands of sea level.

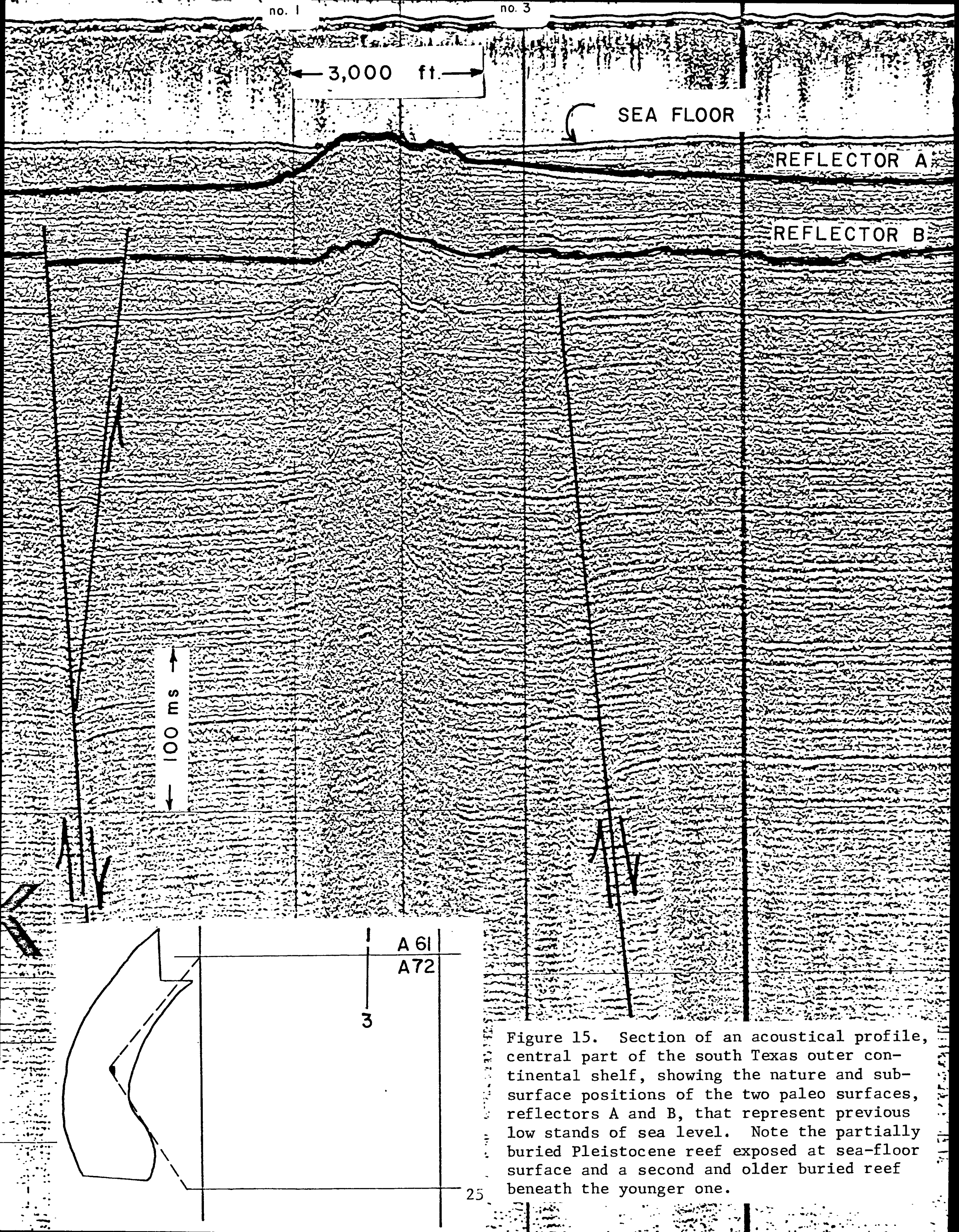


Figure 15. Section of an acoustical profile, central part of the south Texas outer continental shelf, showing the nature and subsurface positions of the two paleo surfaces, reflectors A and B, that represent previous low stands of sea level. Note the partially buried Pleistocene reef exposed at sea-floor surface and a second and older buried reef beneath the younger one.

subsurface position of several post middle Pleistocene surfaces that represent low stands of sea level.

5. The unconformities represented by the strong sound reflecting surfaces define 4 late Pleistocene/Holocene depositional units on the shelf. The stratigraphic relations of the depositional units and the unconformities separating them, as constructed from acoustical profiles, are shown by figures 16, 17, and 18; figure 16 is the index map showing the locations of the profiles shown on figures 17 and 18. The distribution and thickness of the units, in essence the depositional history of the shelf for the time period specified, are shown by the series of isopach and structure contour maps, figures 19 through 25 taken from Pyle and Berryhill (1977). The isopach maps show the thickness of the units; the structure contour maps show the configuration and depth below sea level of each of the unconformities that define the depositional units.

Holocene deposition:

1. The Holocene deposits record the transgression of the rising sea across the shelf from the last low stand. The older Holocene deposits making up the basal part of the unit probably represent different environments from the more recent open shelf deposits. An interpretation of the types

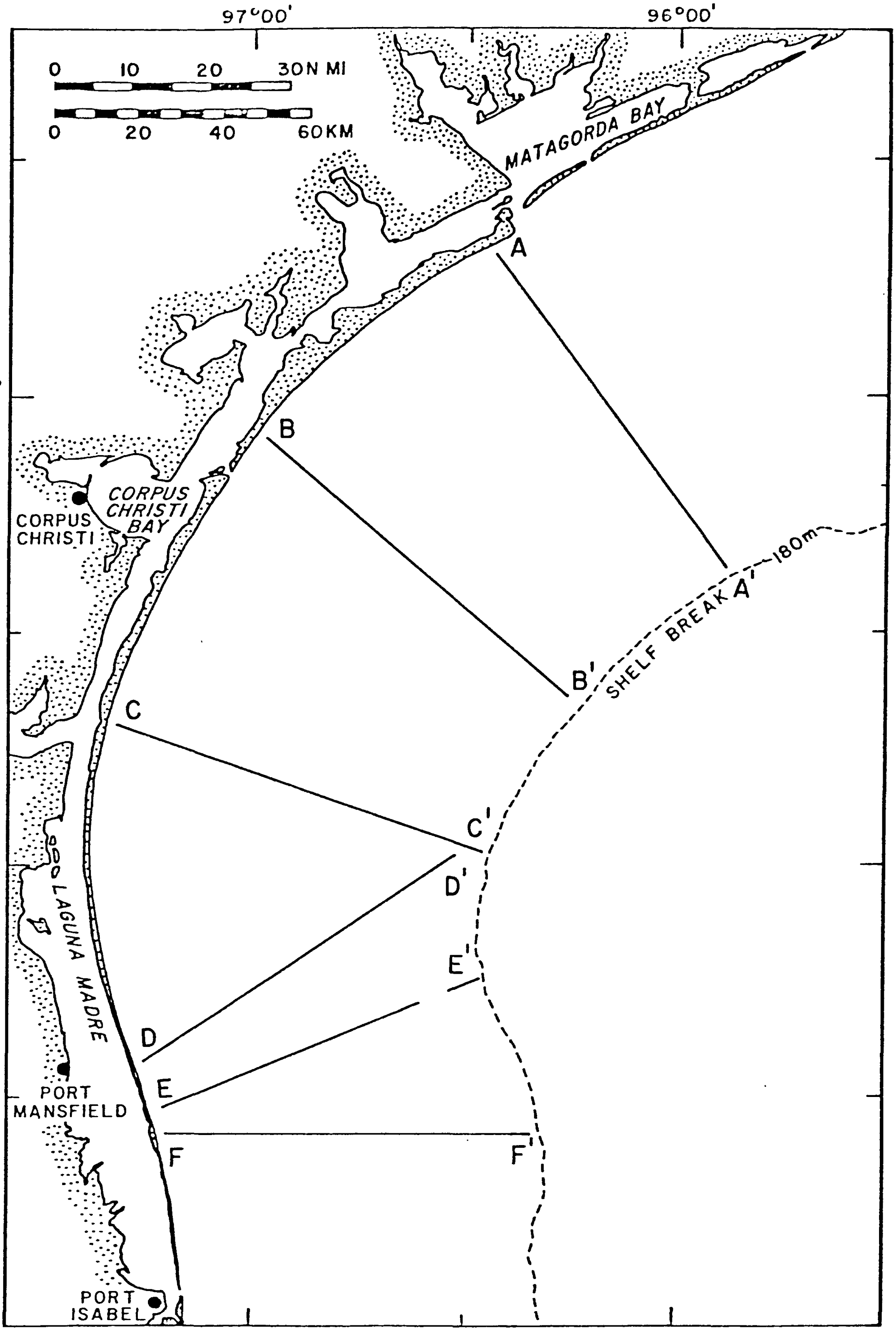


Figure 16. Location of profiles shown on figures 17 and 18. (From Pyle and Berryhill, 1977.)

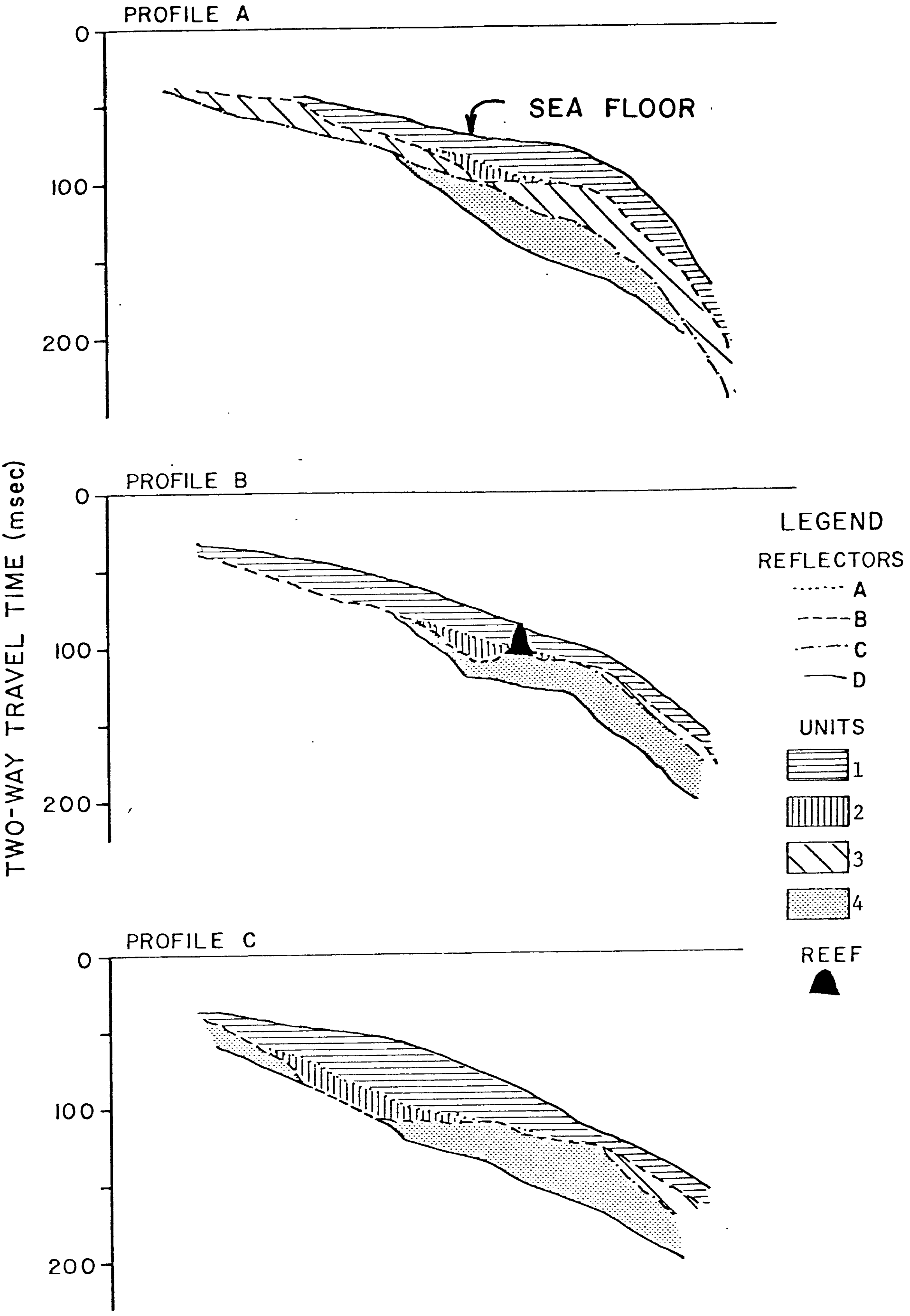


Figure 17. Stratigraphic relations of post middle Pleistocene depositional units, profiles A, B and C. (From Pyle and Berryhill, 1977.)

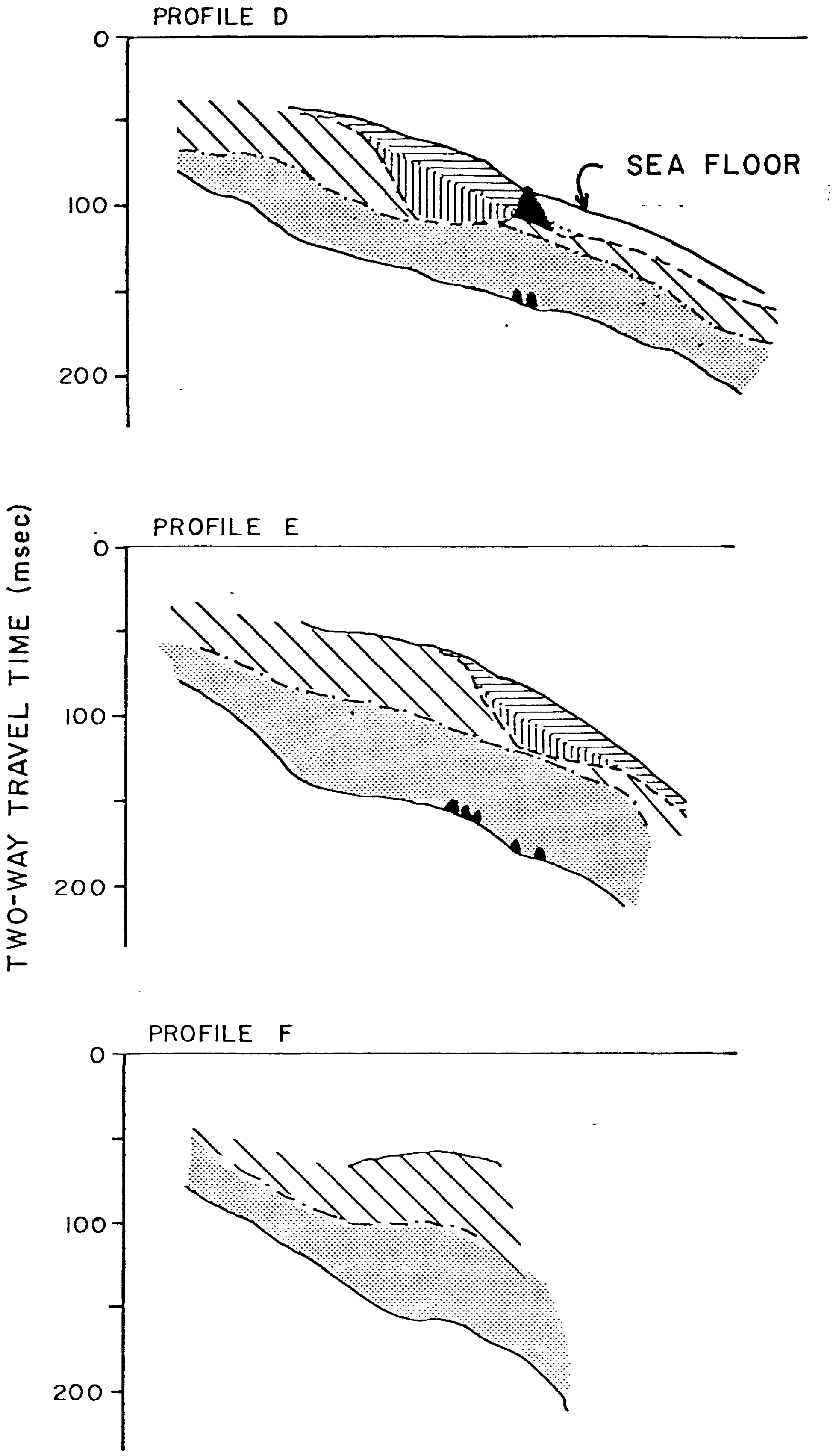


Figure 18. Stratigraphic relations of post middle Pleistocene depositional units, profiles D, E and F. (From Pyle and Berryhill, 1977.) See figure 17 for legend.

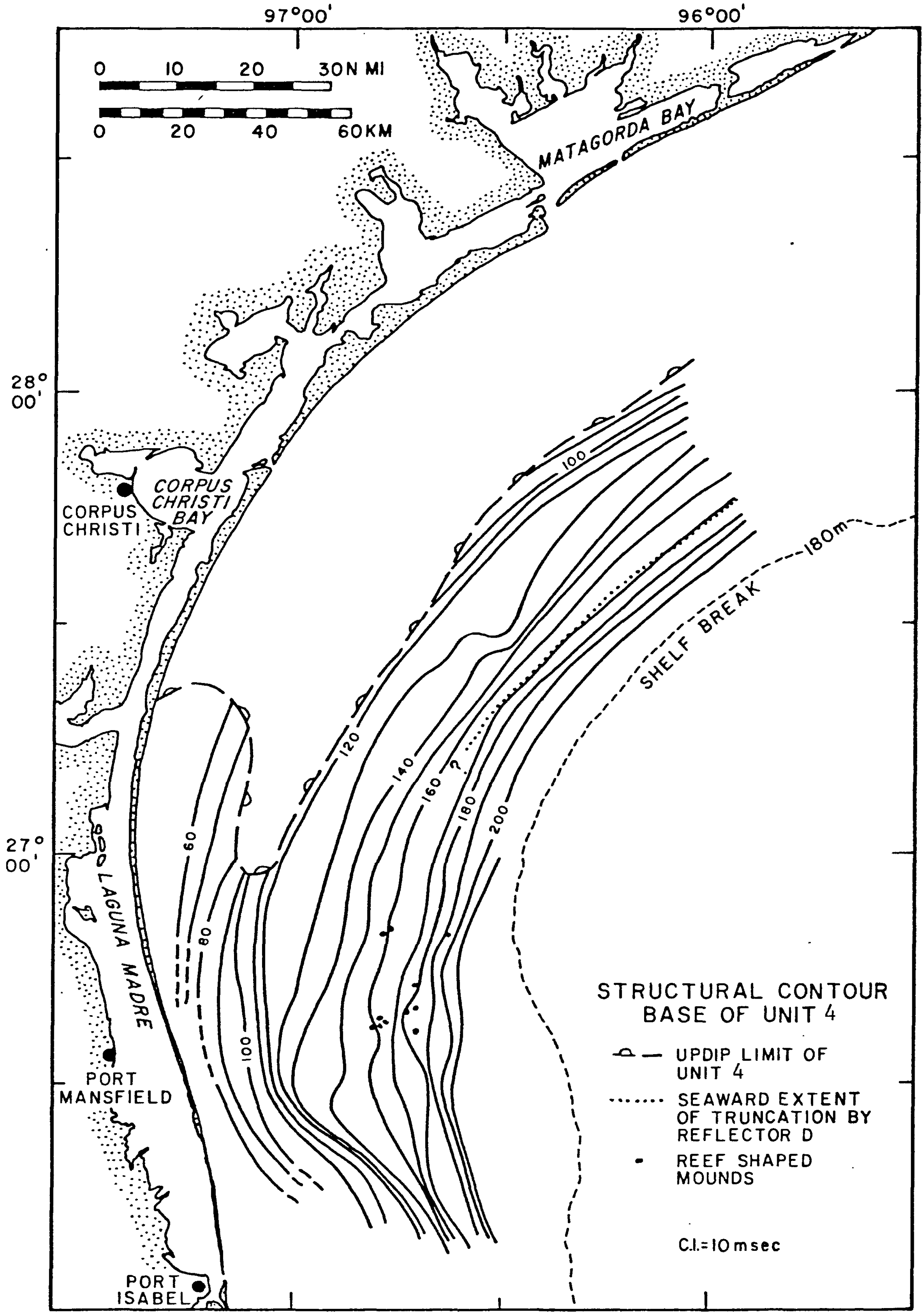


Figure 19. Configuration of the base of unit 4 (reflector D) shown by structure contours in depth below sea level in milliseconds. One ms is assumed to represent ~0.73 m. (From Pyle and Berryhill, 1977.)

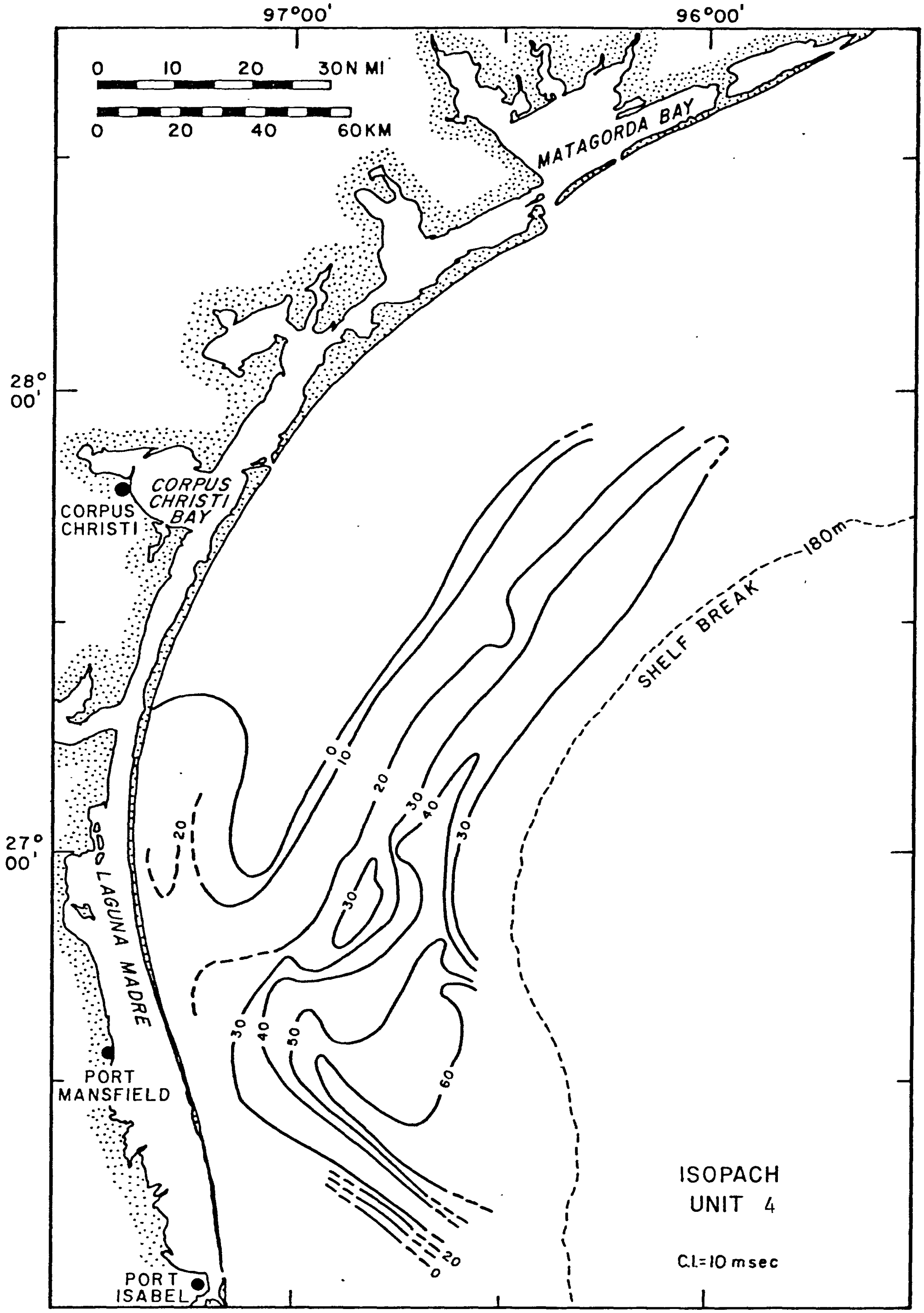


Figure 20. Thickness and distribution of unit 4 in milliseconds. One ms is assumed to represent ~0.73 m. (From Pyle and Berryhill, 1977.)

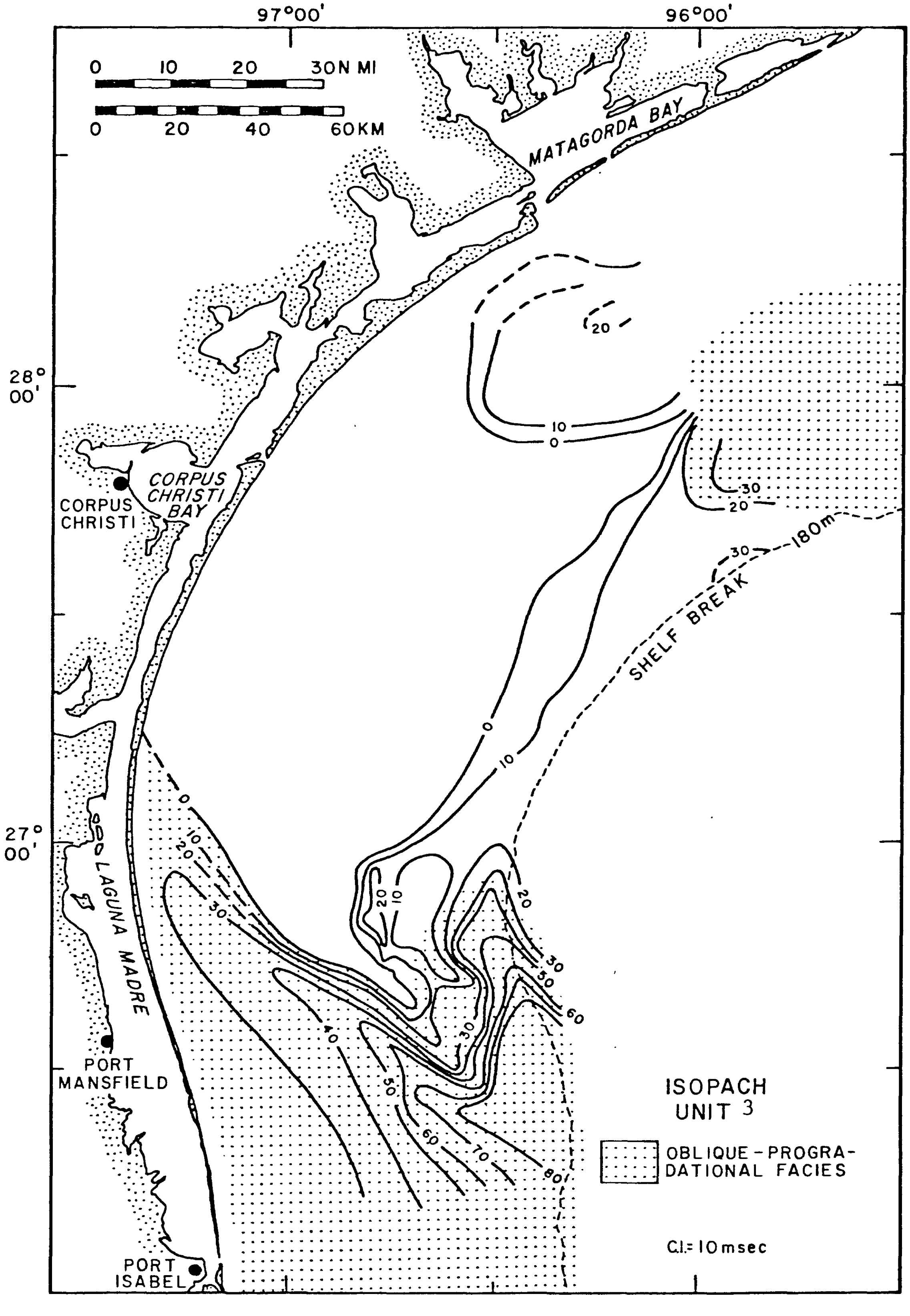


Figure 21. Thickness and distribution of unit 3 in milliseconds. One ms is assumed to represent ~0.73 m. (From Pyle and Berryhill, 1977.)

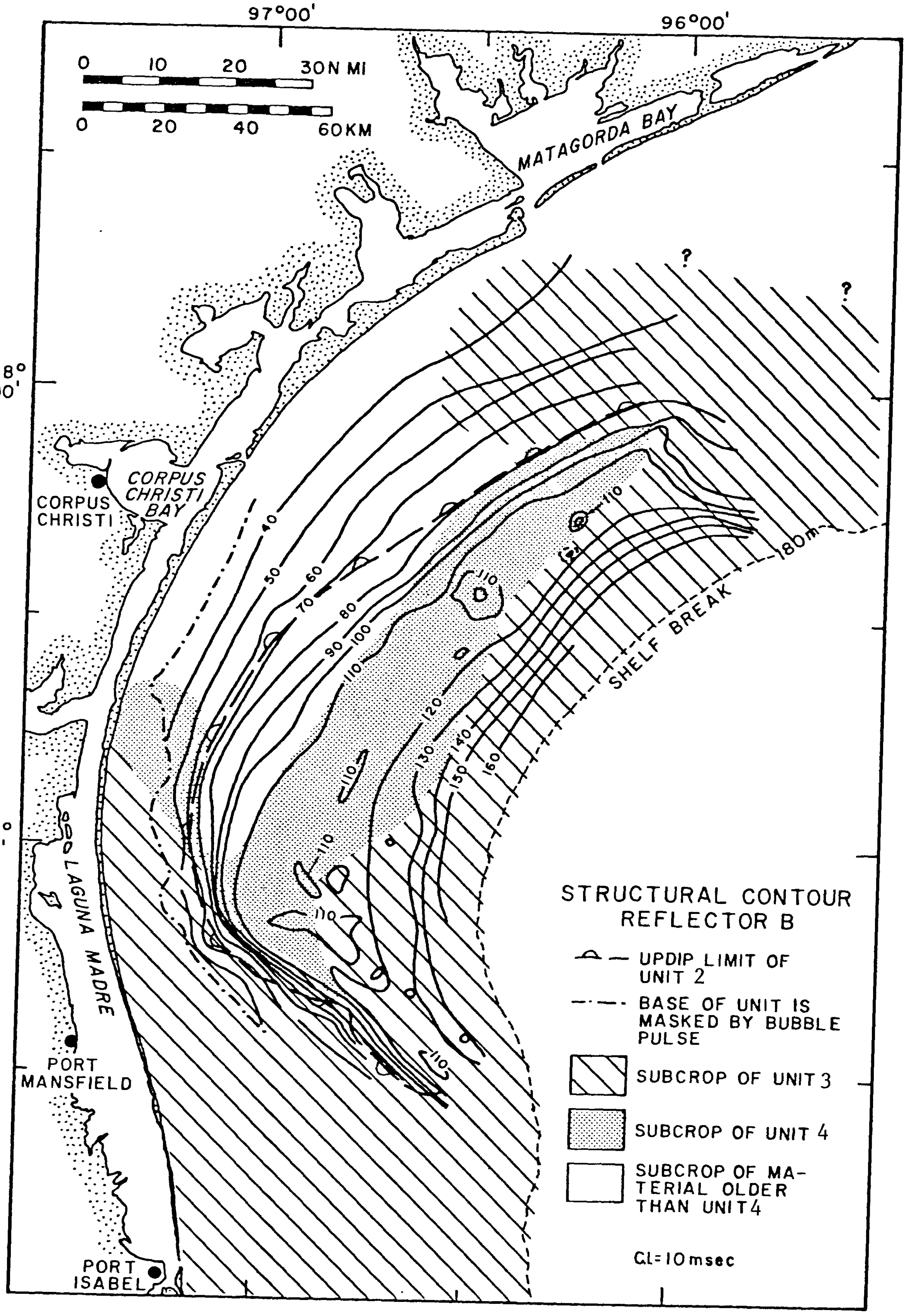


Figure 22. Configuration of reflector B, or base of depositional units 1/2, shown by structure contours in depth below sea level in milliseconds. One ms is assumed to represent ~0.73. (From Pyle and Berryhill, 1977.)

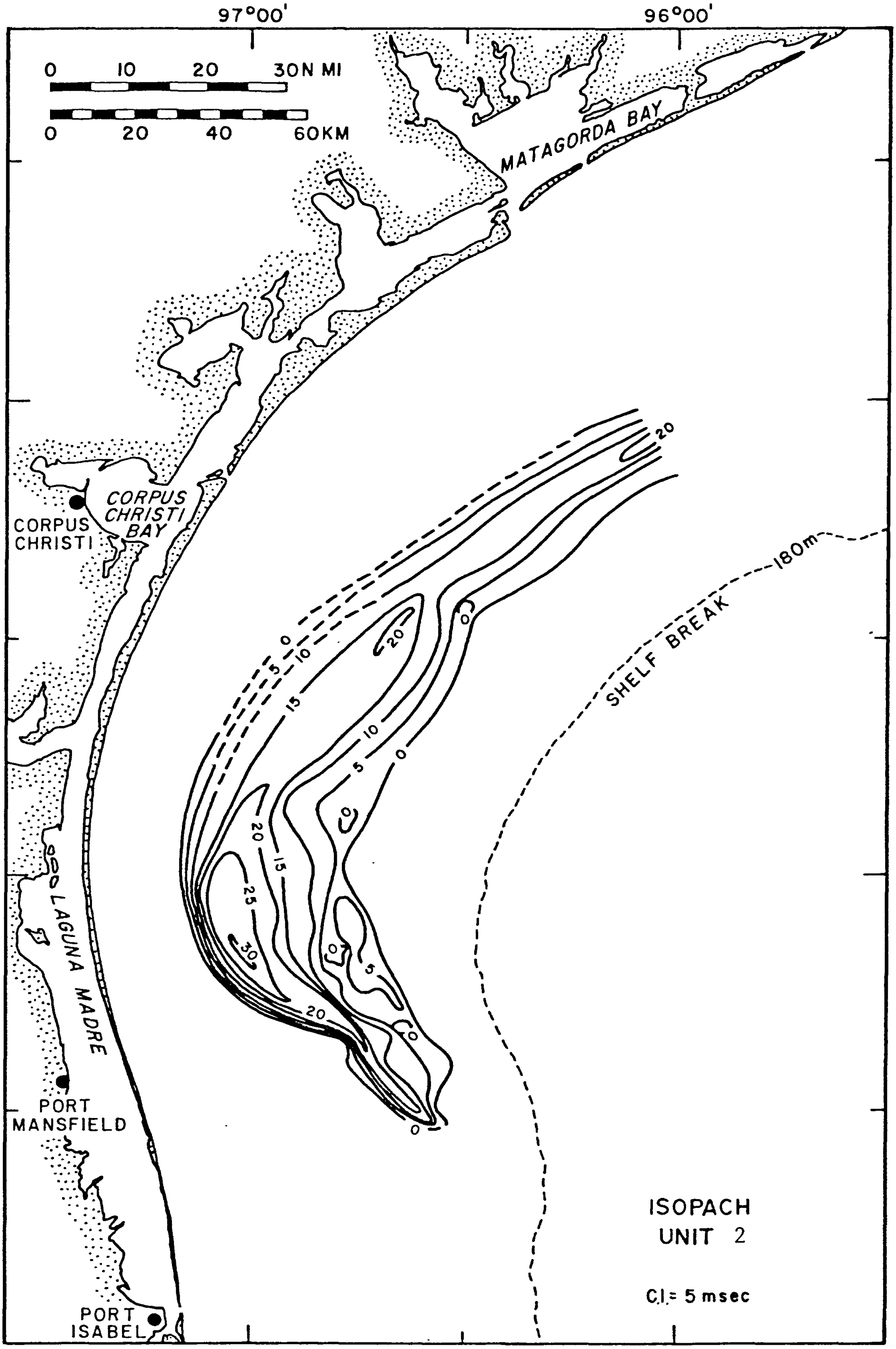


Figure 23. Thickness and distribution of unit 2 in milliseconds. One ms is assumed to represent ~0.73 m. (From Pyle and Berryhill, 1977.)

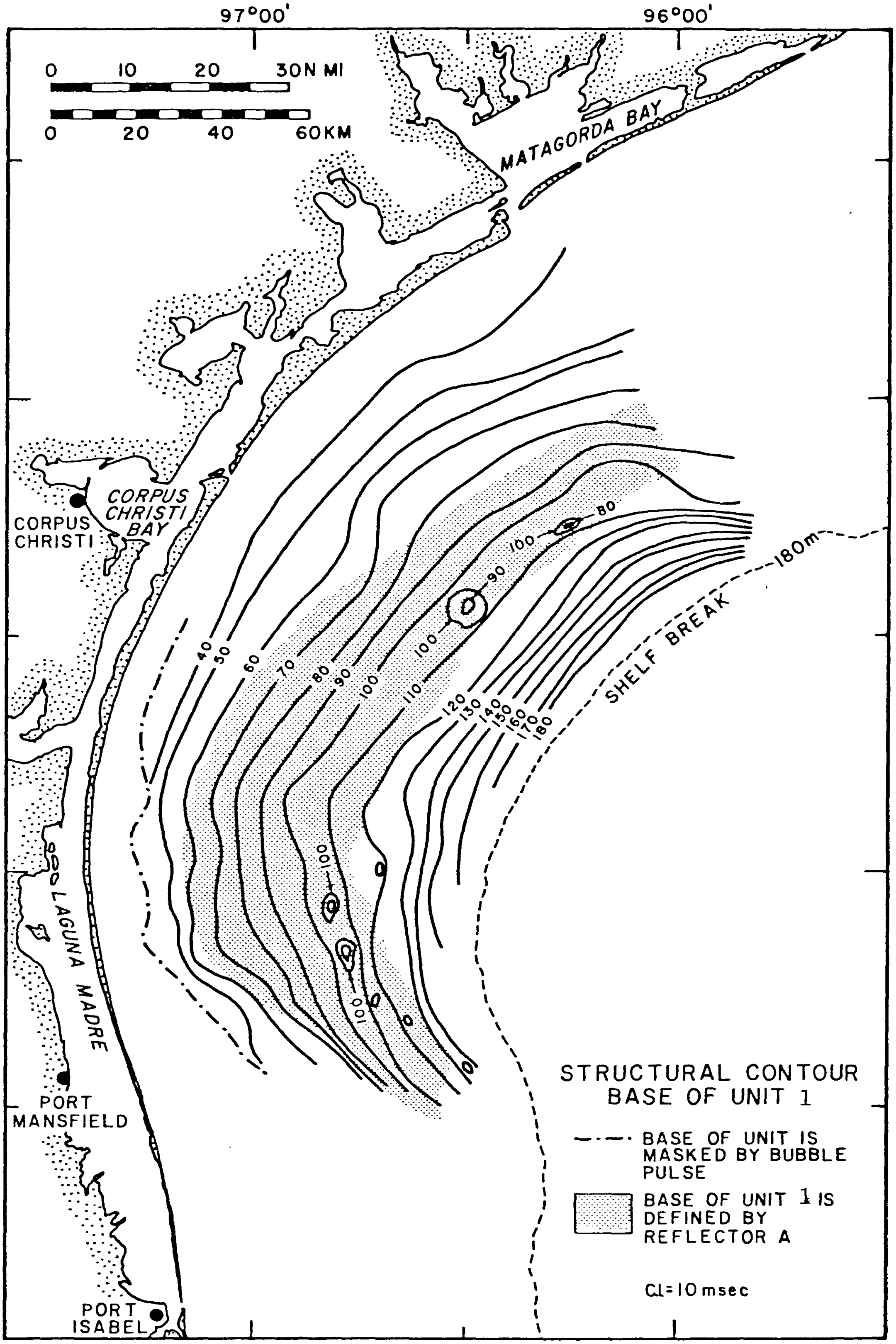


Figure 24. Configuration of the base of unit 1 (reflector A) shown by structure contours in depth below sea level in milliseconds. One ms is assumed to represent ~0.73 m. (From Pyle and Berryhill, 1977.)

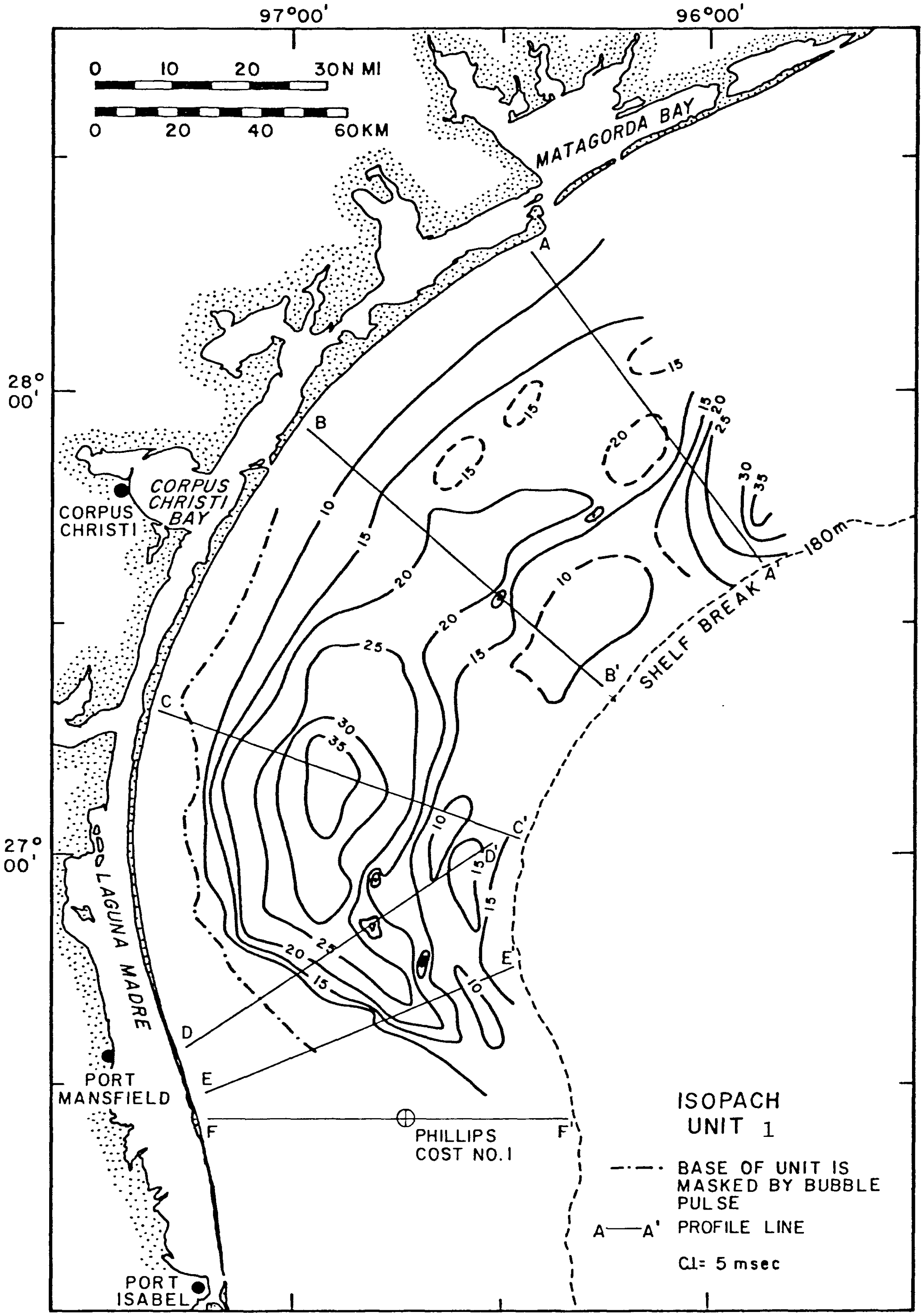


Figure 25. Thickness and distribution of unit 1 in milliseconds. One ms is assumed to represent ~0.73 m. (From Pyle and Berryhill, 1977.)

of sediments represented in the basal Holocene deposits is shown by figure 26.

2. The overall thickness of the Holocene sediments is related to the structural fabric of the continental terrace; the structural grain influences both the directions of sediment transport and the sites of deposition (see thickness map for unit 1, figure 25).

3. The nature (composition and grain size) of most of the Holocene sediments is not known from actual observation, but the seismic records suggest that, except for the basal deposits that seem to vary, the makeup probably is similar to that of the shallow subsurface Holocene deposits penetrated by gravity cores. The textural stratigraphy typical of the shallow subsurface sediments is shown by selected cores (figs. 27 through 30). The several depositional environments of the shelf are represented by the cores: inner shelf, mid shelf, outer shelf, and relict deltaic. (For locations, see figure 4.)

4. Thin discrete layers of sand are typical of the shallow subsurface deposits over the inner half of the shelf. The stratigraphic recurrence and wide geographic distribution

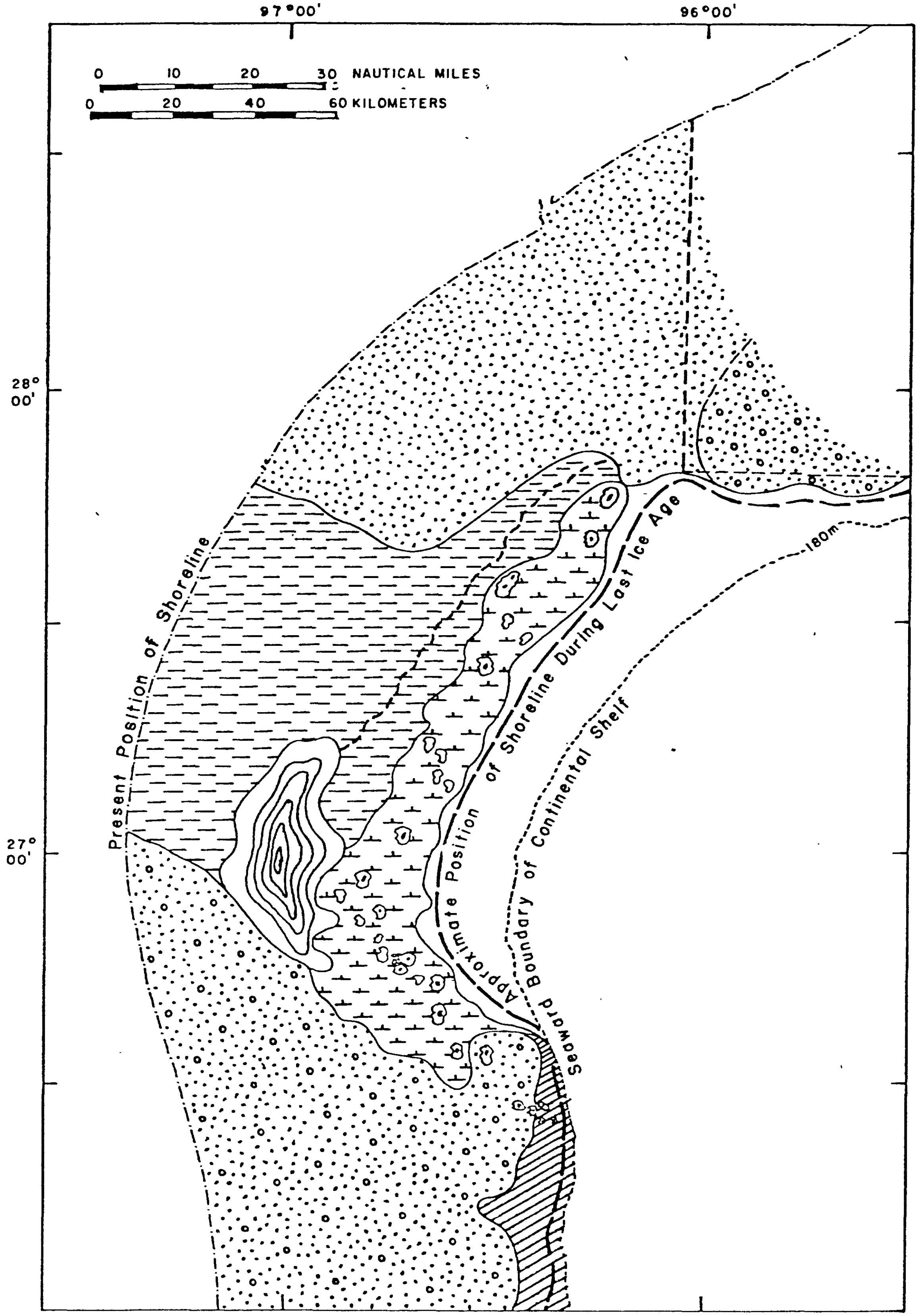
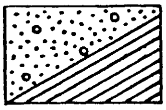


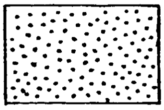
Figure 26. Interpretative environmental classification of the types of sediments represented in basal Holocene deposits. The heavy broken line is the postulated position of shoreline during the last glacial (Wisconsin) epoch. The present position of shoreline is shown by the short dash/dot line. See next page for legend.

EXPLANATION



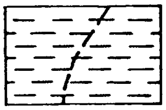
Deltaic

Principally prograded sediments; shelly sand predominates to the depth cored. Ruled pattern indicates area where youngest deltaic sediments are prograded over underlying slumped and contorted sediments.



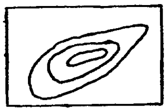
Fluvial

Lobate sheet of coalesced fluvial deposits containing numerous buried stream channels.



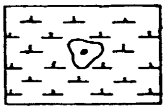
Mixed

Localized fluvial deposits resting on older open shelf deposits. Area east of dashed line probably contains lagoonal deposits.



Lacustrine?

Area outlined on the basis of the acoustical properties of the sediments. Almost complete attenuation of sound suggests either a large amount of shallow gas or high organic content.



Carbonates

Isolated reefs surrounded by irregular thin sheet-like deposits that are believed to be reef debris and small carbonate mounds on the basis of high acoustical reflectivity. Black dot indicates reef exposed on sea floor; irregular shaped circle around the dot represents general extent of the reef platform buried by Holocene sediments.

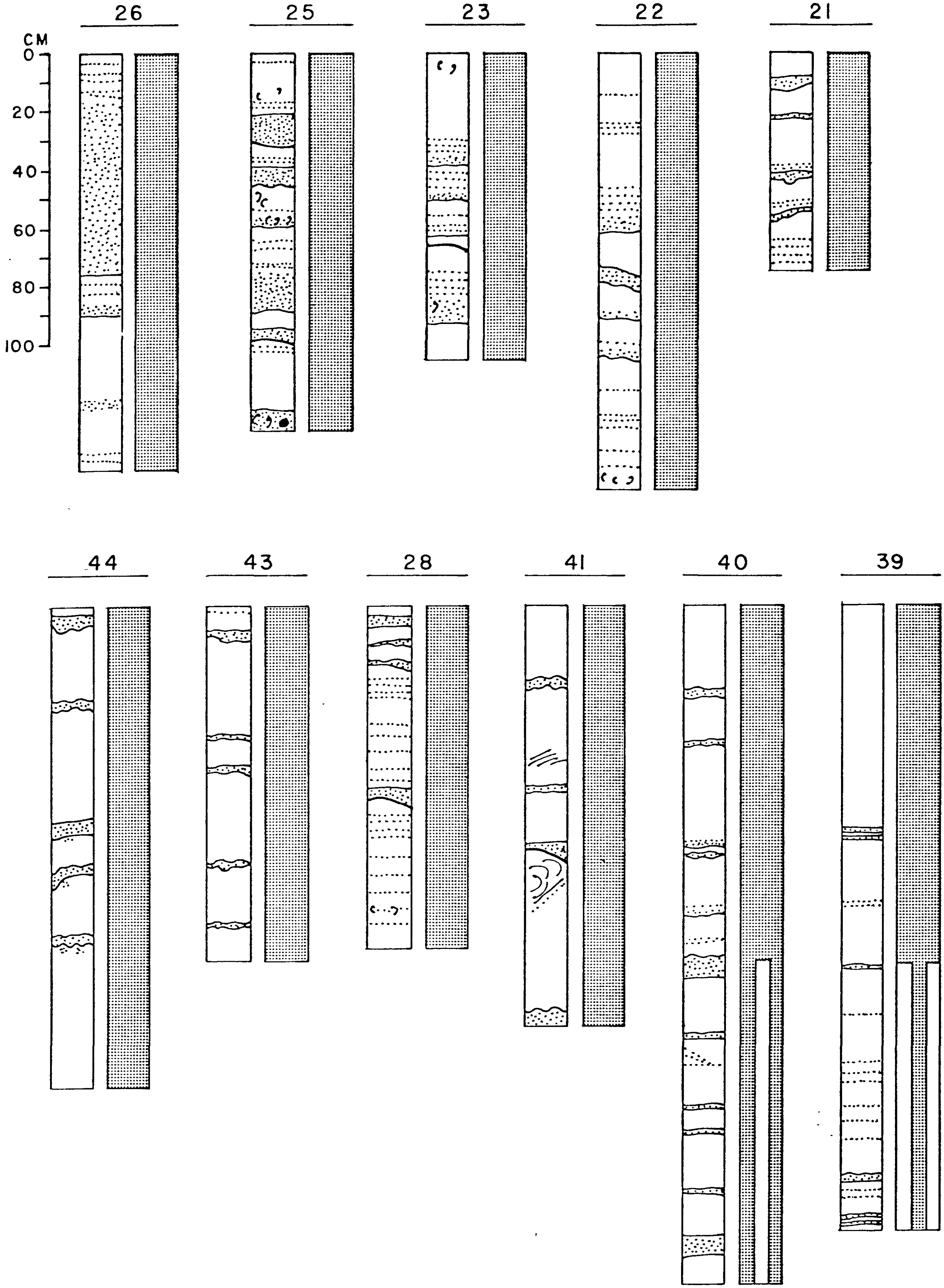


Figure 27. Selected cores, northern part of shelf, showing vertical variations in grain size. Station numbers are at top. Locations are shown by figure 4. Stippling indicates sand; no pattern indicates mixed silt/clay. Comma-shaped marks represent shell remains. Column at right indicates degree of textural modification by bioturbation as determined by Hill, 1976, 1977: full pattern >60%; half pattern <60%.

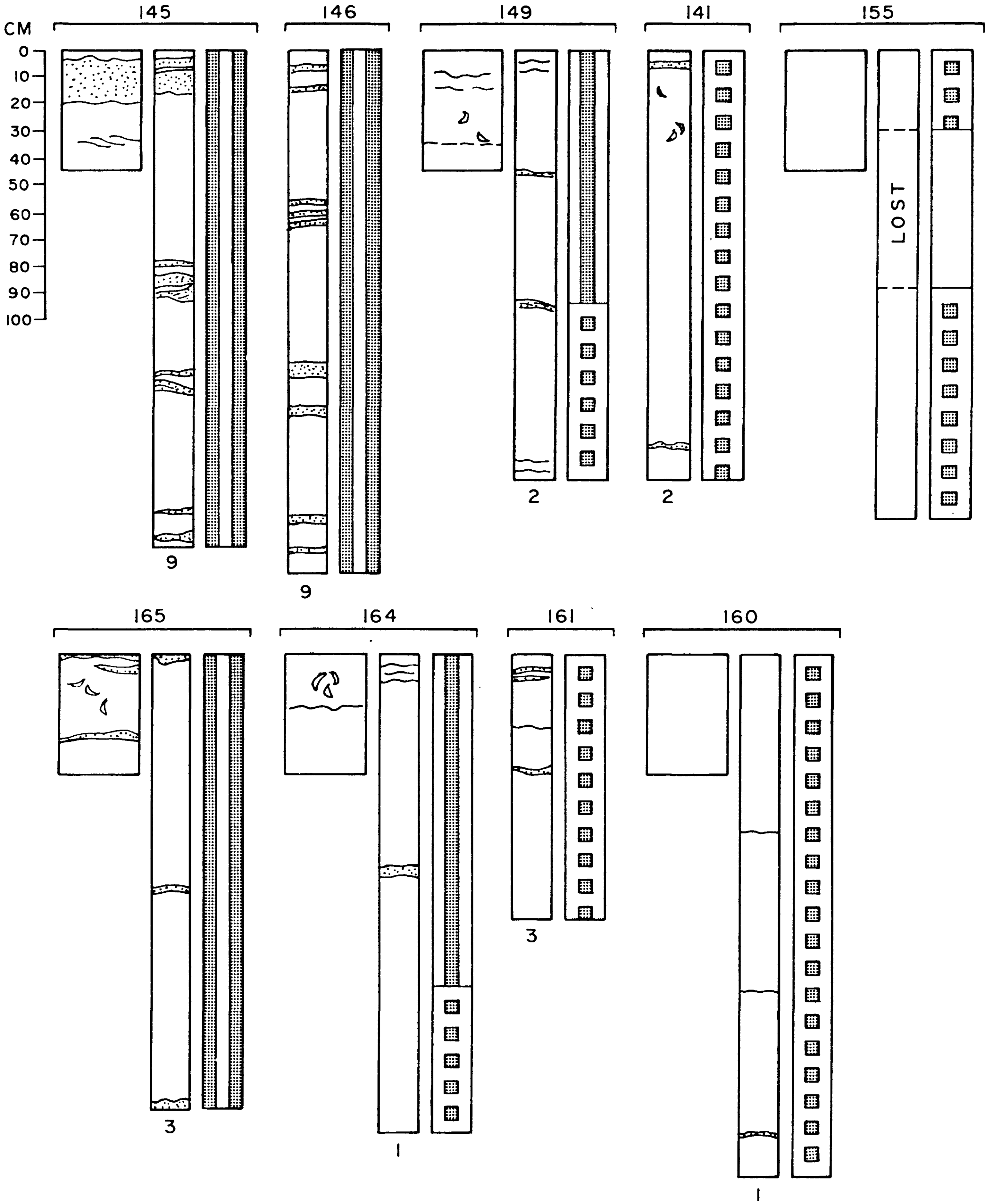


Figure 28. Selected cores, central sector of shelf, showing vertical variations in grain size. Station numbers are at top. Locations are shown by figure 4. Box and piston cores from same station shown. Sand indicated by stippling; lines indicate coarse silt; no pattern indicates mixed silt/clay. Crescents represent shells. Column at right indicates degree of textural modification by bioturbation as determined by Hill, 1976, 1977: half pattern <60%; square <30%.

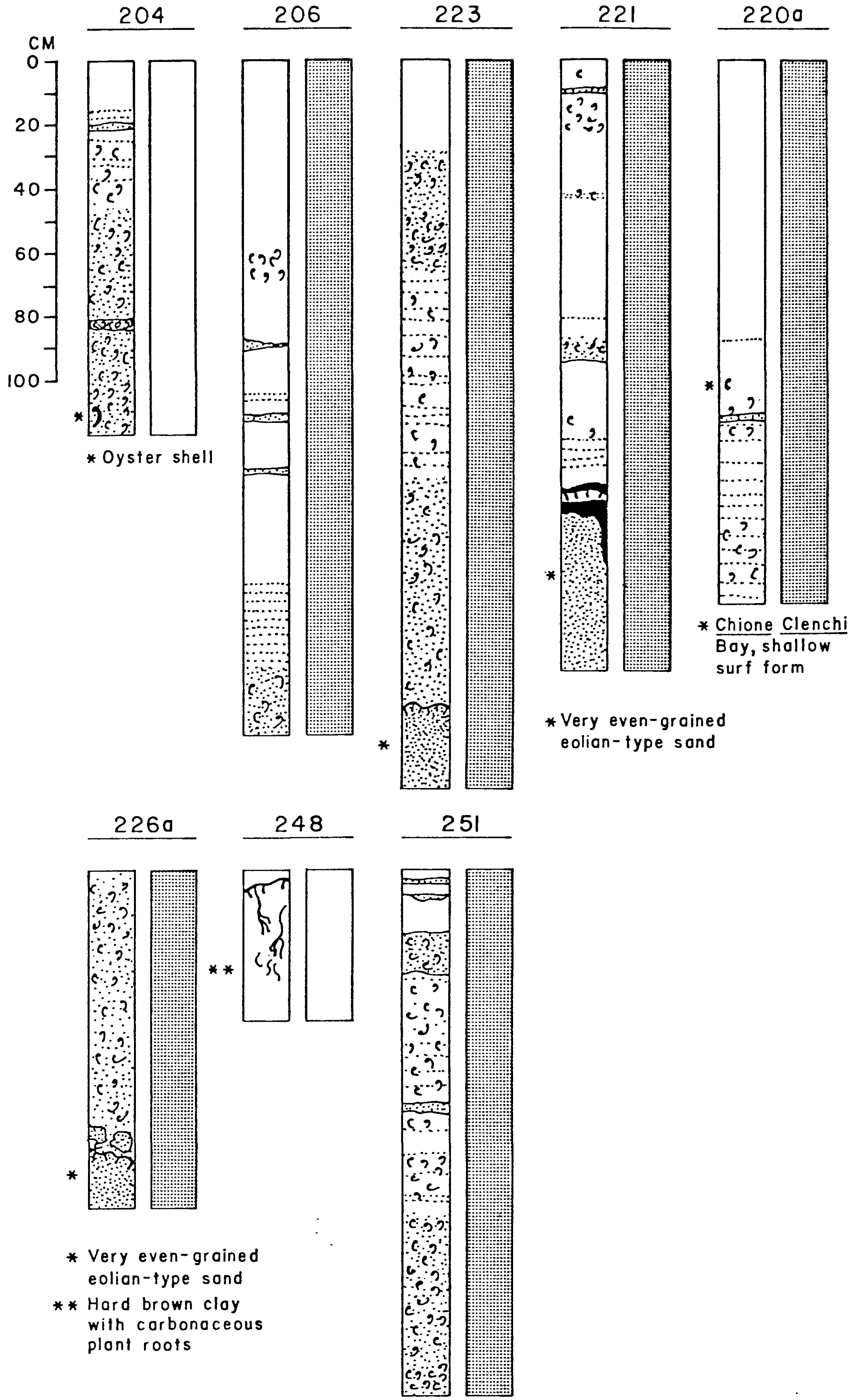


Figure 29. Selected cores from the ancestral Rio Grande delta, southern part of shelf, showing vertical variations in grain size. Station numbers are at top. Locations are shown by figure 4. Stippling indicates sand; no pattern indicates silt/clay. Comma-shaped symbols represent shells; black represents large amount of carbonaceous mud. Column at right indicates amount of textural modification caused by bioturbation, as determined by Hill, 1976, 1977; full stipple >60%.

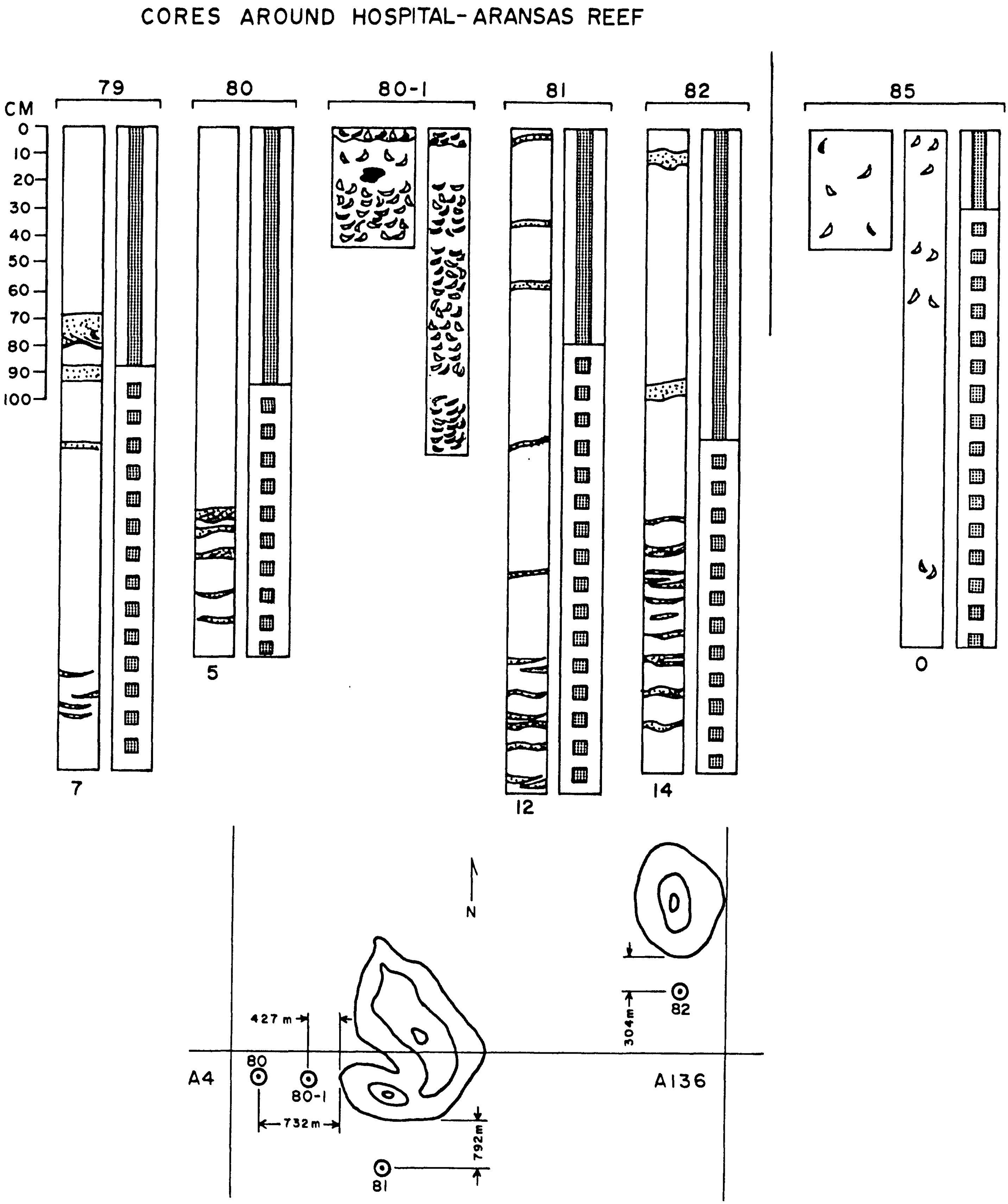


Figure 30. Selected cores from around an exposed Pleistocene reef showing vertical variations in grain size. Stippling indicates sand; no pattern indicates mixed silt/clay. Crescents represent shells. Column at right indicates degree of textural modification by bioturbation, as determined by Hill, 1976, 1977: half pattern <60%; squares <30%.

of the discrete sands suggest periodic relatively rapid water movement or high energy conditions over large parts of the shelf. Hurricane passage may be the principal mechanism by which the sand is distributed beyond the surf and shoreface zone. The area of the shelf in which discrete sands occur is shown by figure 31.

5. Distribution of surficial sediments by grain size indicates that silt is the predominant textural component (Shideler, 1976; 1977). Relict deltaic and ancient shoreline deposits of sand are on the southern and northeastern parts; otherwise the variations in grain size regionally are what might be expected on empirical grounds: increase in the sand-sized fraction shoreward and increase in the clay-sized fraction seaward. The distribution of the surficial sediments by grain size and by sand content are shown by figures 32 and 33; the distribution of the shallow subsurface sediments by grain size is similar to the surficial sediments. The shelf as a whole is a region of typically fine-grained sediments.

6. Dating of the rates of sedimentation during the past few hundred years using ^{210}Pb as the dating agent, indicates that the highest rates of sedimentation have been at midshelf in the northern part of the South Texas OCS (see figure 34,

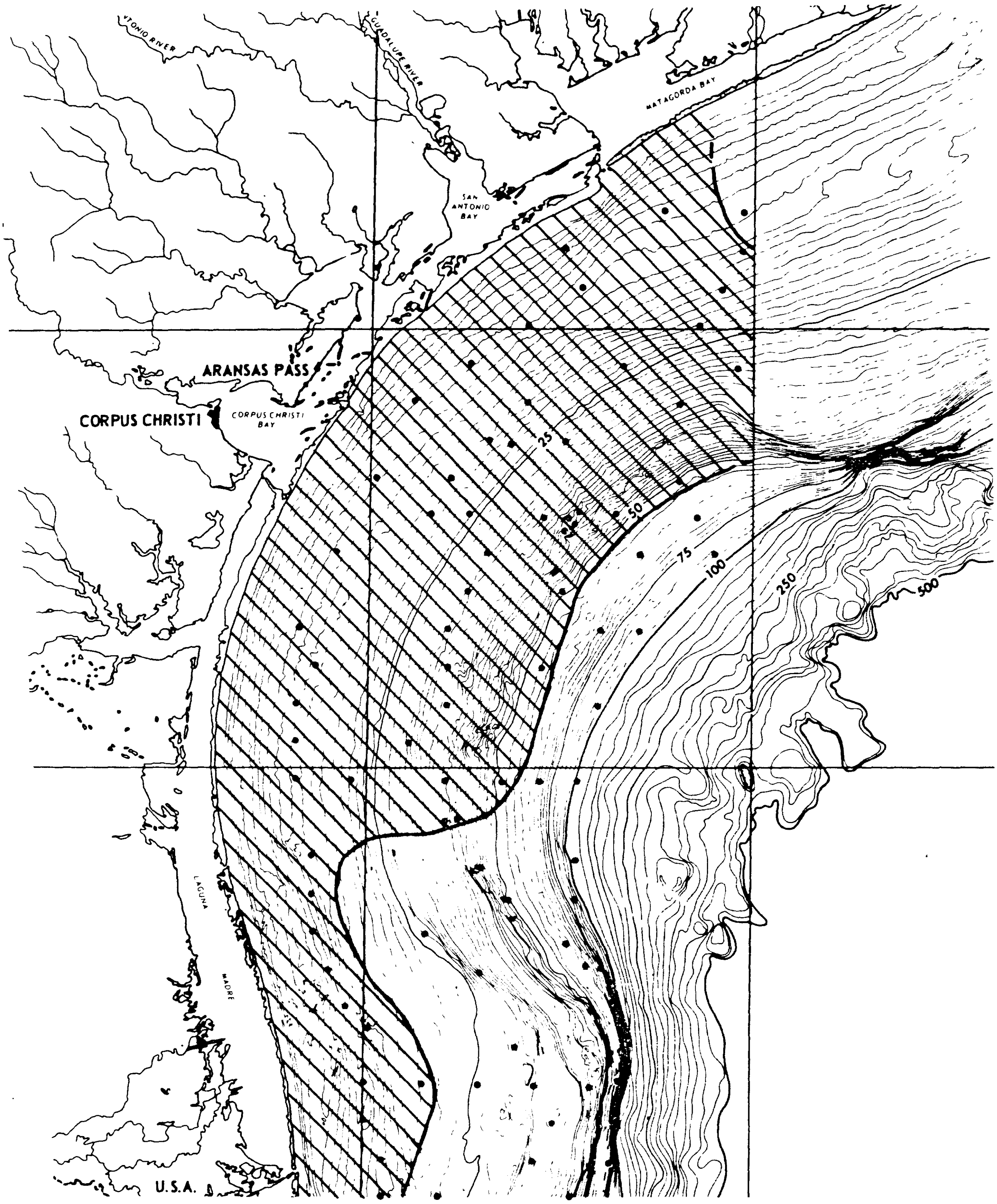


Figure 31. Area of the shelf in which cores indicate discrete sands; possibly spread in the aftermath of hurricane passage.

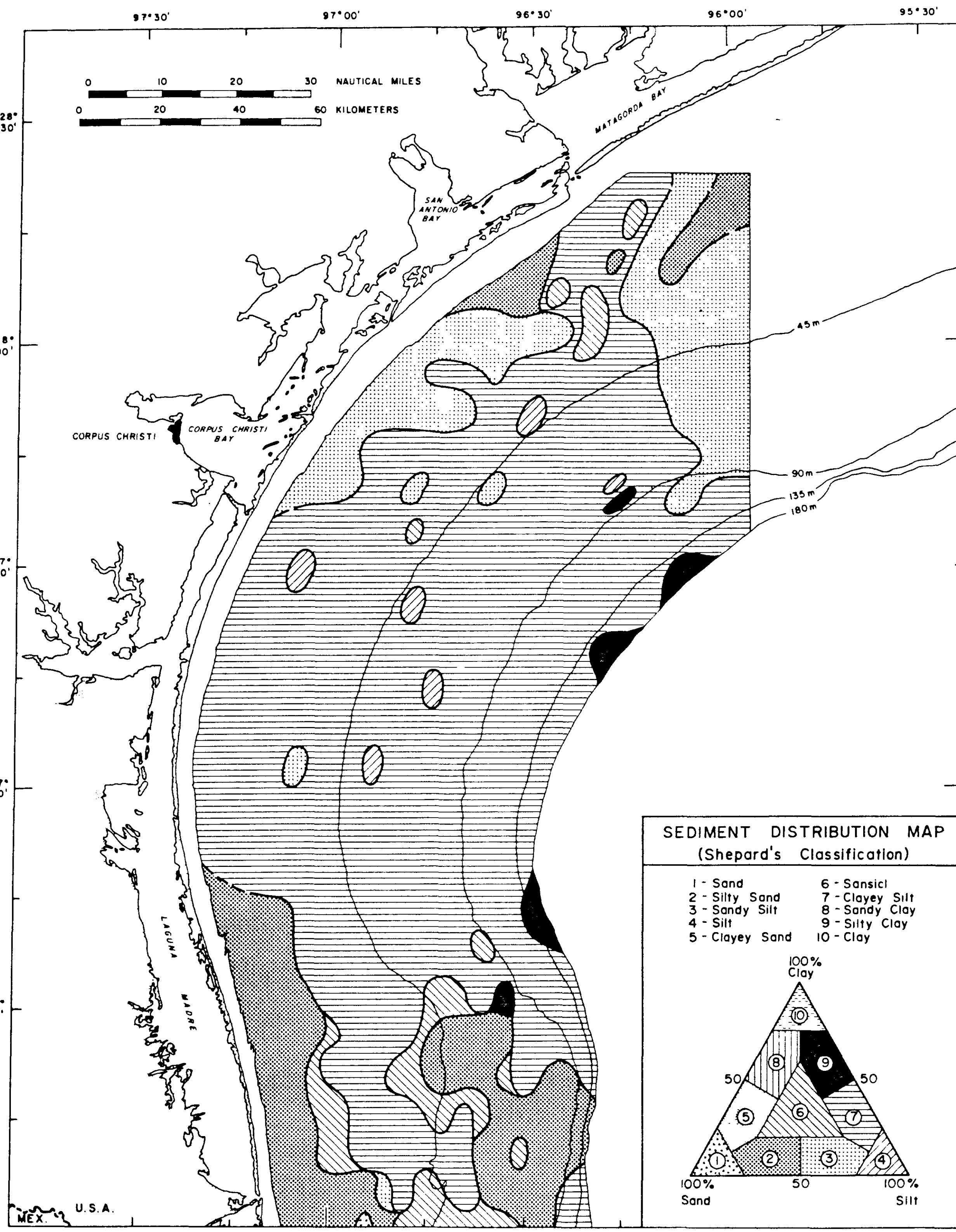


Figure 32. Classification and distribution of surficial sediments by grain size. From Shideler, 1976.

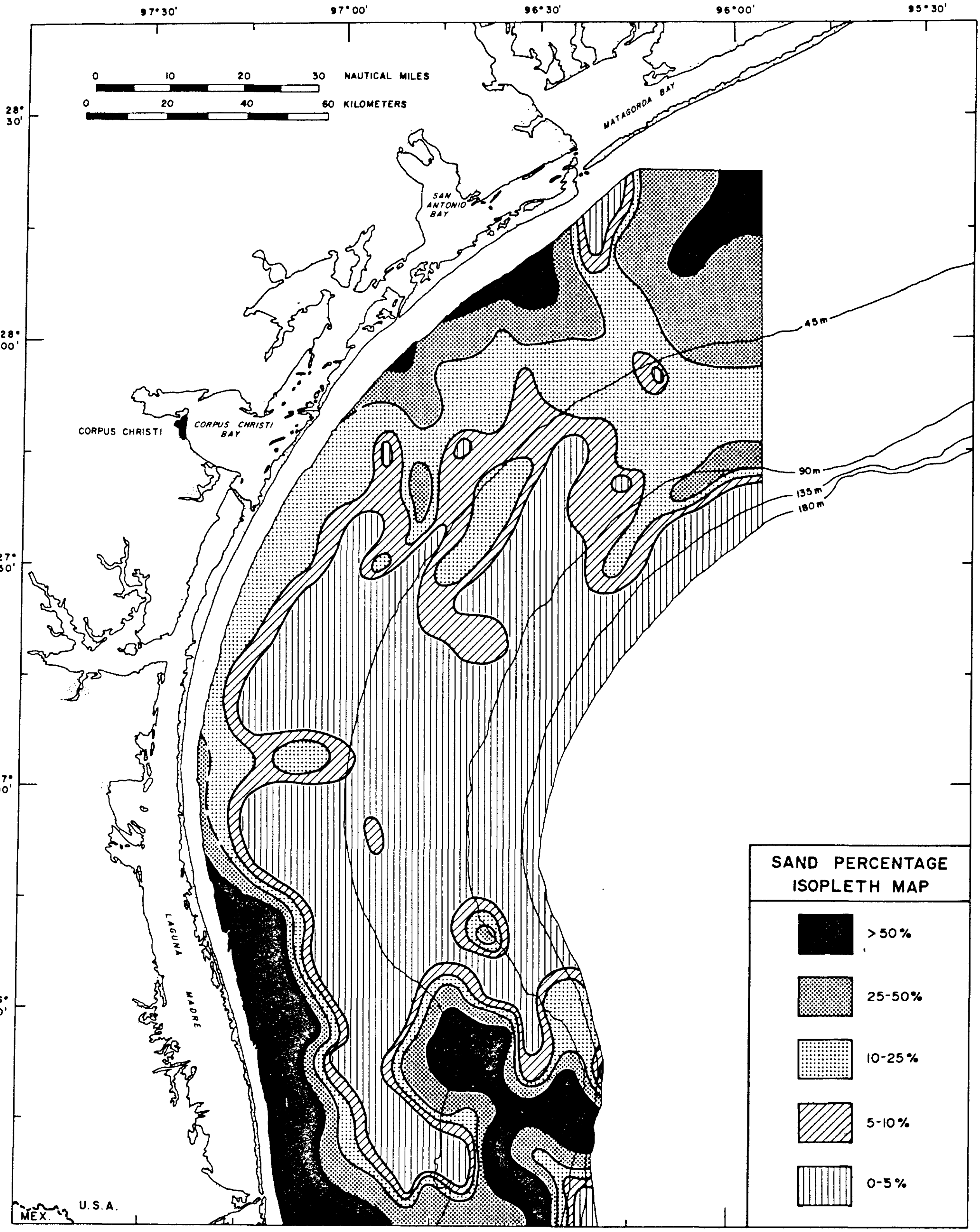


Figure 33. Percent sand in surficial bottom sediments. From Shideler, 1976.

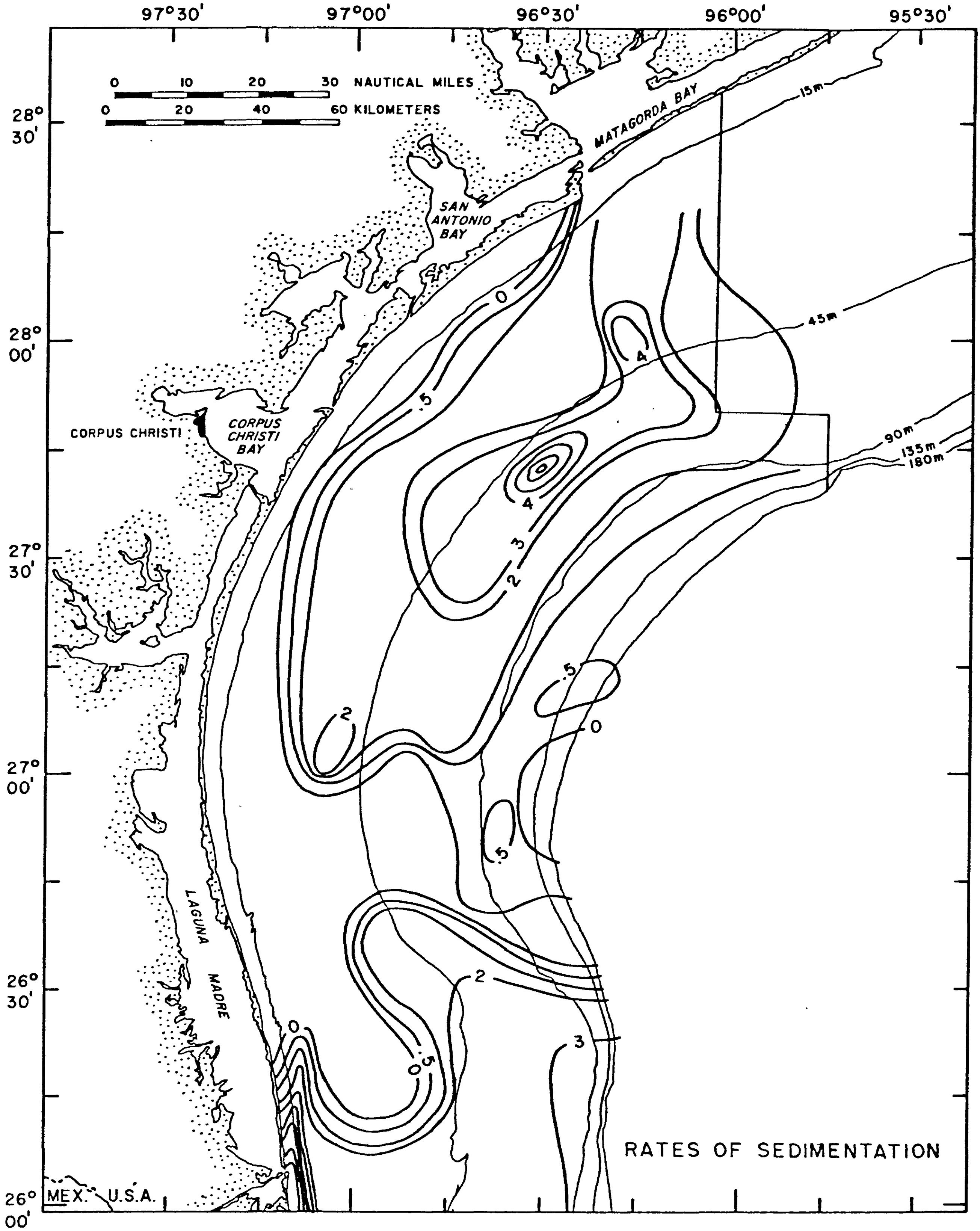


Figure 34. Interpretative contours showing rates of sedimentation in mm per year as determined by ^{210}Pb activity in the sediments. From Holmes and Martin, 1977.

from Holmes and Martin, 1977). Comparison of figures 34 and 25 demonstrates the northward shift of the Holocene depocenter in latest Holocene time.

7. Distribution of trace metals in the surficial bottom sediments indicates two relationships relative to sediment grain size: increased abundance in the finer grained sediments; and increased abundance around certain estuaries where anthropogenic induction is suspected. The use of barium content of the sediments in conjunction with ^{210}Pb dating indicates that sediments are being carried primarily from north to south and obliquely across the South Texas OCS. The barium content of the sediments began to increase in the 1920's as oil well drilling increased. Thus, it is an ideal tracer element for measuring rates and patterns of sediment movement.

Tectonism:

1. Most faults are of the growth type; relative offset along the faults increases downward with increasing subsurface depth, indicating continued movement through time. Growth-type faulting is well illustrated by figure 8. Note the increased offset with depth along individual faults.

2. Faulting, though relatively continuous over the broader span of time from the middle Pleistocene to the present, appears to have been episodic when viewed in shorter increments of time, possibly as a result of the cyclicity of the alternating periods of glacial sea level withdrawal and interglacial deposition. The faults have been plotted relative to two of the subsurface reflectors already discussed to determine both the geographic patterns of faulting and the variations in the intensity of faulting with time. The depths below the sea floor of the two subsurface reflectors (equivalent to reflectors B and D respectively, in figures 17-25) is shown by the section of an acoustical profile, figure 35. The geographic locations of faults that cut reflector B but not A are shown by figure 36 and those that cut both A and B, by figure 37.

3. Comparison of the two maps shows that the faulting has migrated seaward across the shelf during late Pleistocene/Holocene time.

4. Faulting during the Holocene has been concentrated along the outer edge of the continental shelf.

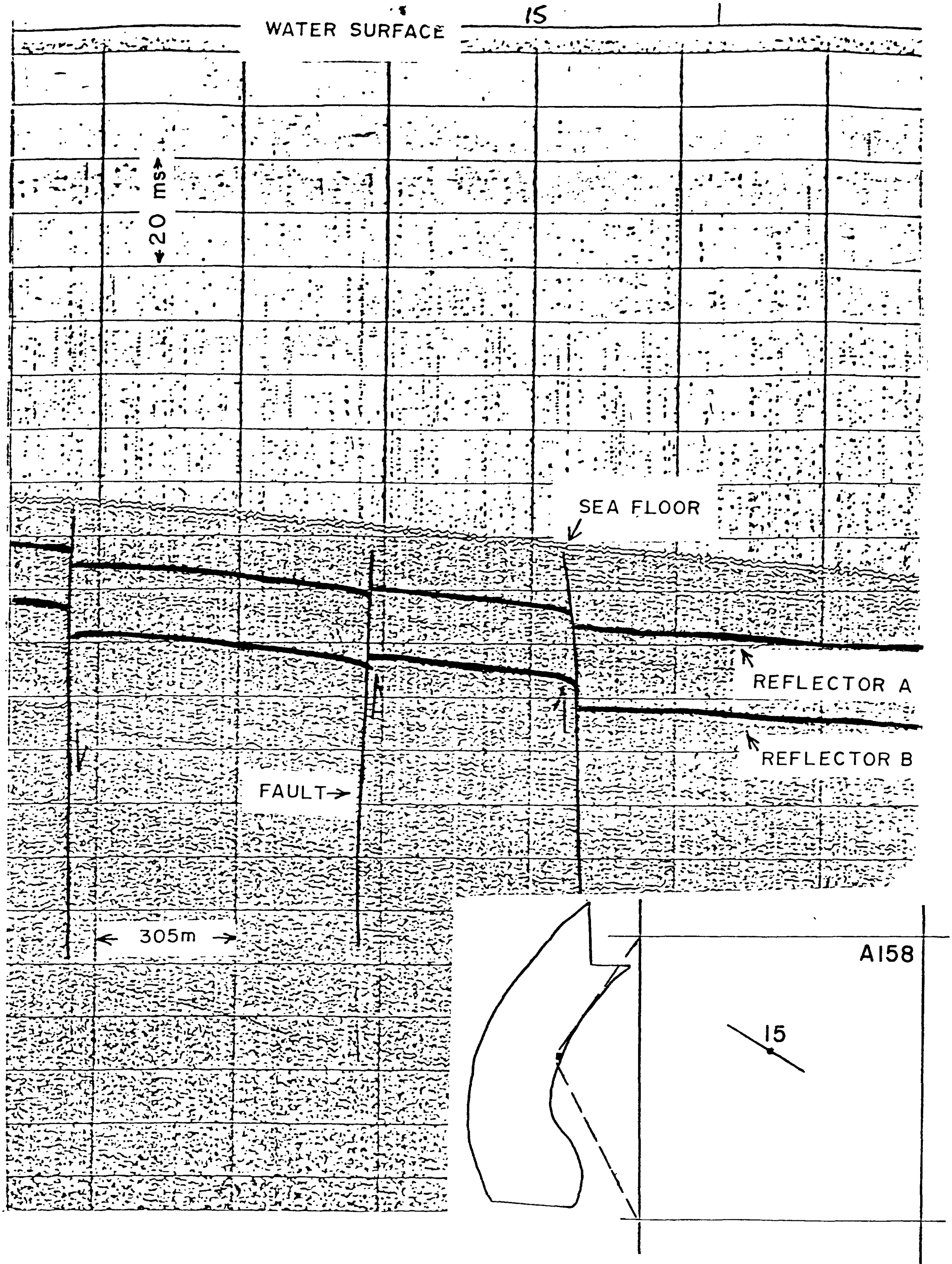


Figure 35. Section of an acoustical profile showing the subsurface position of reflectors A and B, stratigraphic reference horizons used to determine geographically the extent and intensity of faulting through time.

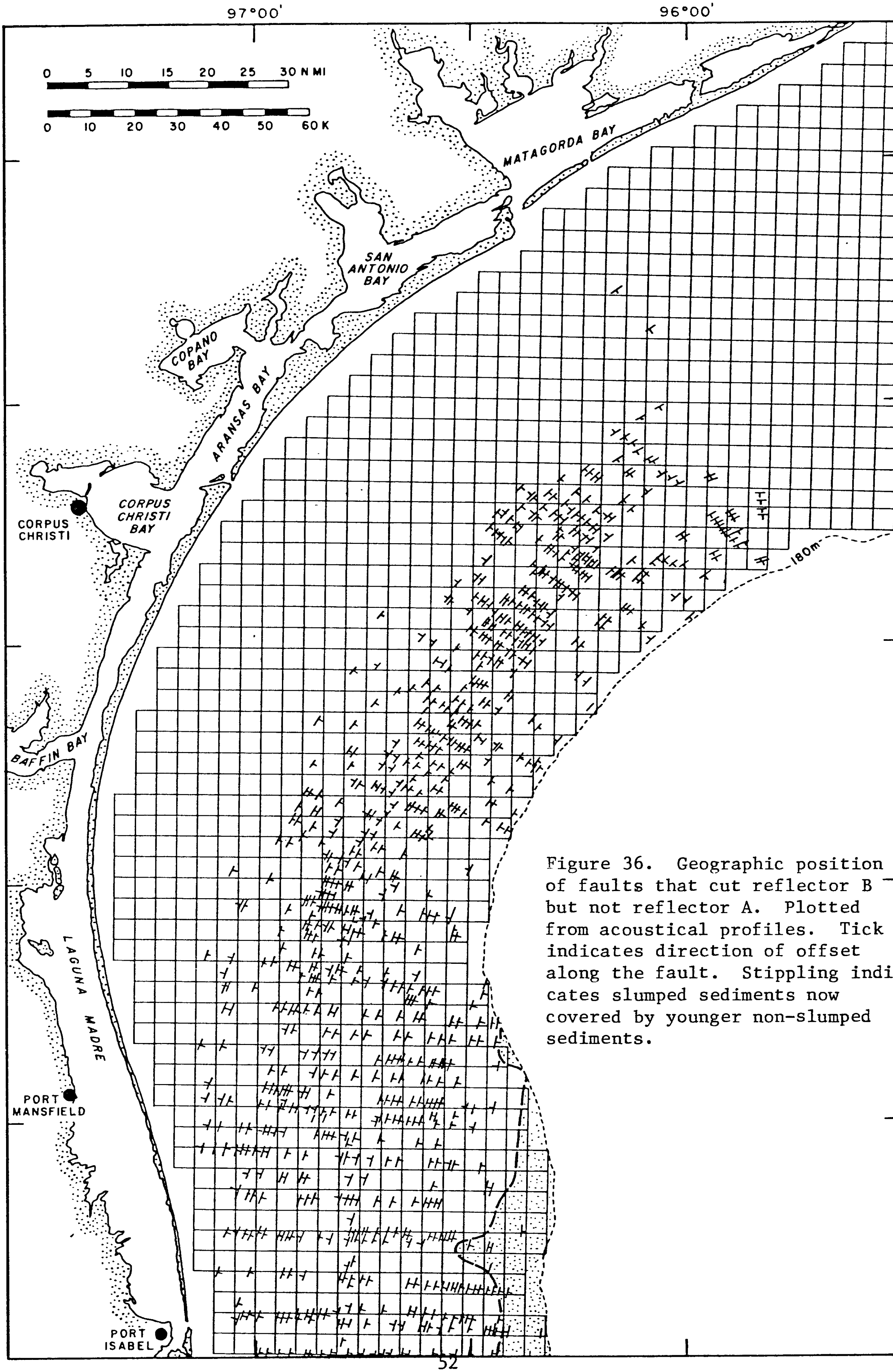


Figure 36. Geographic position of faults that cut reflector B but not reflector A. Plotted from acoustical profiles. Tick indicates direction of offset along the fault. Stippling indicates slumped sediments now covered by younger non-slumped sediments.

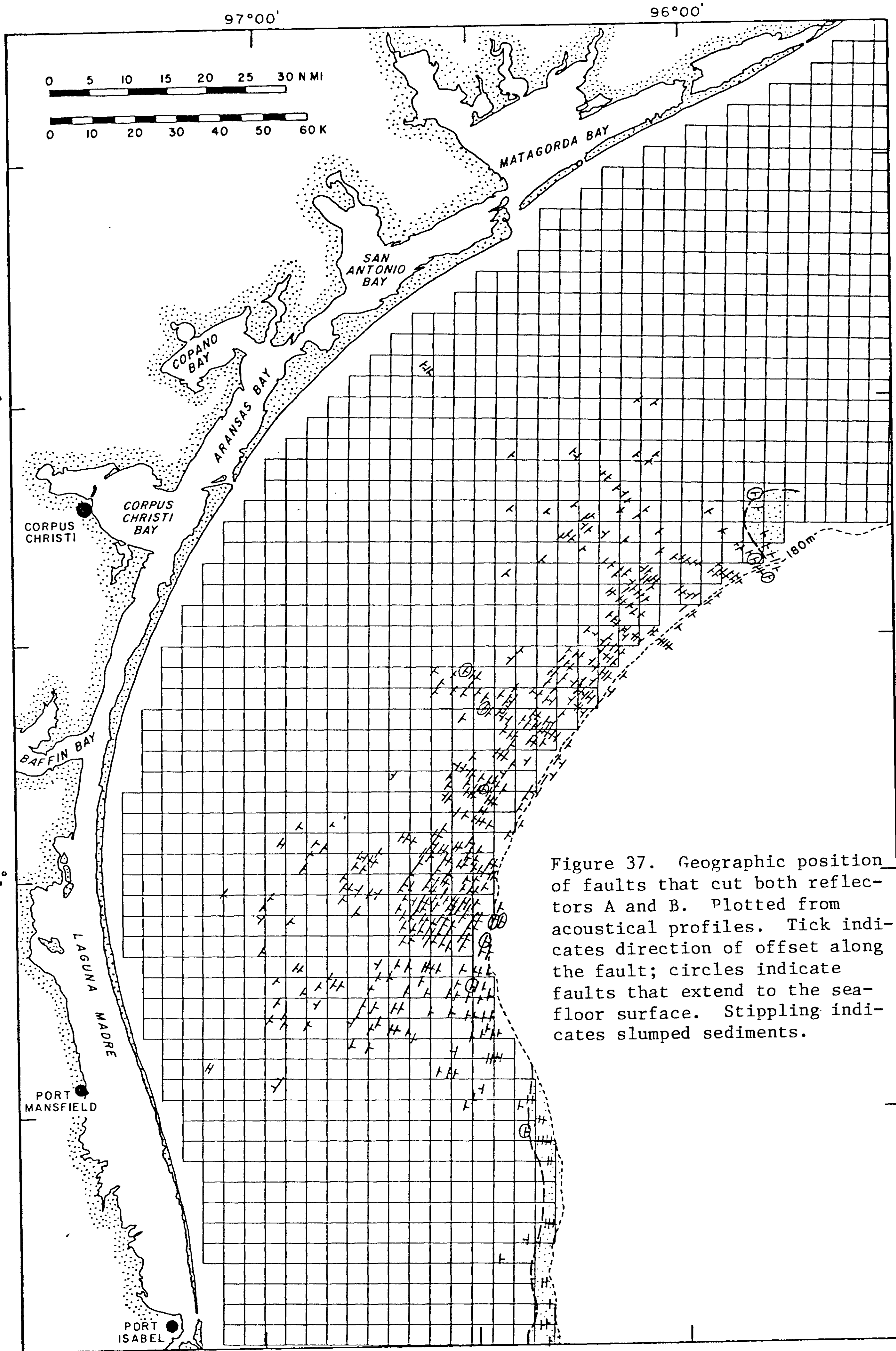


Figure 37. Geographic position of faults that cut both reflectors A and B. Plotted from acoustical profiles. Tick indicates direction of offset along the fault; circles indicate faults that extend to the seafloor surface. Stippling indicates slumped sediments.

IV. Relative stability of the sea floor

A. General classification of the shelf and slope (figure 38)

Subarea 1

1. Generally stable. No movement apparent over most of the inner half of shelf in post middle Pleistocene time, but in the southern part of the OCS recent faults cross the shoreline from shelf to coastal plain; the faults are expressed at the sea floor as topographic ridges (see fig. 39).
2. Movements at mid shelf have decreased during the late Pleistocene, but localized fault movement along the crests of folds is indicated. At isolated sites, faults reach the sea floor (see fig. 38).

Subarea 2

1. Generally stable but faulting has been both extensive and intensive over the outer third of the shelf in the central sector of the OCS during the Holocene.
2. The faulting along the outer shelf has been caused by the combination of sediment loading and isostatic adjustment; subsidence has been countered to a degree by the buttressing effect of a rising anticline whose crest lies just beyond the shelf edge beneath the uppermost part of the continental slope. Figure 8 is a section across the outer shelf and upper slope showing the structural relationships.

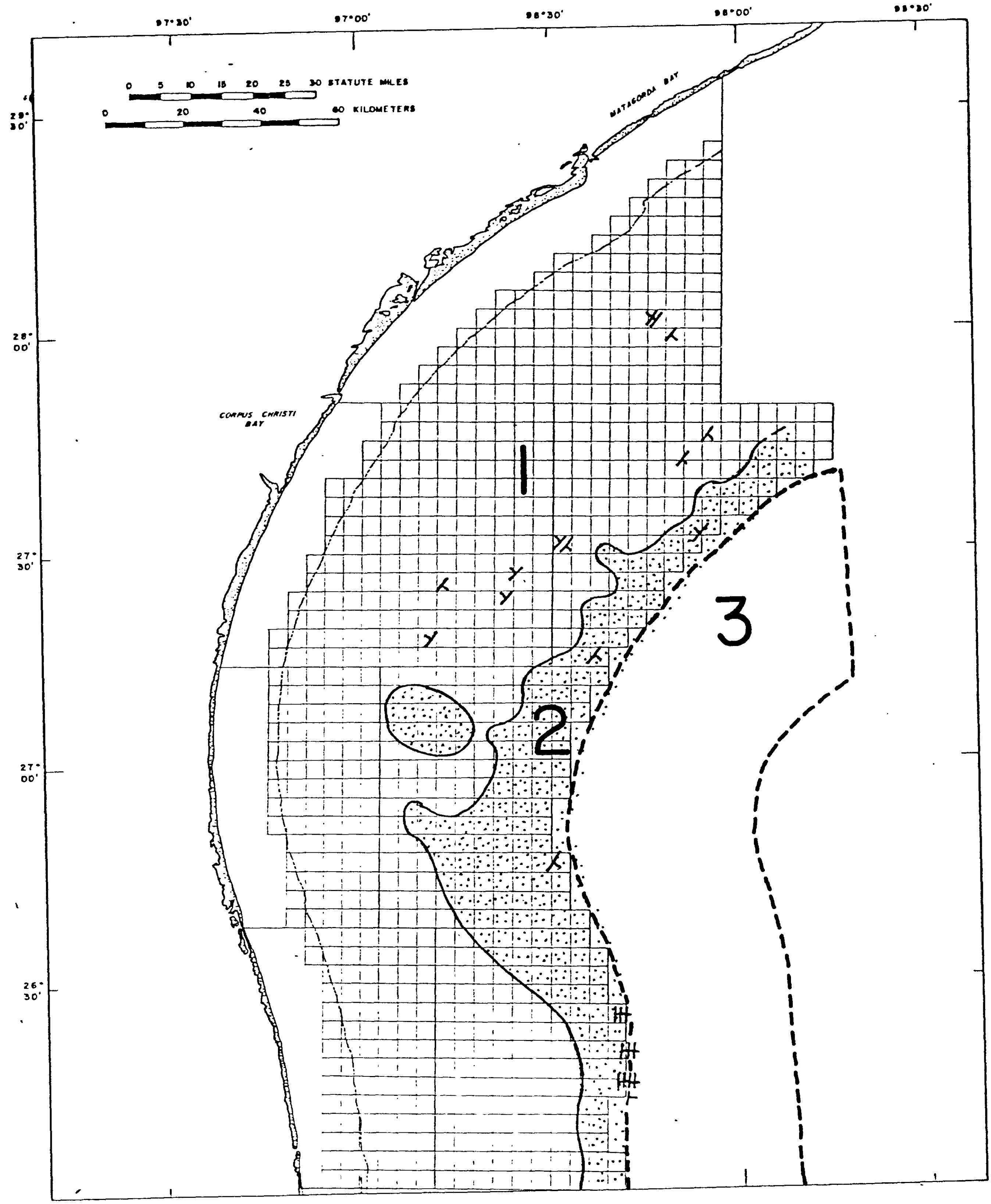


Figure 38. Interpretative classification of stability, continental terrace: subarea 1, generally stable except for isolated sites indicated by symbols where faults reach the sea floor; subarea 2, outer shelf where faulting has been extensive during the Holocene; and subarea 3, the continental slope where slumping and diapiric movements have been extensive.

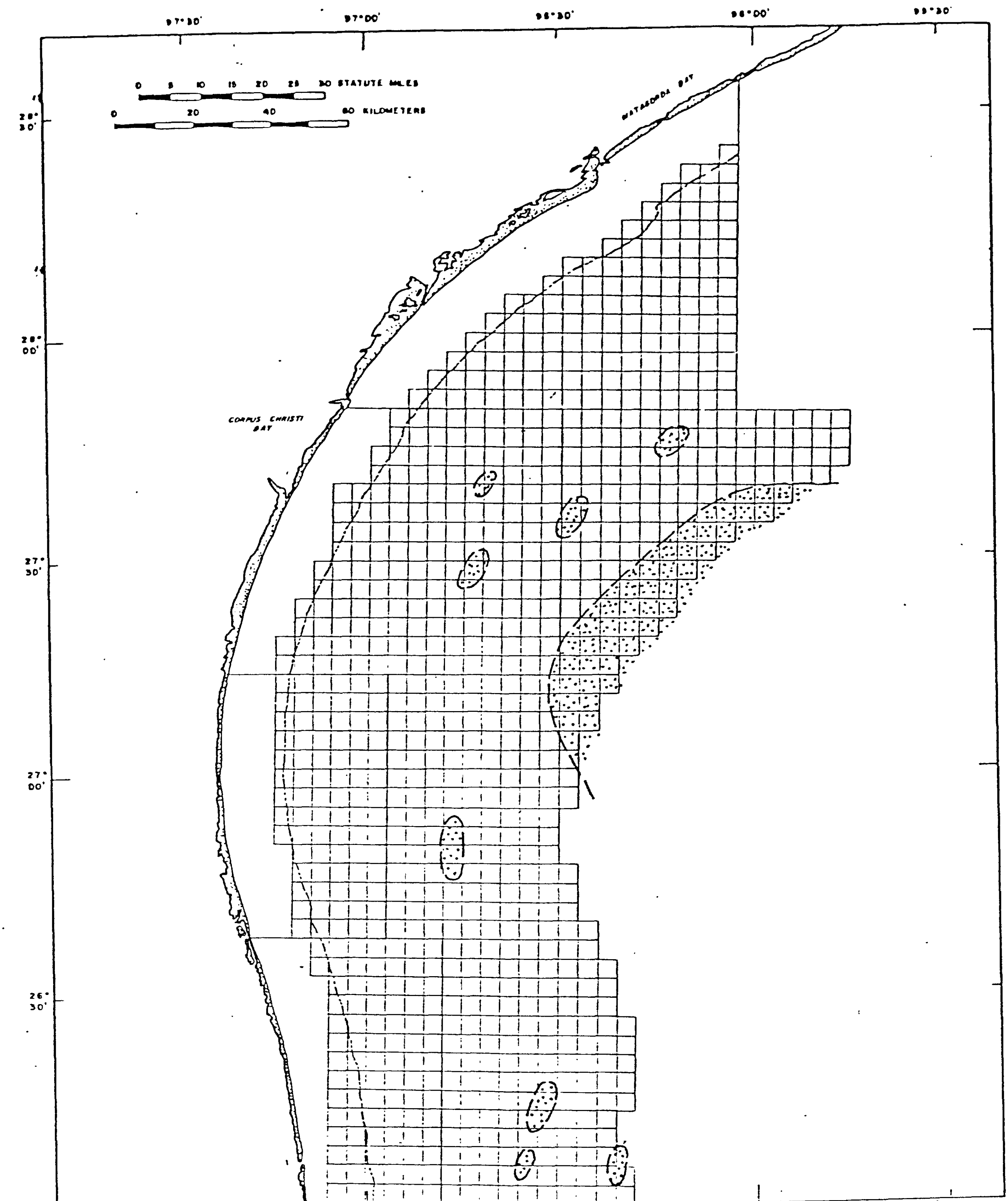


Figure 38A. General outline of areas where "plumes" suggesting natural gas seepage were recorded on acoustical profiles.

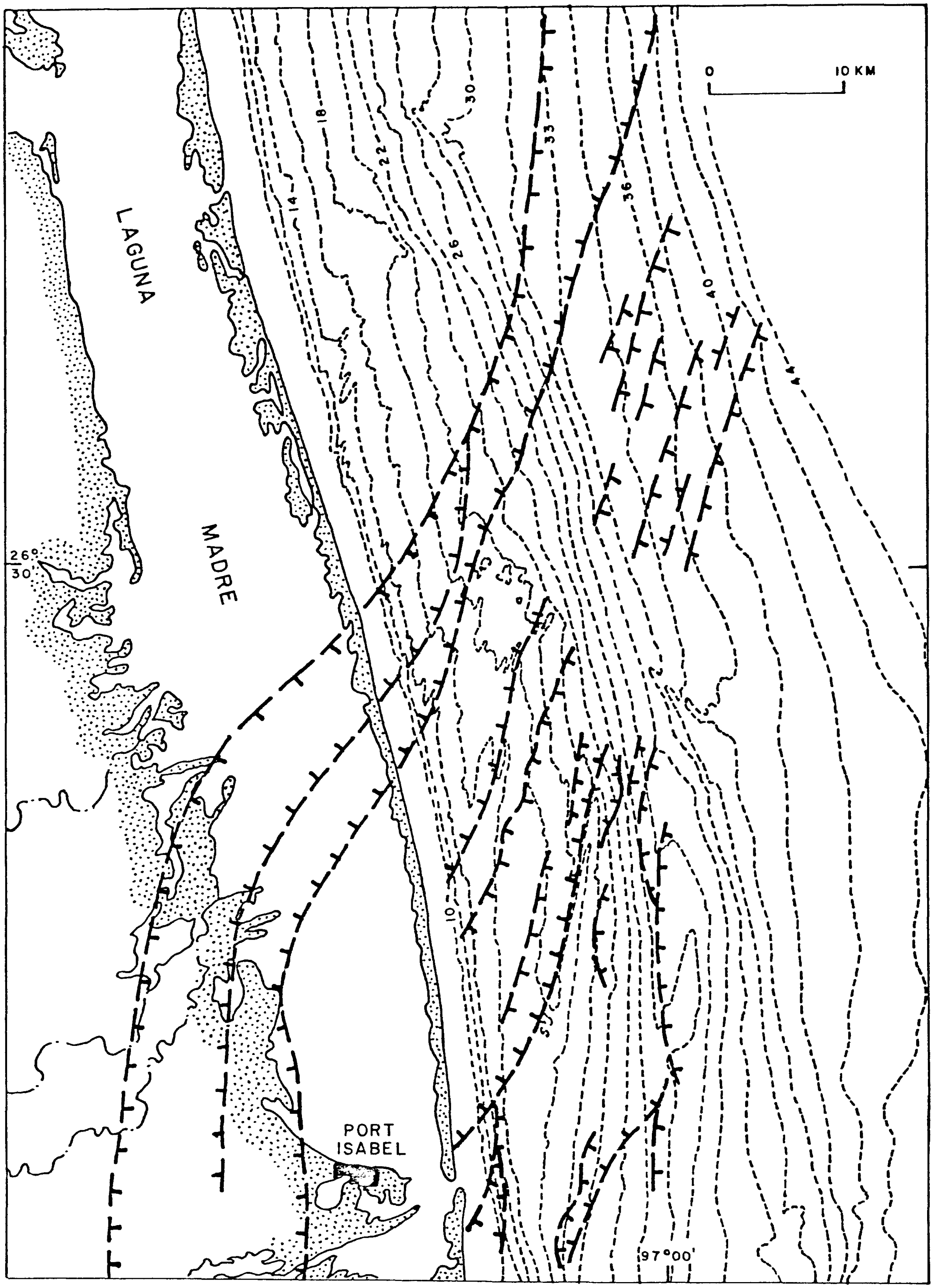


Figure 39. Fault pattern, inner shelf in southern part of the South Texas OCS. Note the association of some of the faults with the elongate topographic features, indicating the relatively recent age of the faulting.

3. Gravity slumping of sediments and associated shallow faulting is evident in the southern and northeastern parts of the OCS near the shelf edge and on the adjacent uppermost slope.

Subarea 3

1. The continental slope has been a mobile area and relative instability is indicated. Mobility has been primarily of two types: massive, large scale gravity slumping of relatively soft sediments down the increased topographic gradient of the continental slope; and diapiric movement of salt. The characteristic hummocky topography of the slope surface is expressed by the bathymetry map, figure 1.
2. Some of the rotational, gravity faulting on the slope does extend to considerable depth in the subsurface, indicating the tendency for the entire outer part of the continental terrace to slide toward the deeper central part of the Gulf of Mexico because of sediment outbuilding and loading.
3. The relative instability at the shelf edge and on the continental slope is primarily a function of the increased topographic gradient which in turn relates to the adjustments caused by sediment buildup and overloading.

B. Analysis of the unstable conditions in Subarea 3, shelf edge and adjacent continental slope, by geographic segments from south to north: southern, central, and northeastern

1. Southern

a. Geologic characteristics: edge of ancestral Rio Grande delta coincides with shelf edge; increase in sea-floor gradient; slumped and diapirically deformed sediments of a generally chaotic nature lie beneath younger prograded and undeformed sediments; shallow faults are associated with surficial slumping and sliding; deep-seated gravity faults are associated also with broader scale basinward slumping.

b. Types of instability and potential hazards: (Examples shown by 2 sets of figures that are adjoining sections of acoustical profiles: numbers 40A-40C; 40D-40H).

(1) Buried older slumped and chaotic sediments beneath prograded undisturbed sediments. Potential for overpressured zones and high gas content. Examples across strike or down the slope are shown by the two adjoining sections of an acoustical profile shown in figures 40A and 40B and also in the single section, figure 40D. Examples of the same type of features along strike or parallel to the edge of the shelf are shown by figures 41A, 41B, and 41C.

(2) Surficially slumped and faulted sediments along edge of shelf/uppermost slope (figs. 40A, 40C, and 40D).

(3) Primarily surficial, shallow seated sliding and some slumping on the upper to middle slope (adjoining

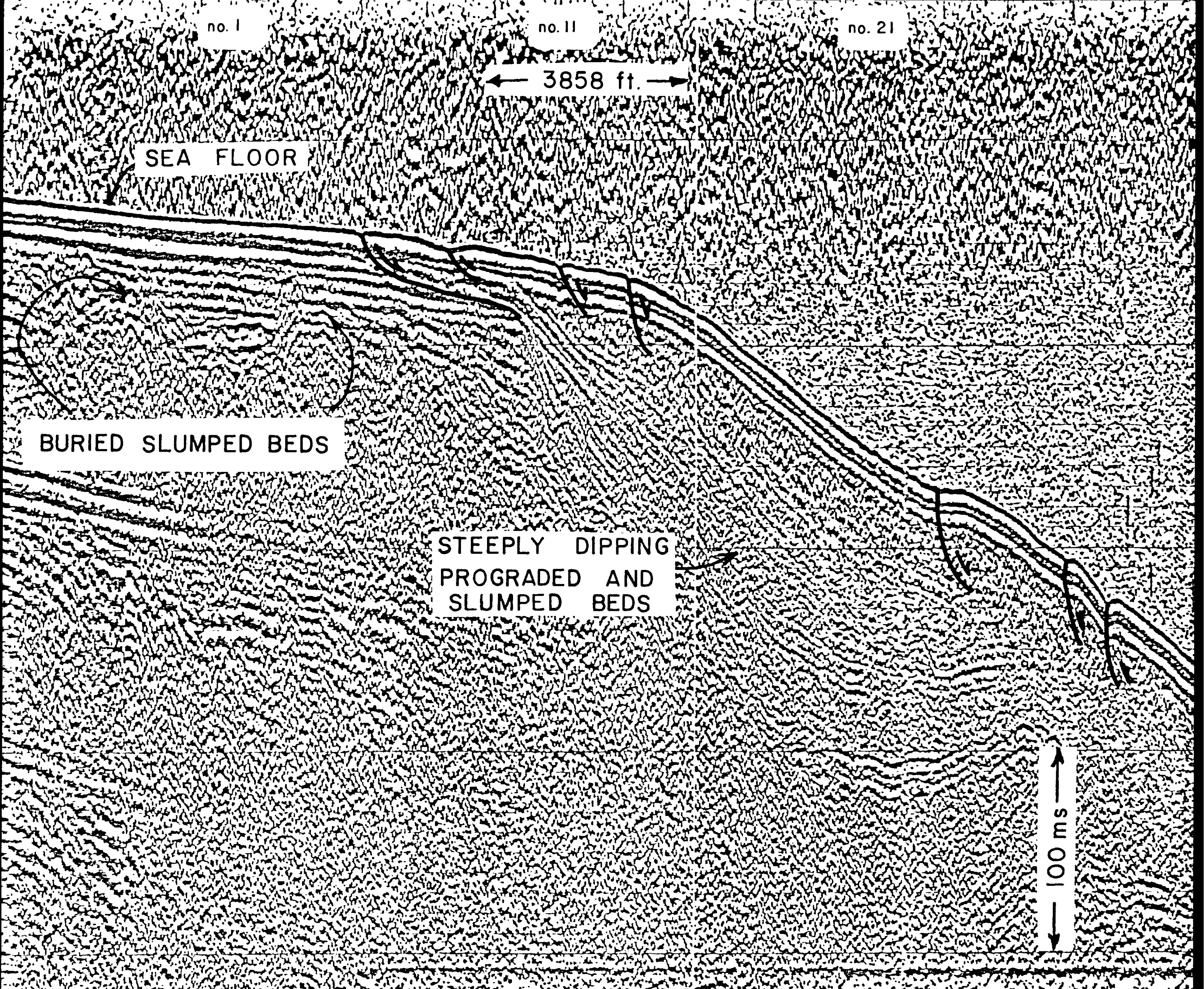
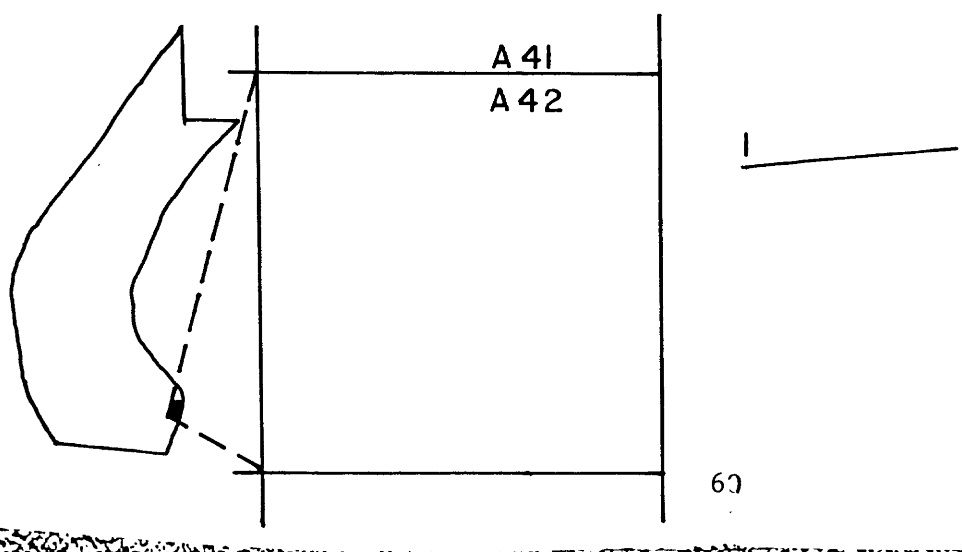


Figure 40A. Section of an acoustical profile along line 5, figure 2A, showing structural and sedimentological characteristics of the shelf edge and upper slope off the Rio Grande delta. Note slumped and diapiric beds beneath flat-lying prograded beds.



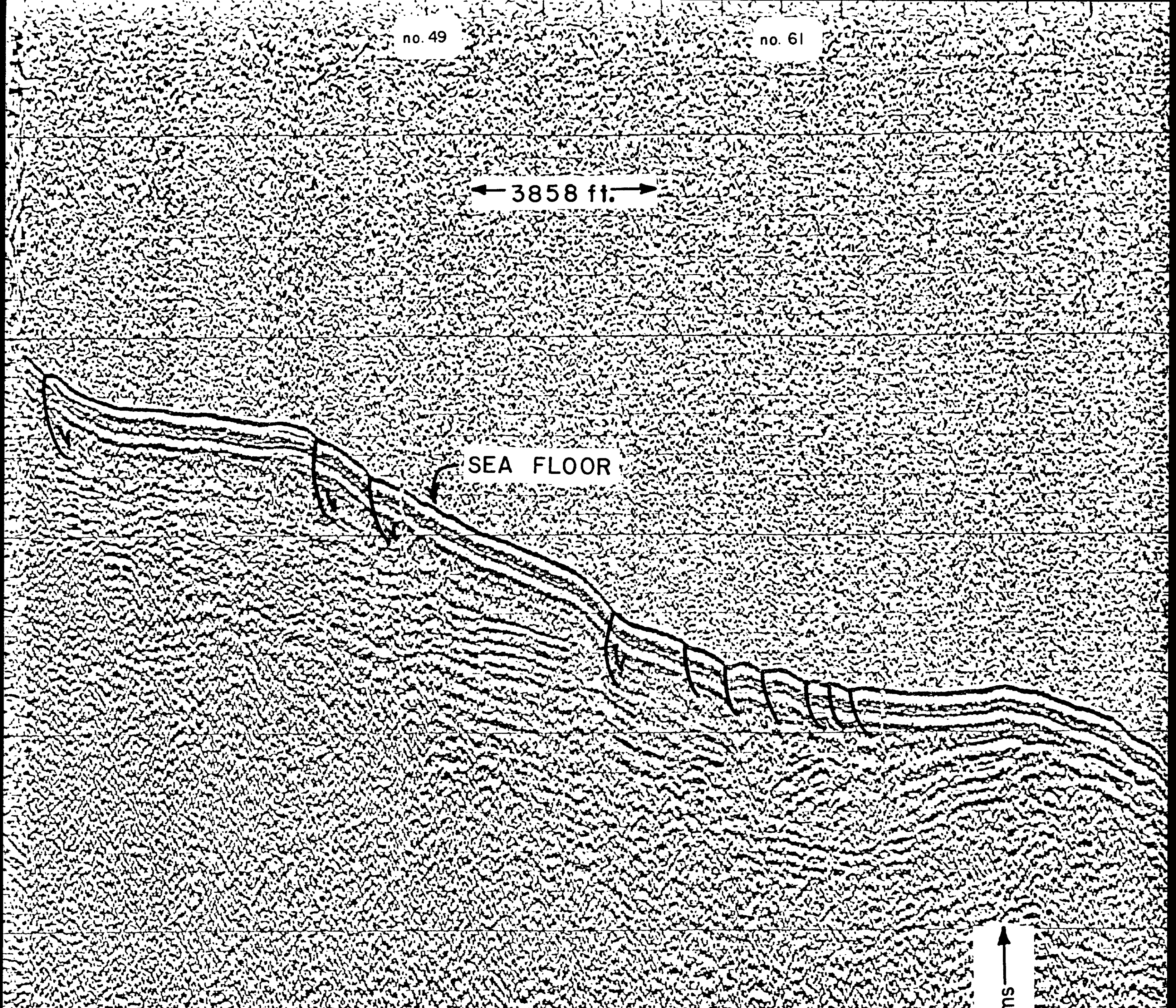
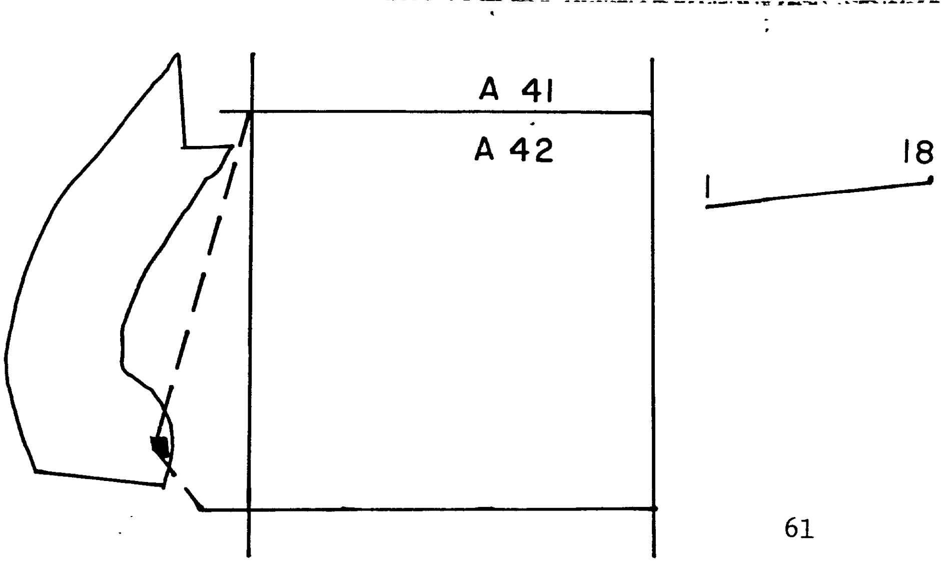


Figure 40B. Section of an acoustical profile adjoining on the east that in figure 40A showing the slumped and faulted sediments on the continental slope.



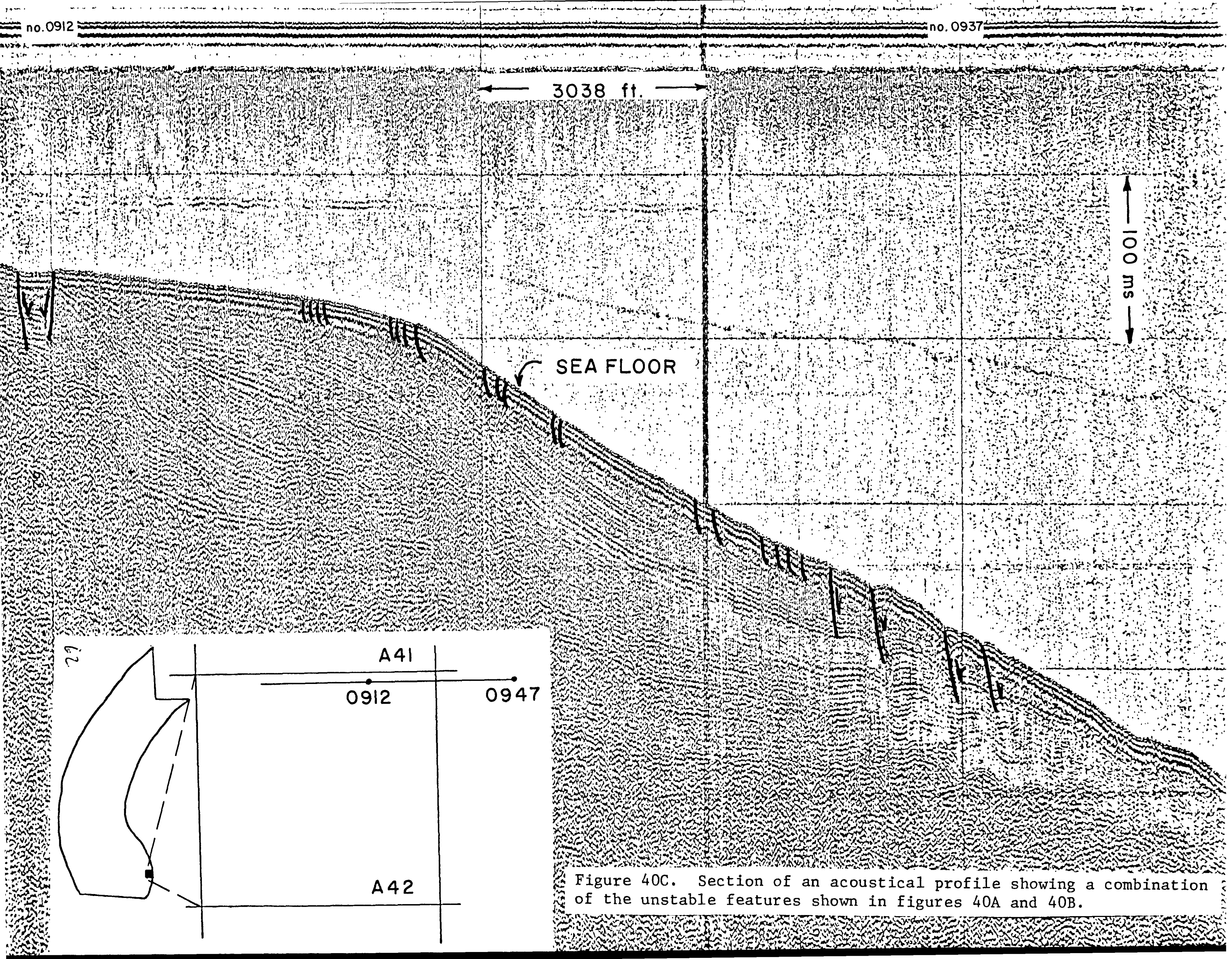


Figure 40C. Section of an acoustical profile showing a combination of the unstable features shown in figures 40A and 40B.

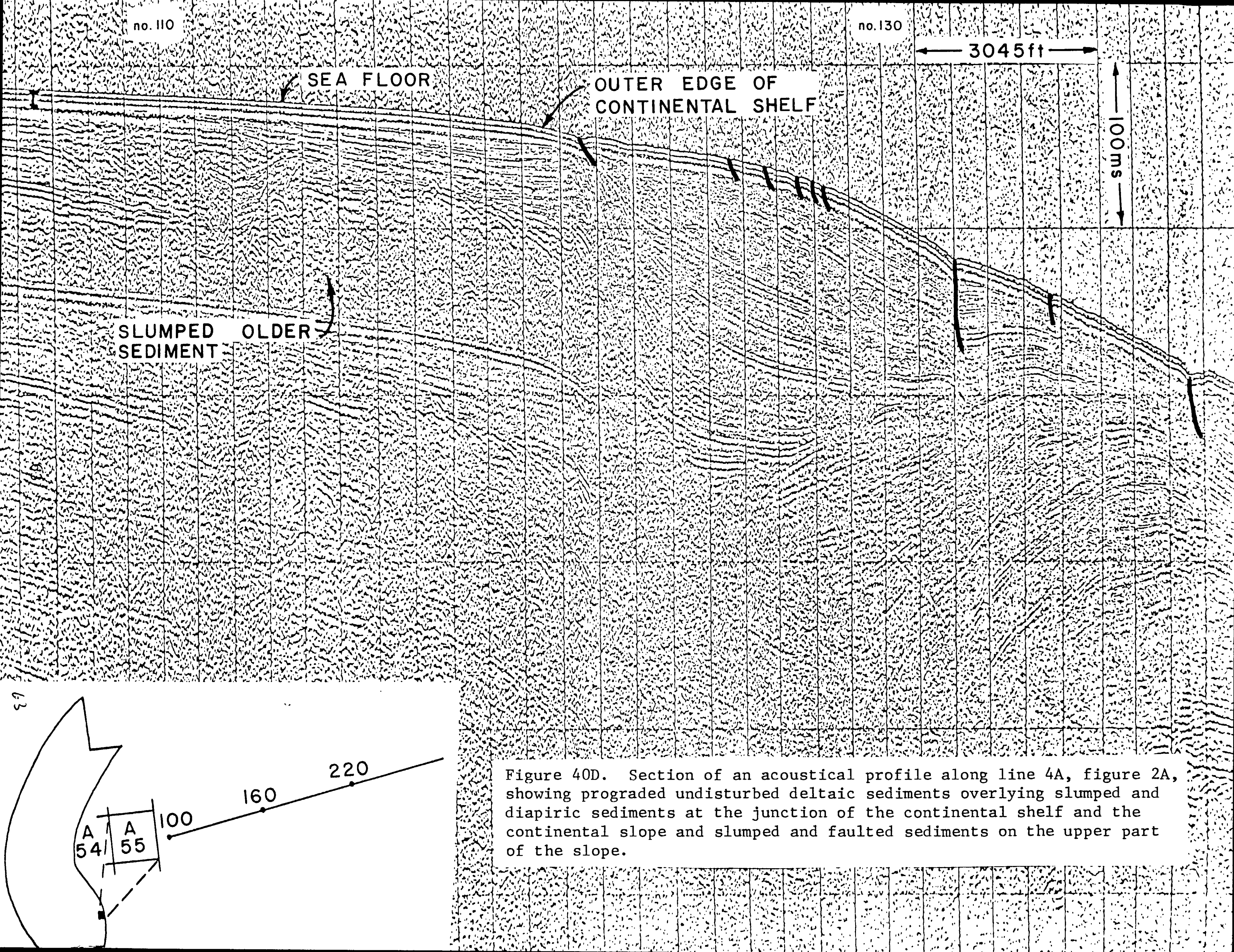


Figure 40D. Section of an acoustical profile along line 4A, figure 2A, showing prograded undisturbed deltaic sediments overlying slumped and diapiric sediments at the junction of the continental shelf and the continental slope and slumped and faulted sediments on the upper part of the slope.

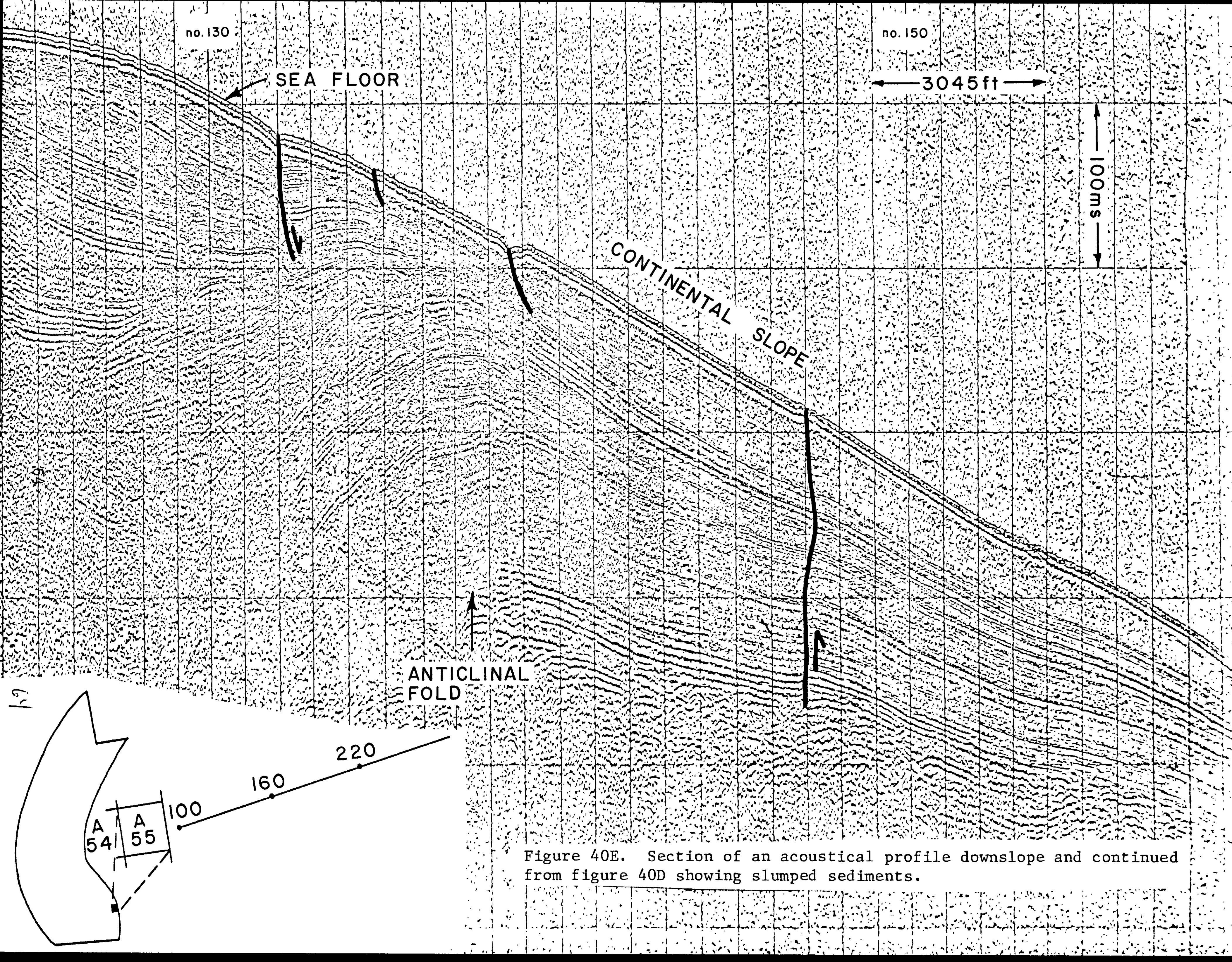


Figure 40E. Section of an acoustical profile downslope and continued from figure 40D showing slumped sediments.

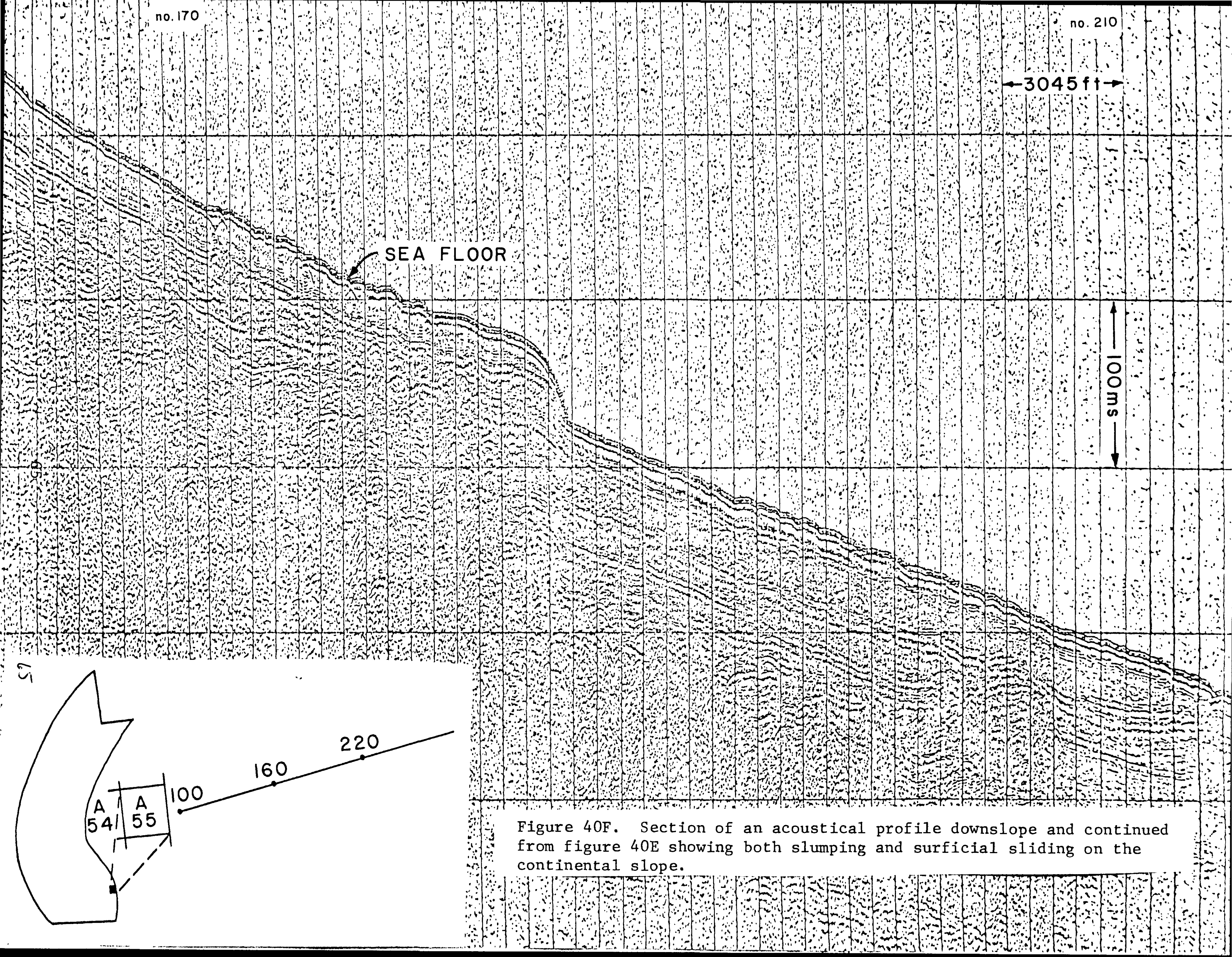


Figure 40F. Section of an acoustical profile downslope and continued from figure 40E showing both slumping and surficial sliding on the continental slope.

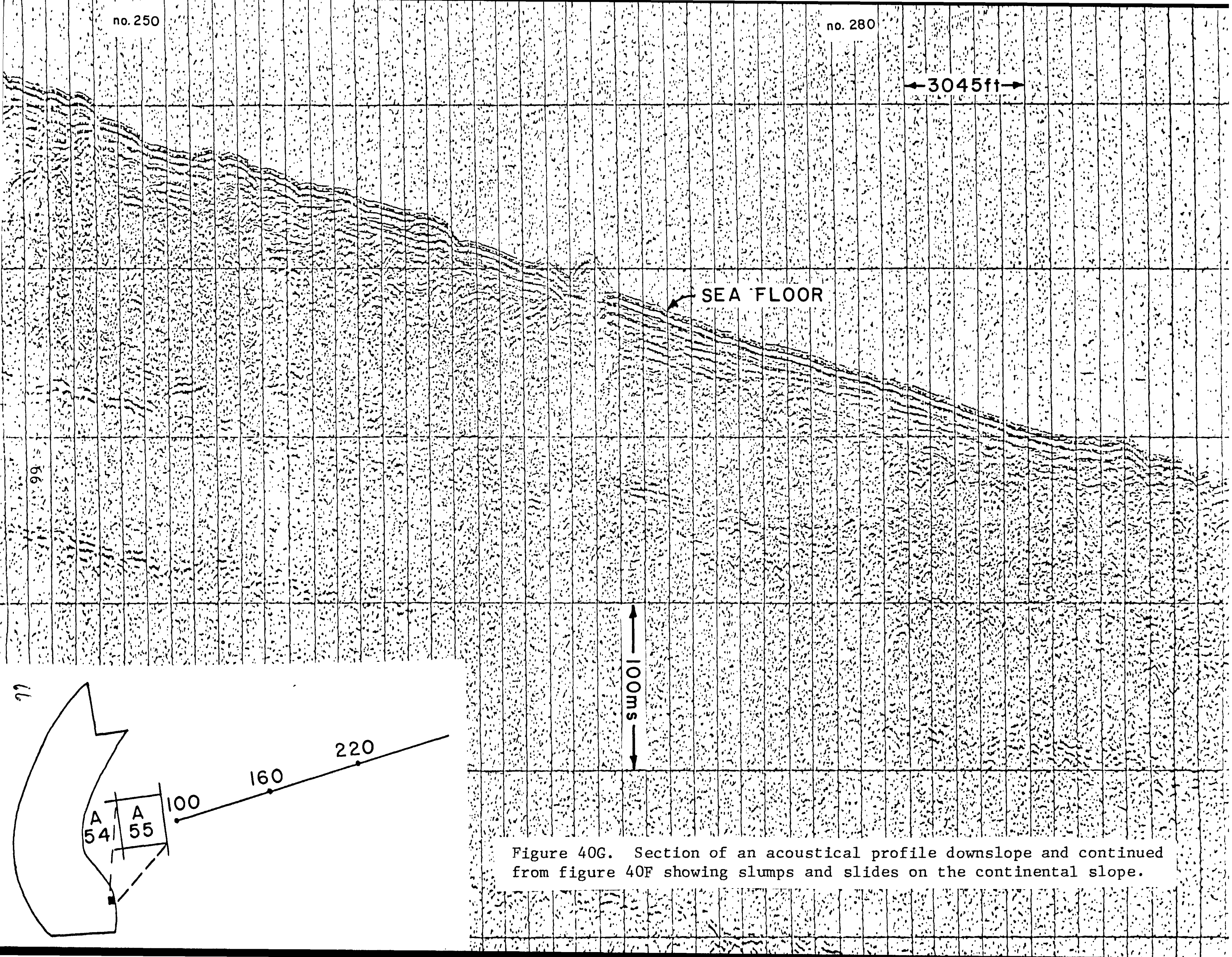
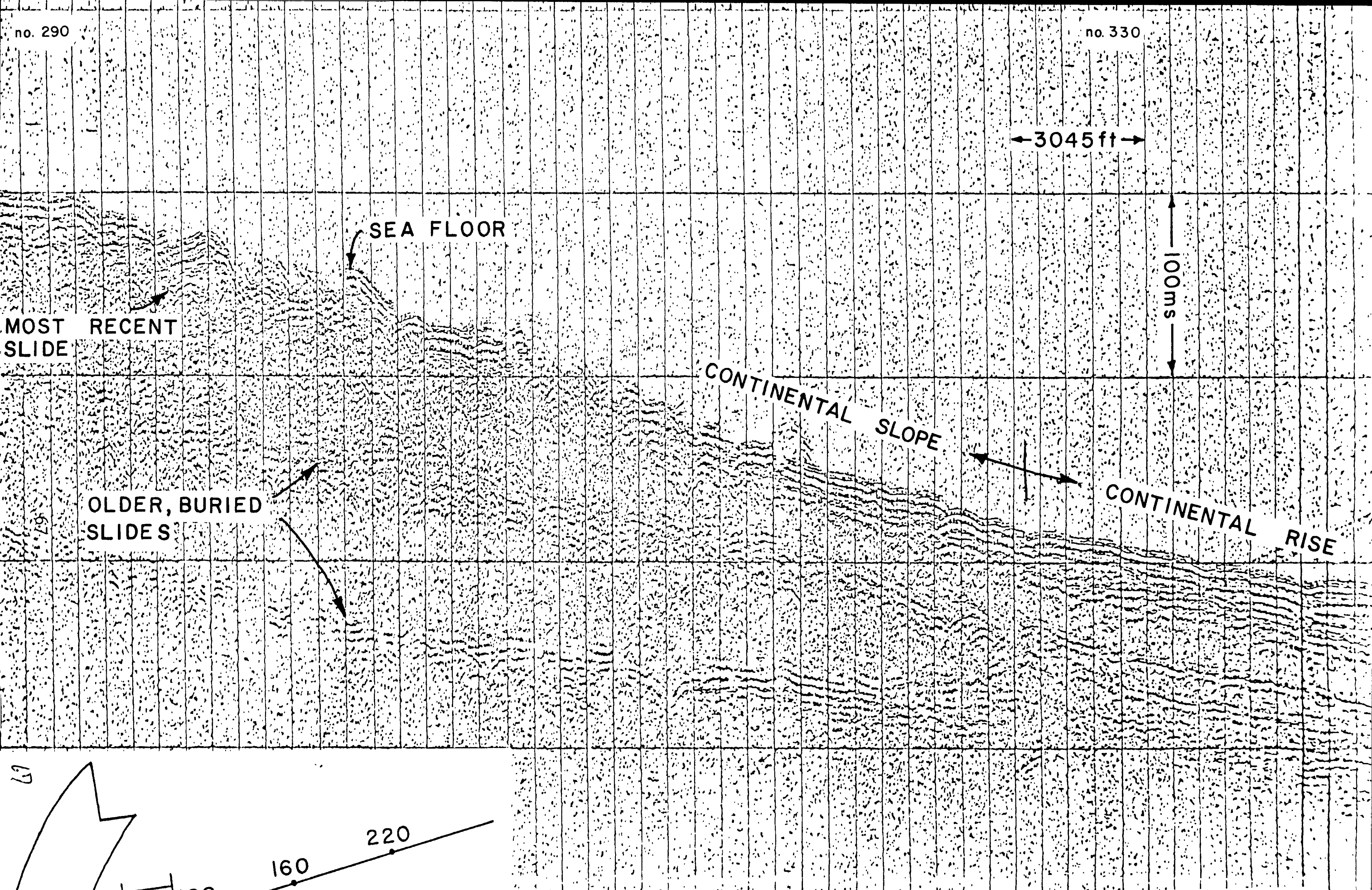


Figure 40G. Section of an acoustical profile downslope and continued from figure 40F showing slumps and slides on the continental slope.



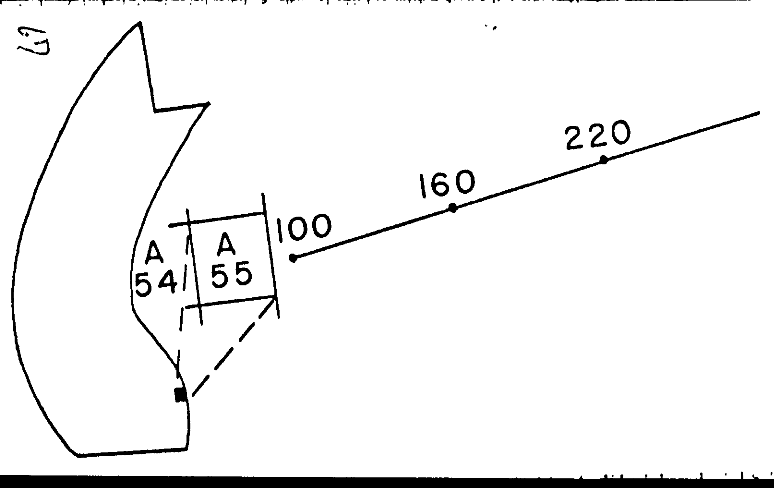


Figure 40H. Section of an acoustical profile downslope and continued from figure 40G showing pile up of slumps at the base of the continental slope.

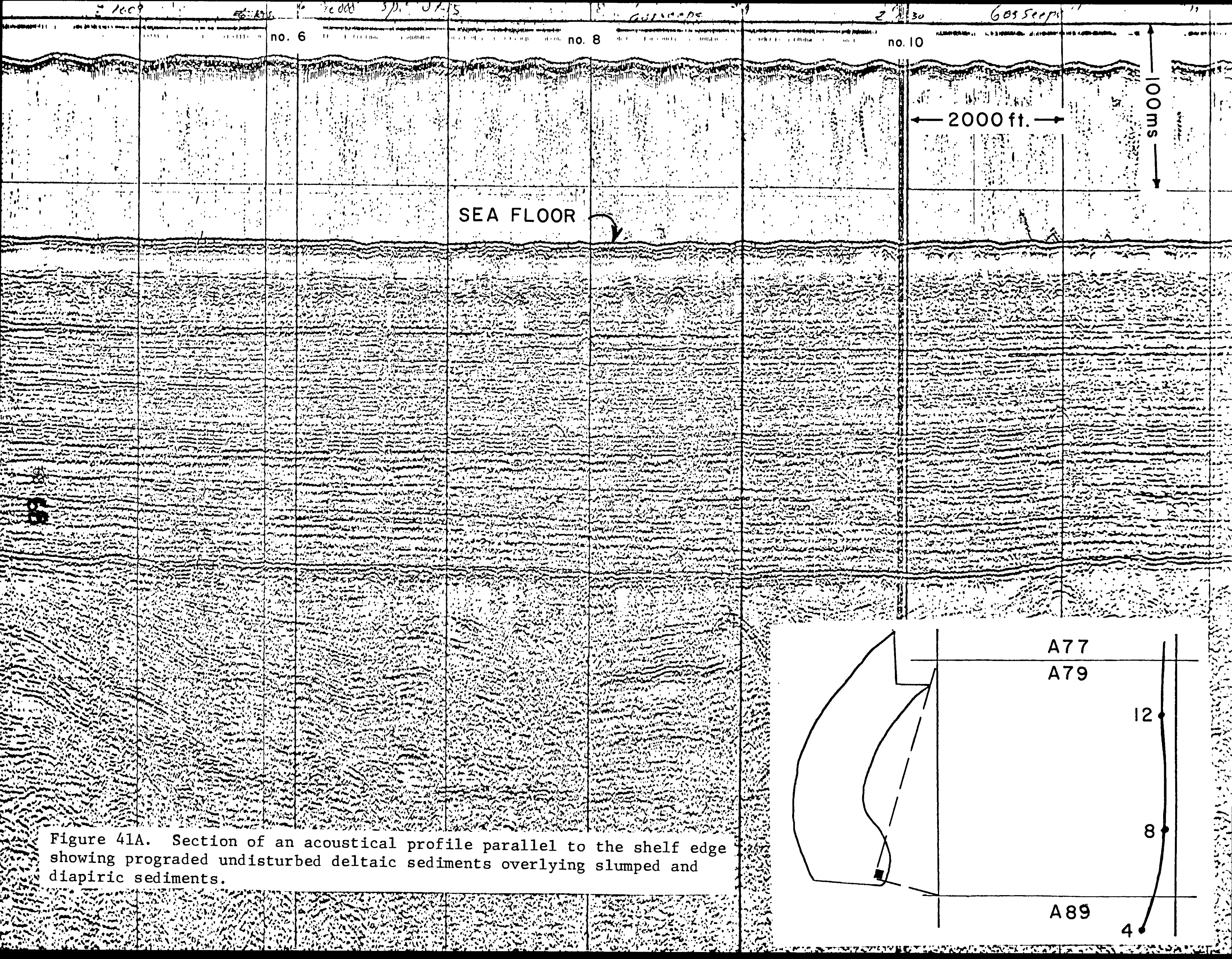


Figure 41A. Section of an acoustical profile parallel to the shelf edge showing prograded undisturbed deltaic sediments overlying slumped and diapiric sediments.

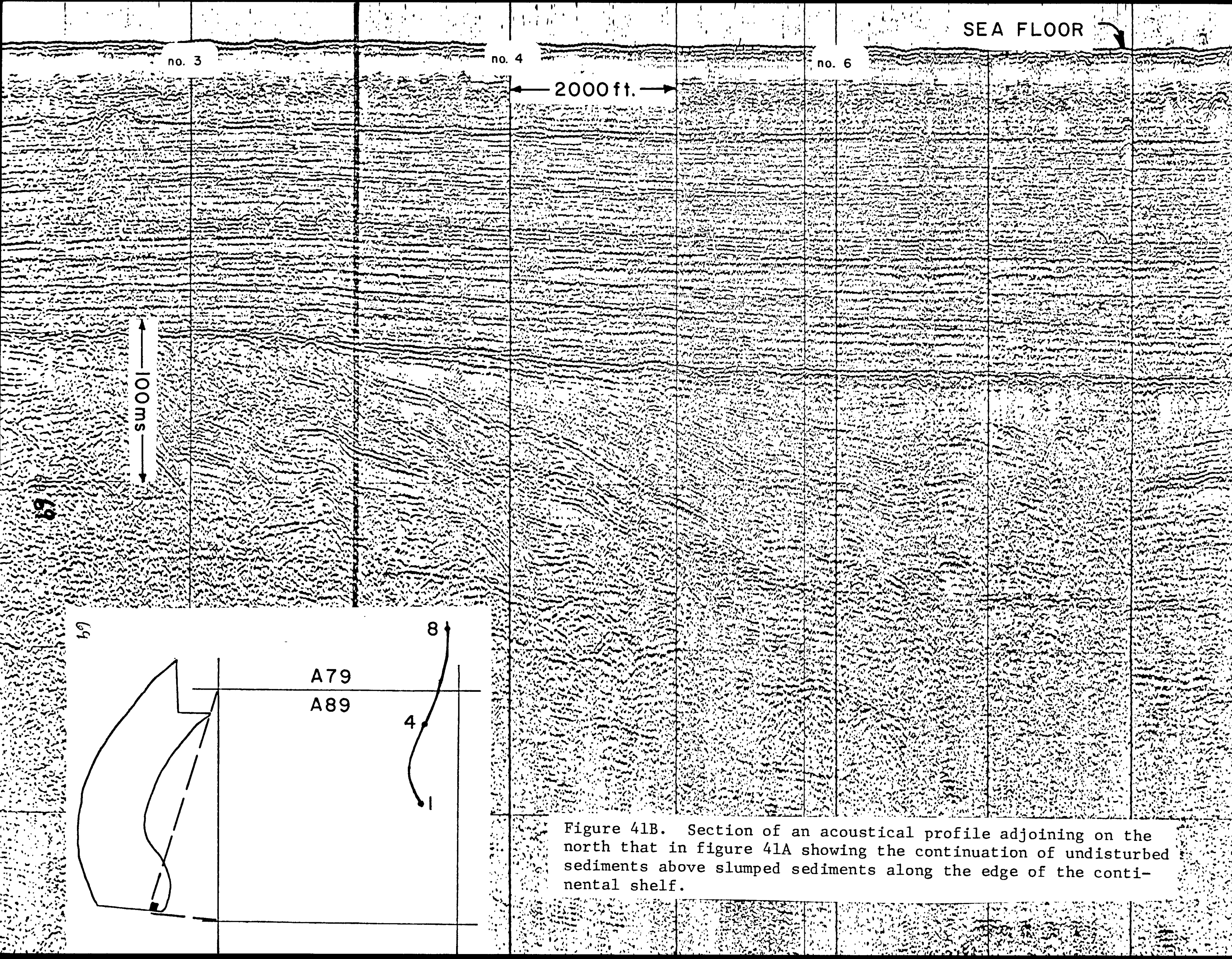


Figure 41B. Section of an acoustical profile adjoining on the north that in figure 41A showing the continuation of undisturbed sediments above slumped sediments along the edge of the continental shelf.

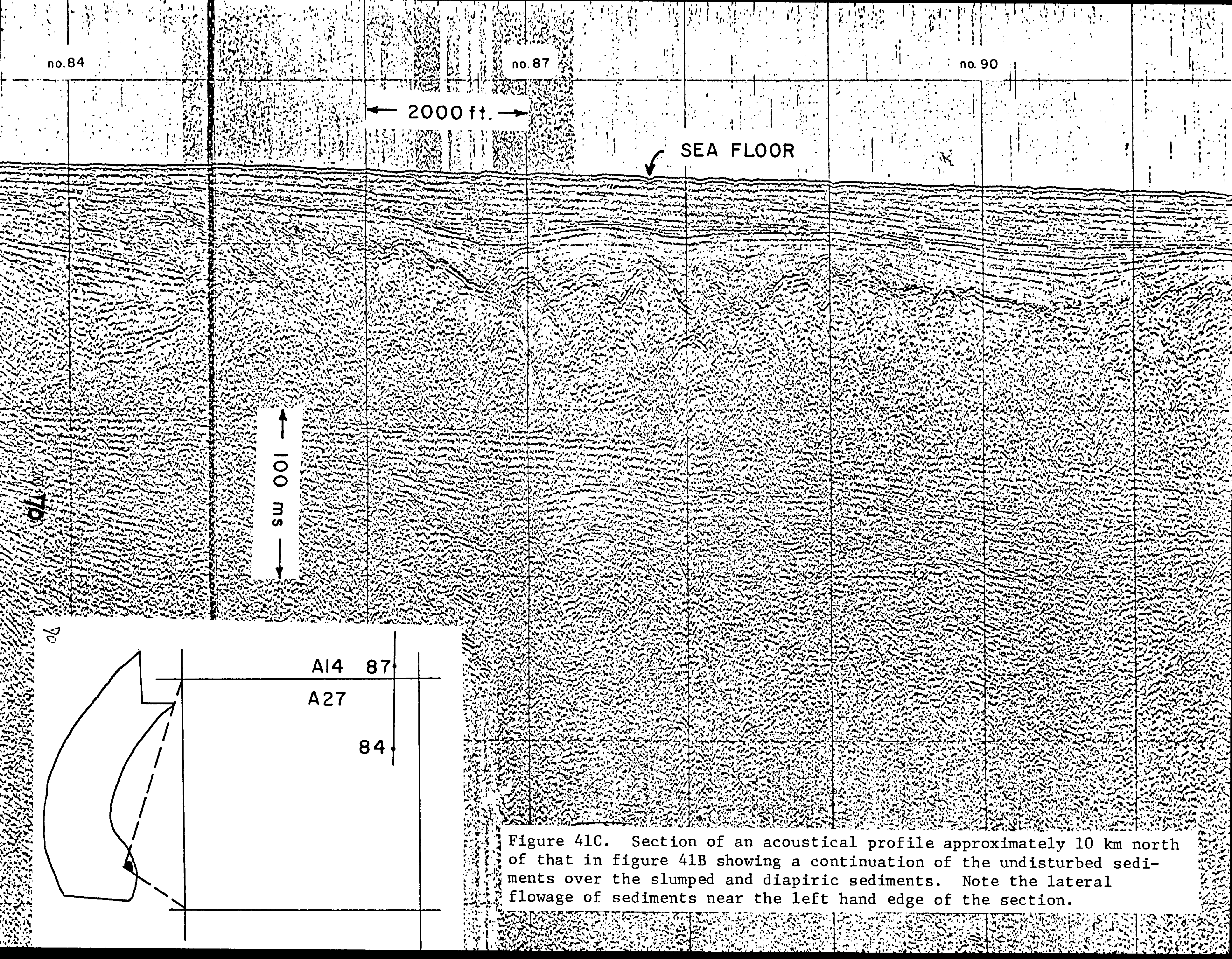


Figure 41C. Section of an acoustical profile approximately 10 km north of that in figure 41B showing a continuation of the undisturbed sediments over the slumped and diapiric sediments. Note the lateral flowage of sediments near the left hand edge of the section.

figures 40F-40H). Compare the two sets and note the difference in the type of deformation.

(4) Large scale slump/folding and faulting on the middle to lower continental slope involving sediments to considerable depth below the sea-floor surface (adjoining sections, figures 42A-42E).

2. Central

a. Geologic characteristics: subsiding edge of shelf being countered by rising anticlinal ridge that has isolated diapirs along its trend; many deep seated rotational faults and tensional faults; increase in topographic gradient at shelf edge less abrupt than to south and north and no previous surficial sliding or slumping of the sediments on the upper slope is indicated. Gas seepage in association with faults is indicated over the general outer central sector (fig. 38A).

b. Types of instability and potential hazard:

(1) Active anticlinal fold beneath the upper continental slope.

(2) Active diapirs: two along the anticlinal crest that lies beneath the upper slope and at least 6 large

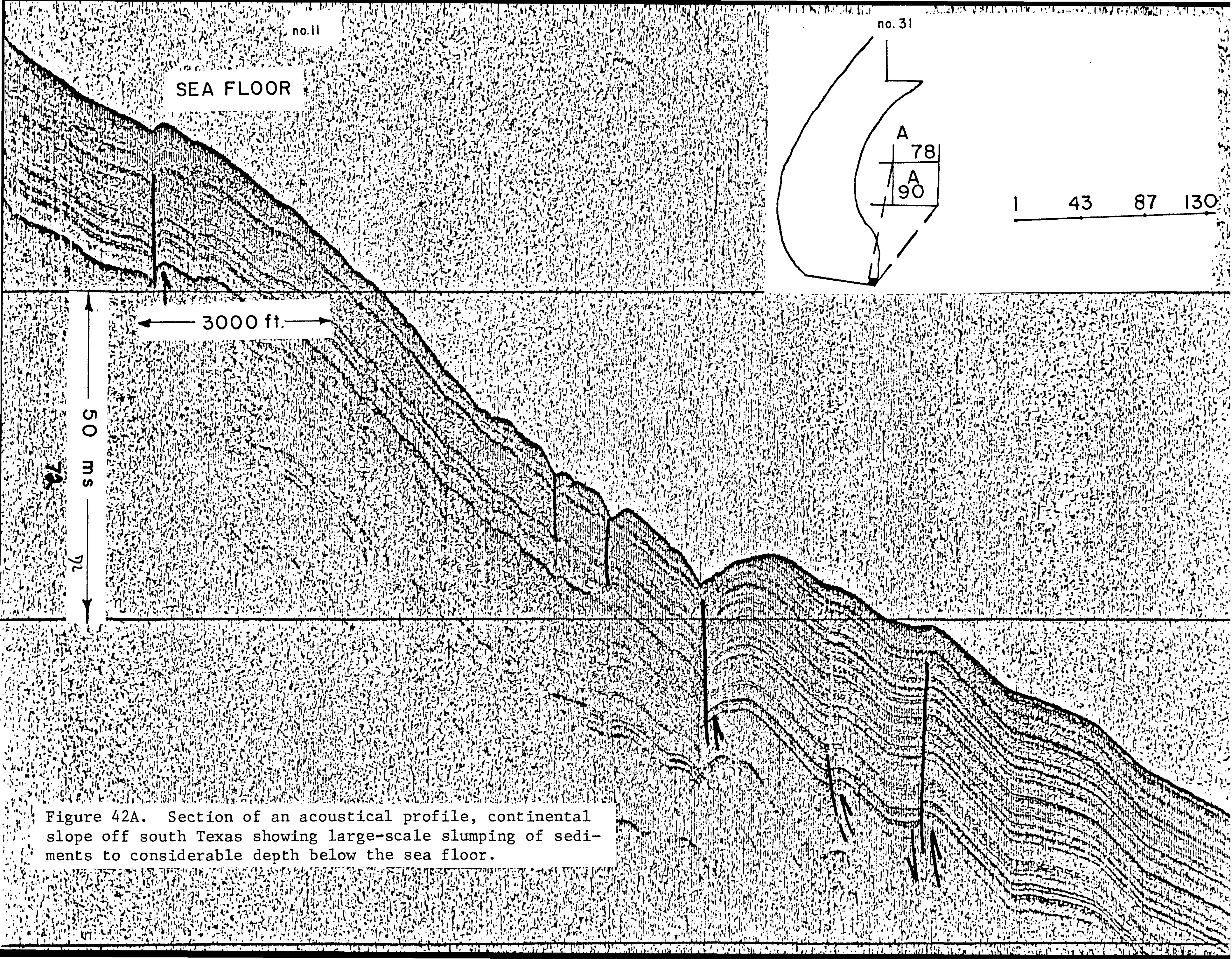


Figure 42A. Section of an acoustical profile, continental slope off south Texas showing large-scale slumping of sediments to considerable depth below the sea floor.

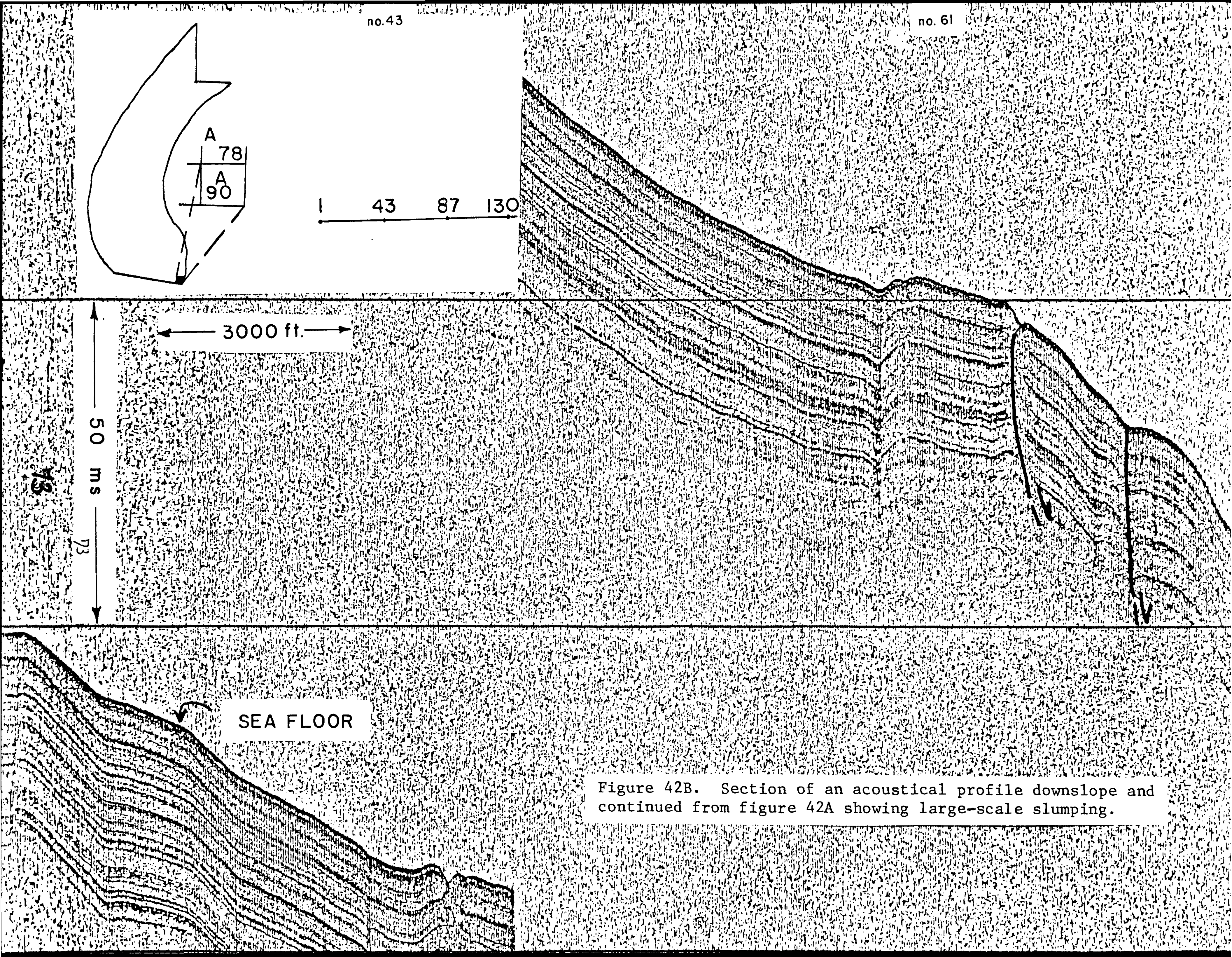


Figure 42B. Section of an acoustical profile downslope and continued from figure 42A showing large-scale slumping.

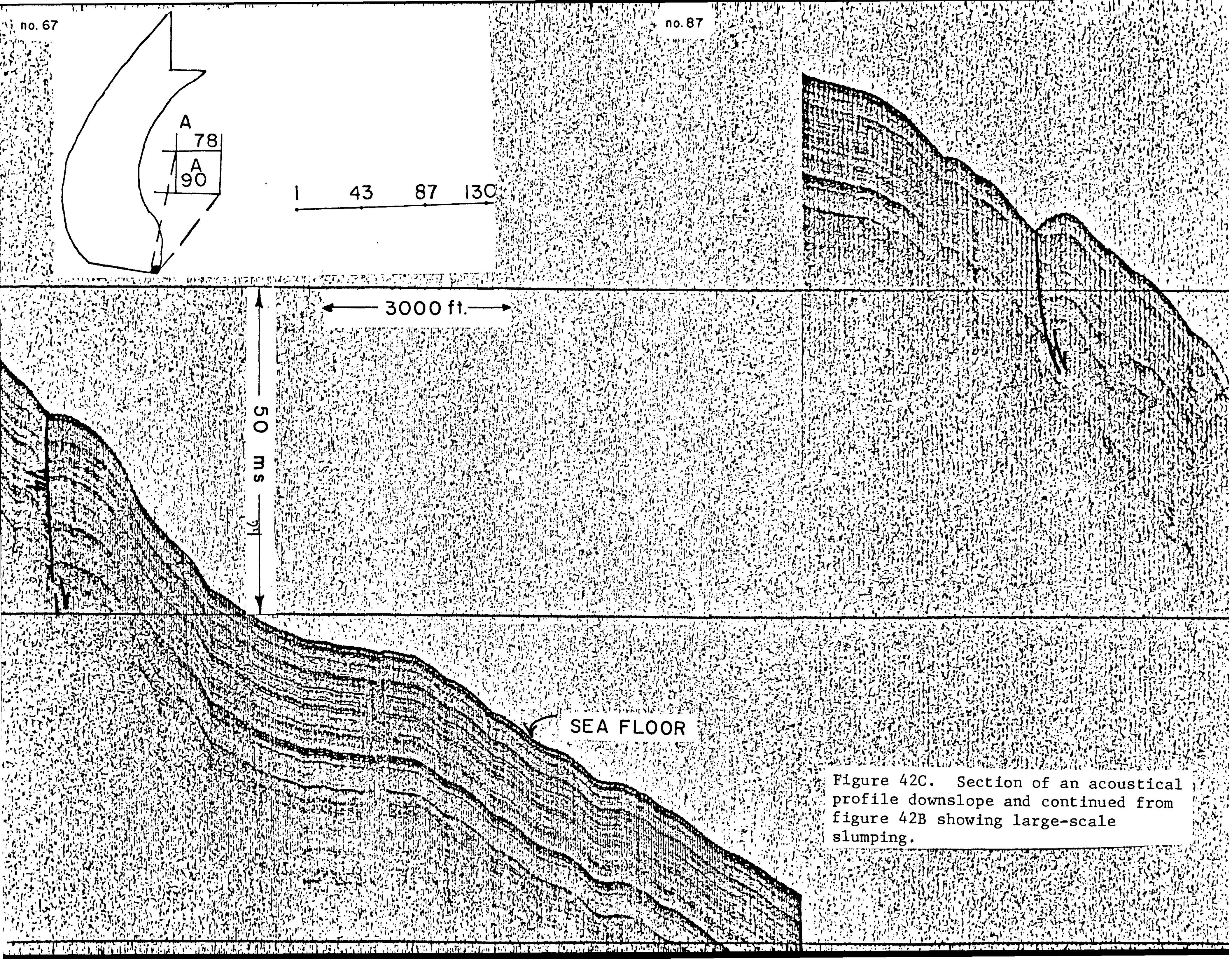


Figure 42C. Section of an acoustical profile downslope and continued from figure 42B showing large-scale slumping.

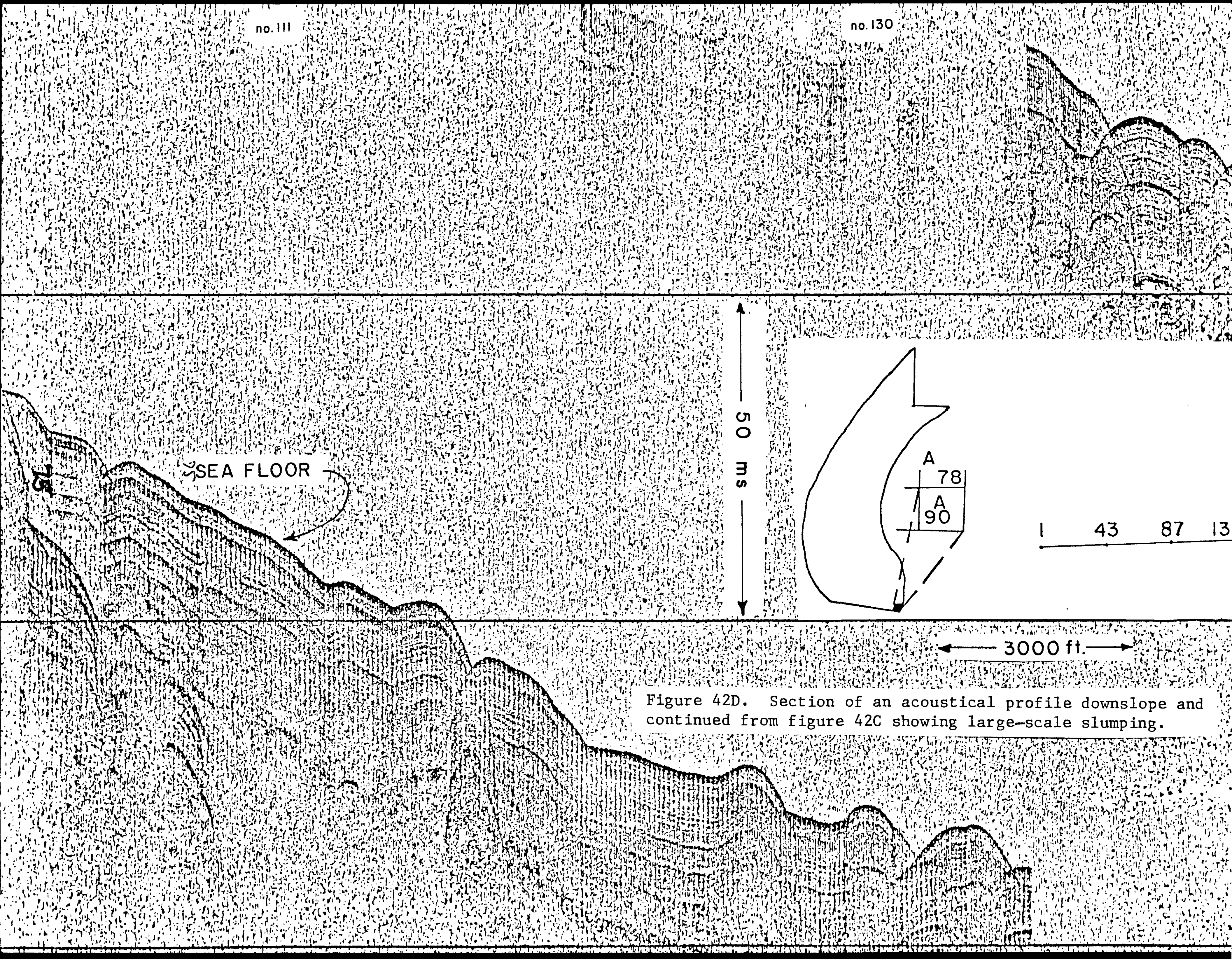


Figure 42D. Section of an acoustical profile downslope and continued from figure 42C showing large-scale slumping.

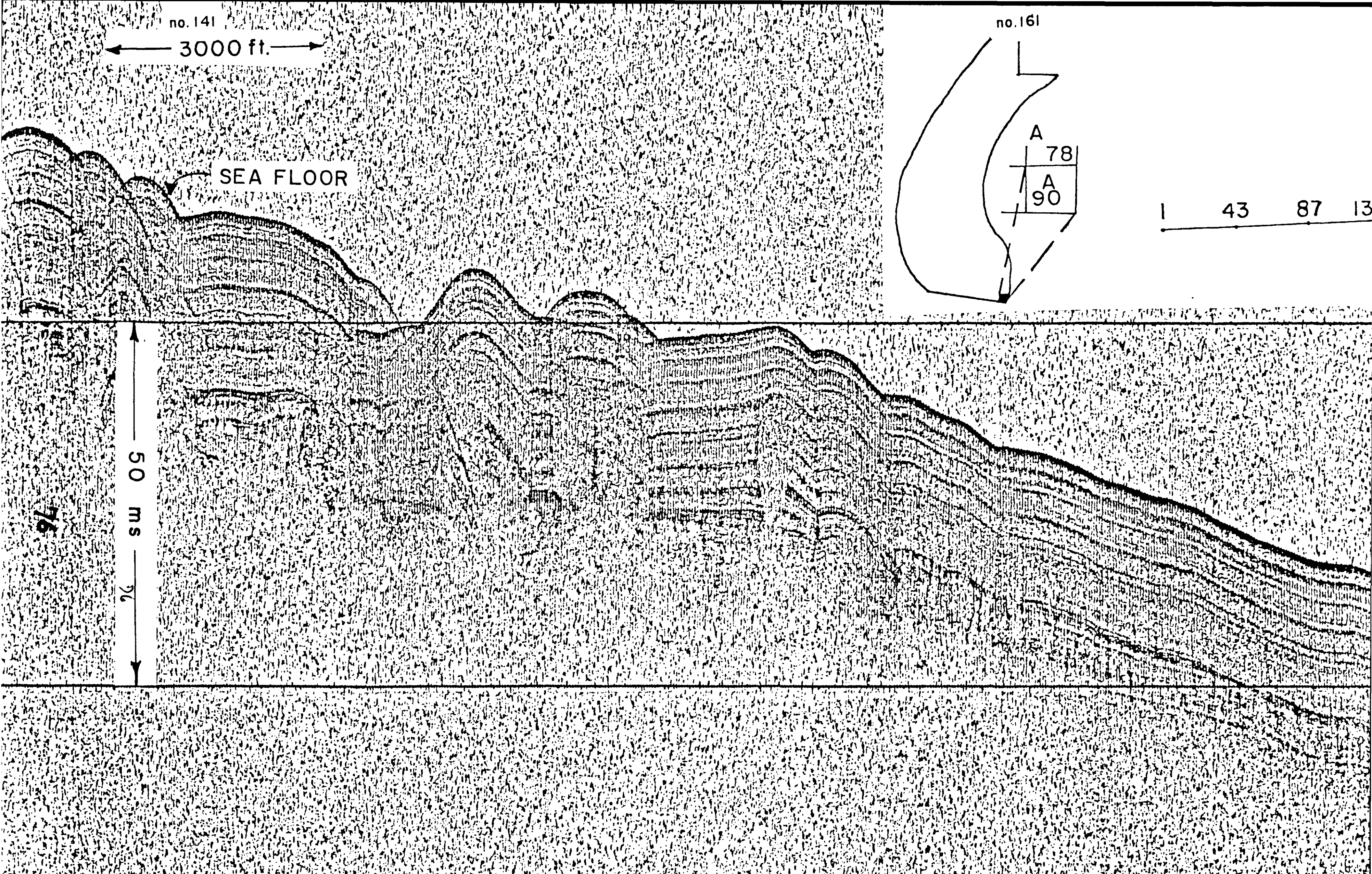


Figure 42E. Section of an acoustical profile downslope and continued from figure 42D showing large-scale slumping. The continental slope merges with the continental rise near right hand side of the illustration.

diapiric masses further seaward beneath the middle and lower slope. Characteristics of the outermost shelf and the adjacent continental slope in the central sector are shown by figures 43A, 43B, and 43C; upper slope, 43A; mid slope, 43B; and diapiric mound on lower slope, 43C.

3. Northeastern

   a. Geologic characteristics: edge of ancestral Brazos-Colorado River delta coincides with shelf edge; increase in topographic gradient at shelf edge relatively abrupt in contrast to the central sector; slumped and diapiric sediments lie beneath prograded younger sediments; shallow faults associated with surficial slumping; hummocky topography caused by slumping on the continental slope.

   b. Type of instability and potential hazard:

      (1) Slumped and diapirically deformed older sediments beneath prograded younger sediments (fig. 44A).

      (2) Slumped and faulted sediments beneath the steep upper part of the continental slope (fig. 44B).

      (3) Relatively steep and irregular bedding in prograded sediments along edge of delta (fig. 44A).

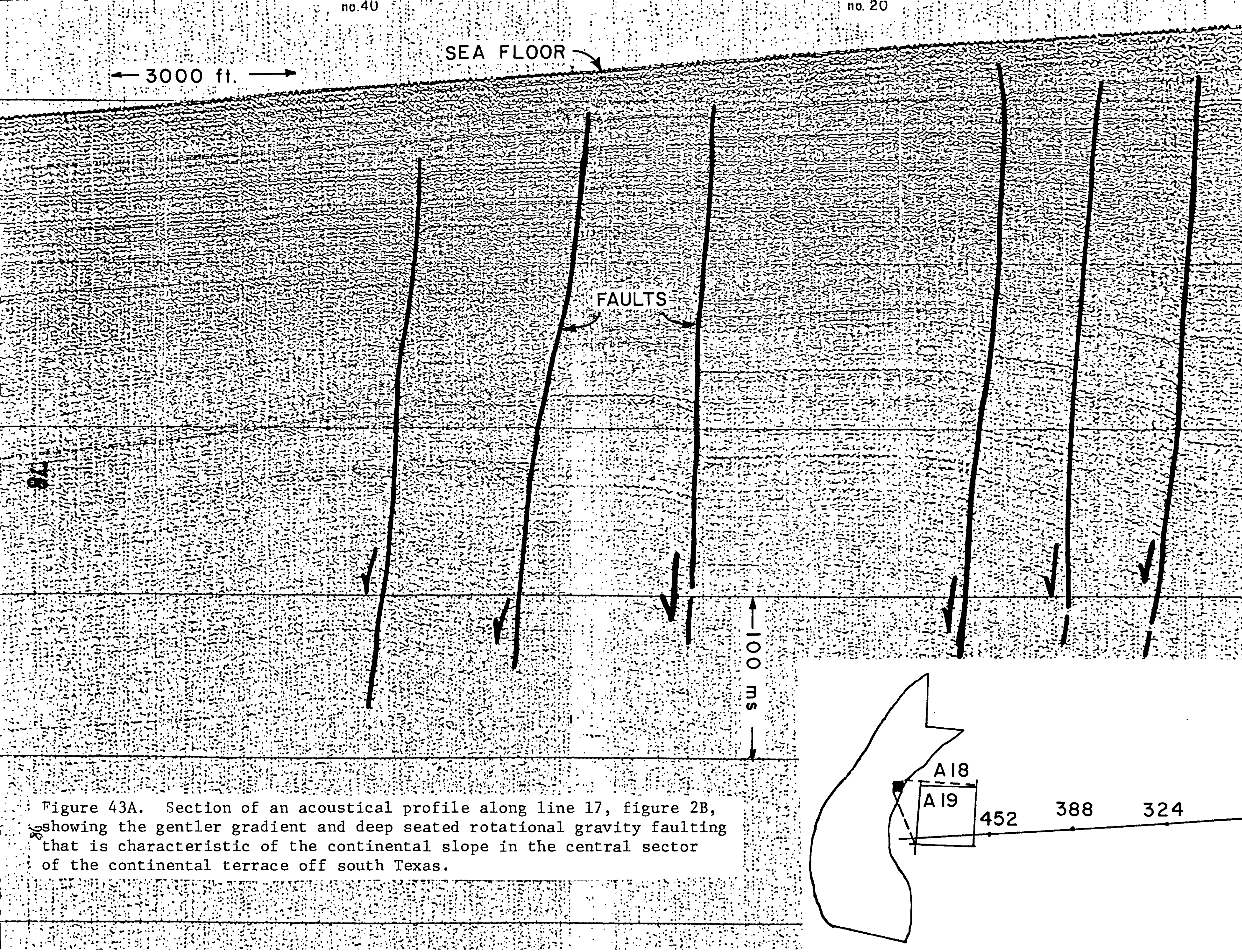


Figure 43A. Section of an acoustical profile along line 17, figure 2B, showing the gentler gradient and deep seated rotational gravity faulting that is characteristic of the continental slope in the central sector of the continental terrace off south Texas.

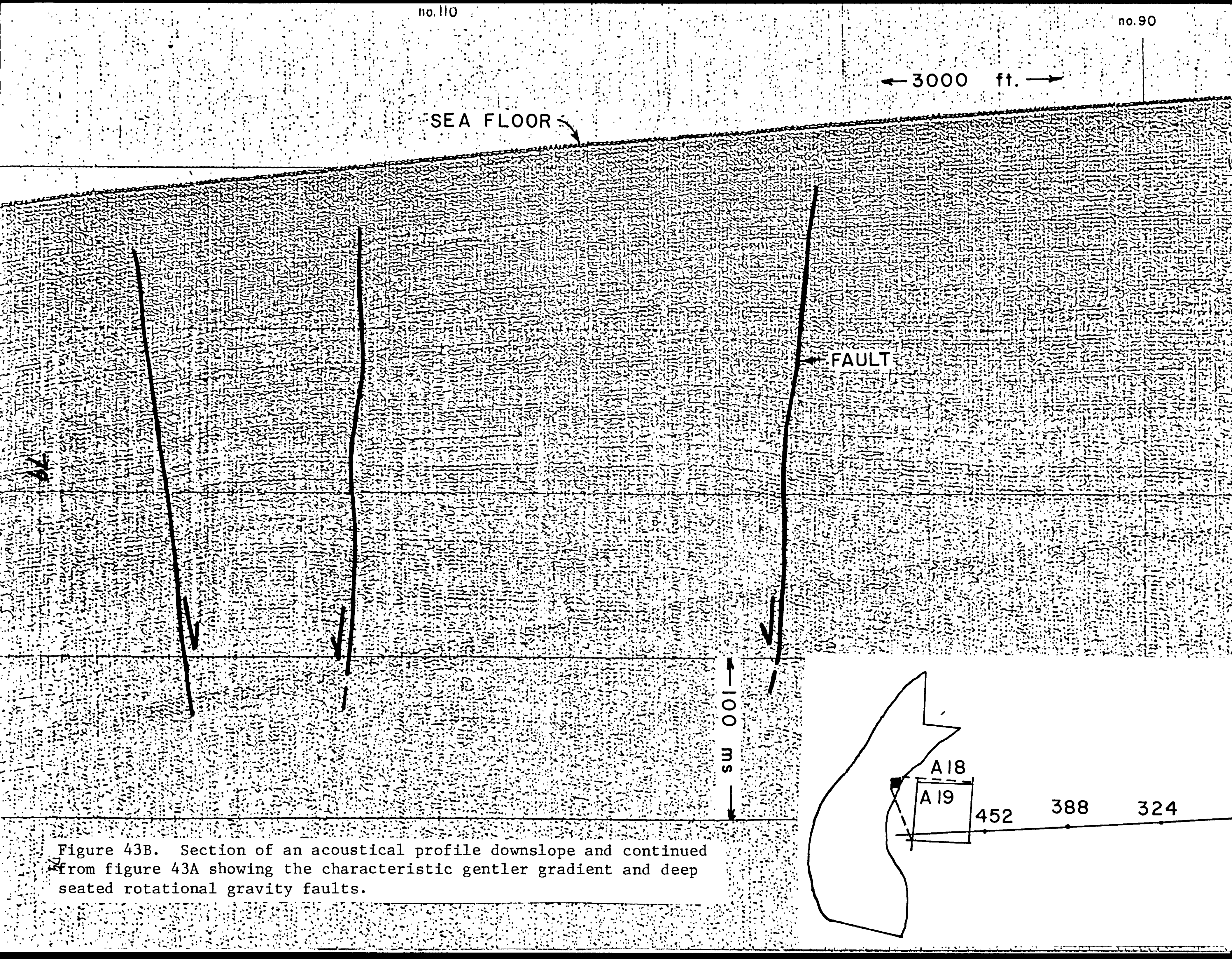


Figure 43B. Section of an acoustical profile downslope and continued from figure 43A showing the characteristic gentler gradient and deep seated rotational gravity faults.

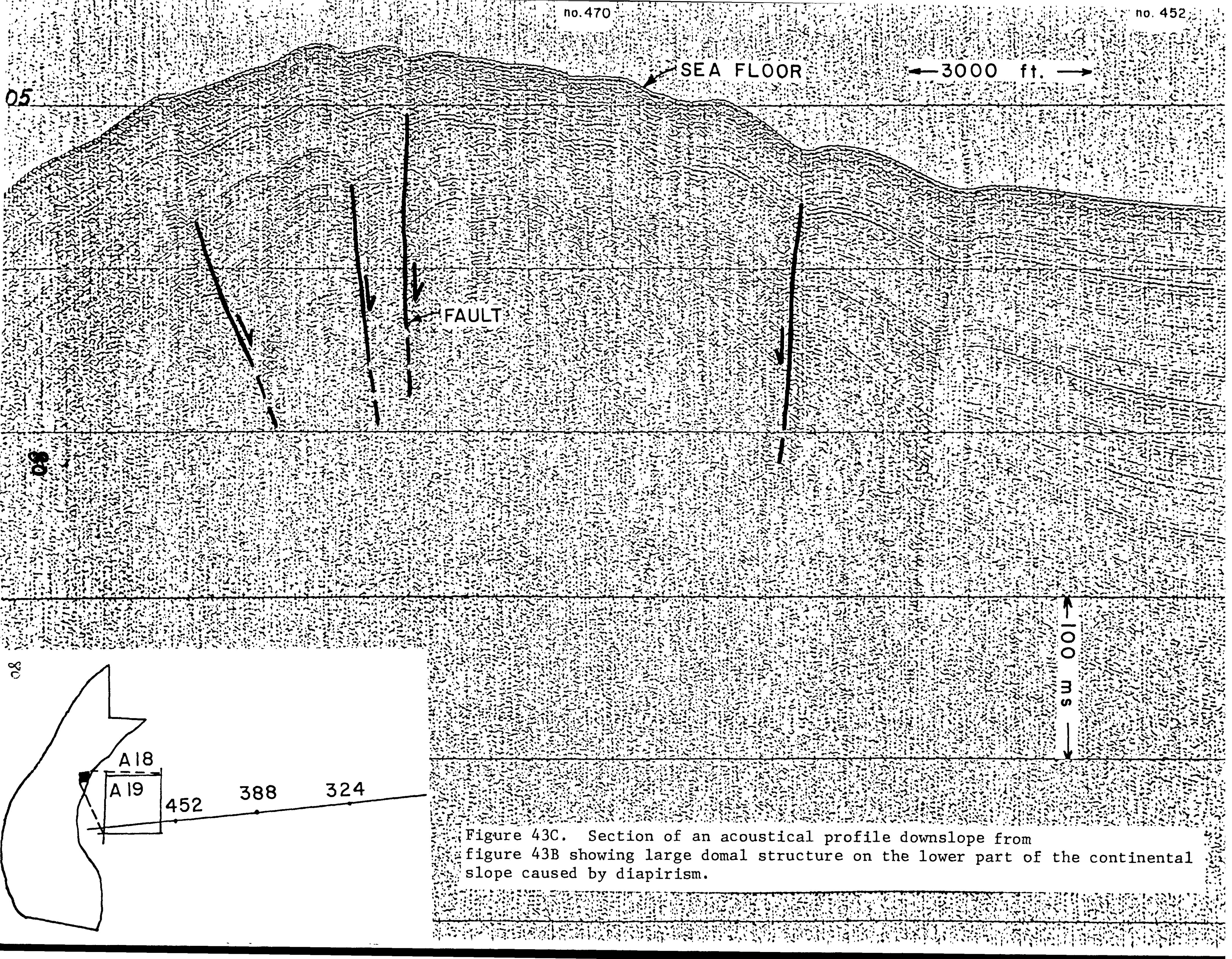
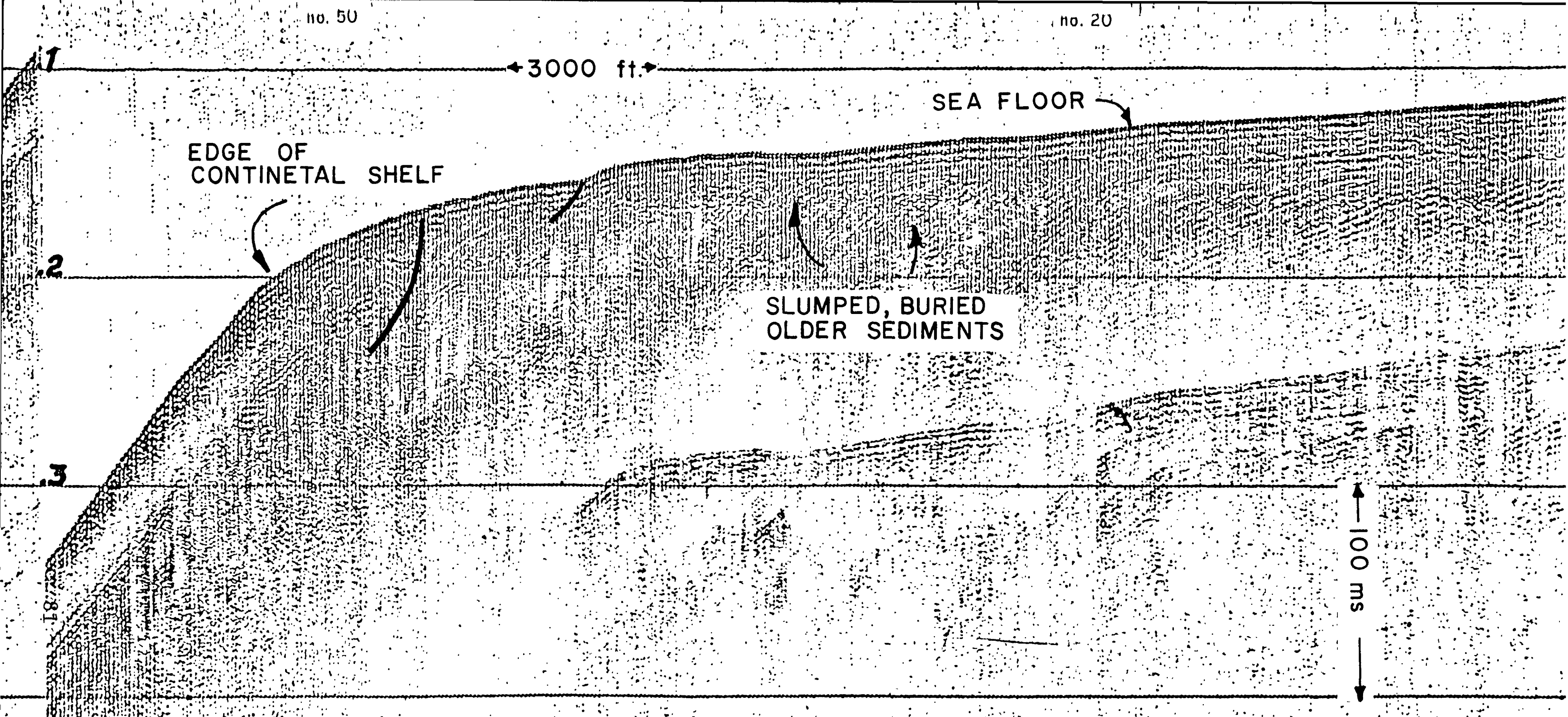


Figure 43C. Section of an acoustical profile downslope from figure 43B showing large domal structure on the lower part of the continental slope caused by diapirism.



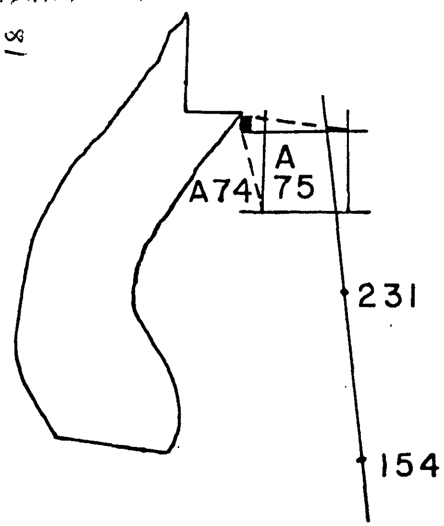


Figure 44A. Section of an acoustical profile along line 39, figure 2B, showing slumped and deformed older deltaic sediments beneath younger prograded sediments and faulting associated with slumping on the continental slope (northeastern sector of continental terrace off south Texas).

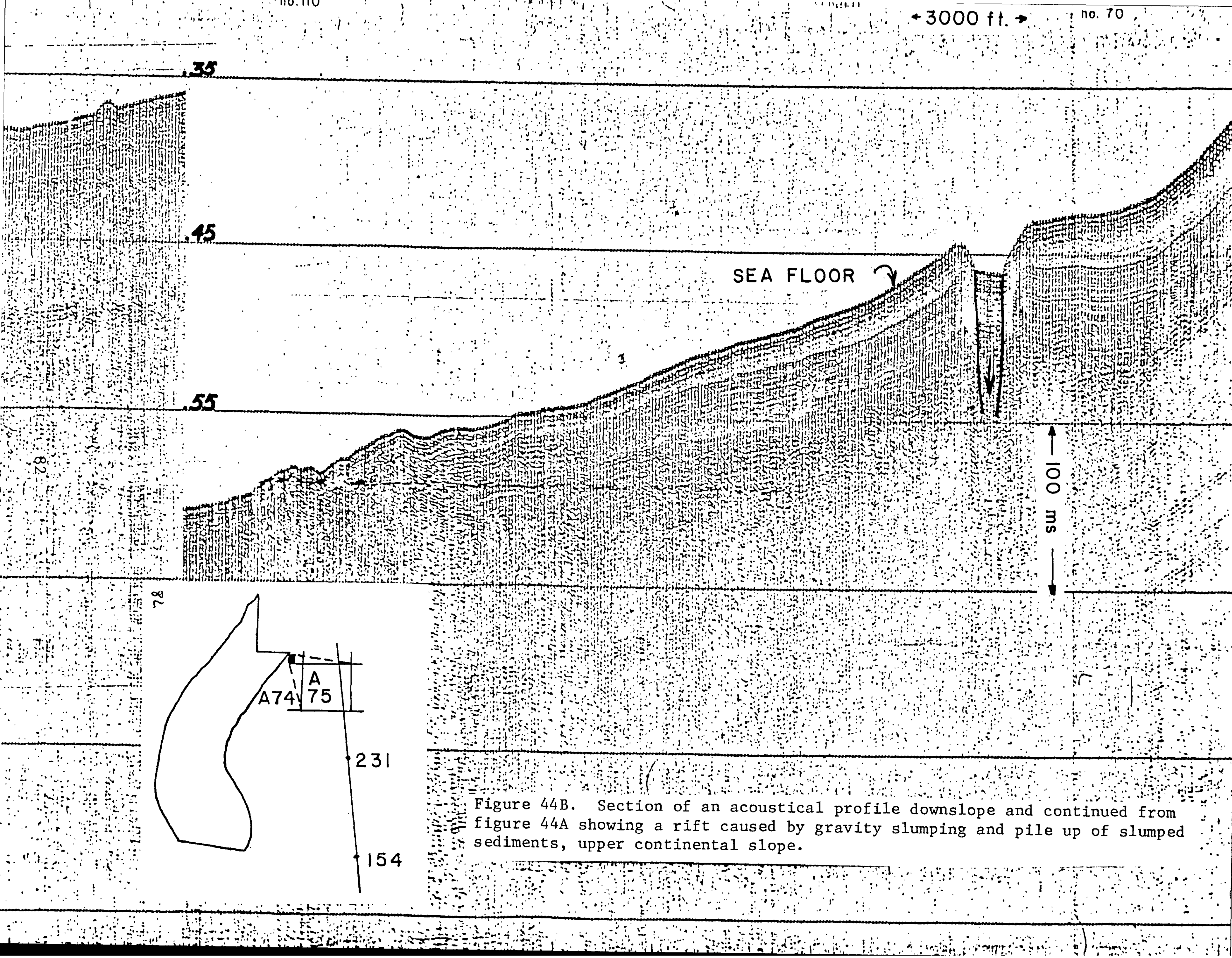


Figure 44B. Section of an acoustical profile downslope and continued from figure 44A showing a rift caused by gravity slumping and pile up of slumped sediments, upper continental slope.

(4) Intensely slumped and chaotic sediments forming a relatively thin skin above older sediments that were subjected to earlier deep-seated gravity faulting rather than large scale slumping (figs. 44C, 44D, and 44E).

4. Summary:

a. The edge of the continental shelf has prograded younger deltaic sediments overlying older slumped sediments of chaotic structure in the southern and northeastern parts and an active anticline parallel to the edge in the central part. Faulting has been extensive over the seaward half of the shelf.

b. The continental slope is a complex of deformed sediments of various types. (Figure 45 is a map showing the areal relationship of the various types of deformed sediments.)

c. Primary factors leading to instability:

(1) Increase in the topographic gradient at the edge of

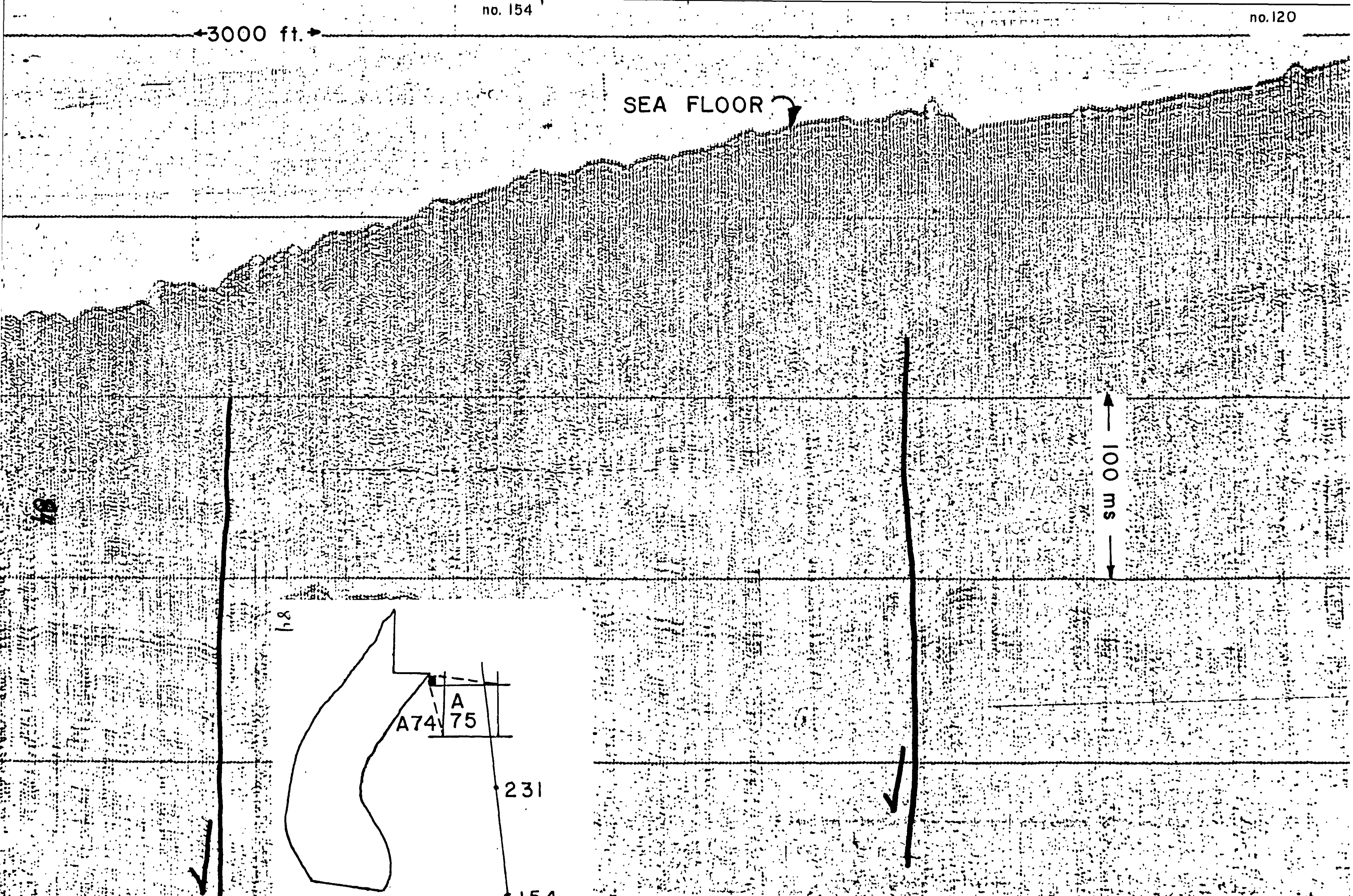


Figure 44C. Section of an acoustical profile downslope and continued from figure 44B showing characteristic hummocky topography above slumps and slides. The chaotic shallower sediments overlie older gravity faulted sediments.

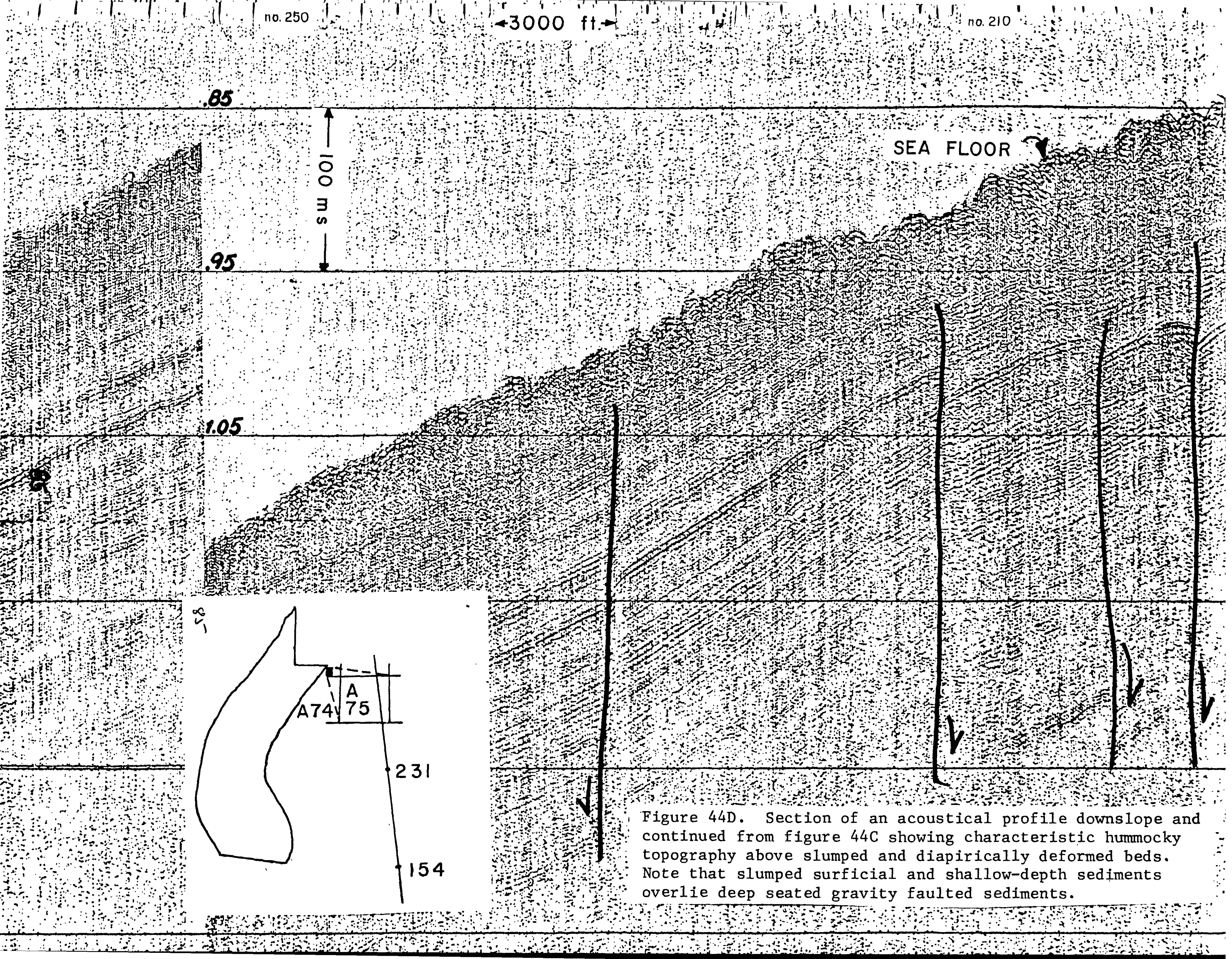


Figure 44D. Section of an acoustical profile downslope and continued from figure 44C showing characteristic hummocky topography above slumped and diapirically deformed beds. Note that slumped surficial and shallow-depth sediments overlie deep seated gravity faulted sediments.

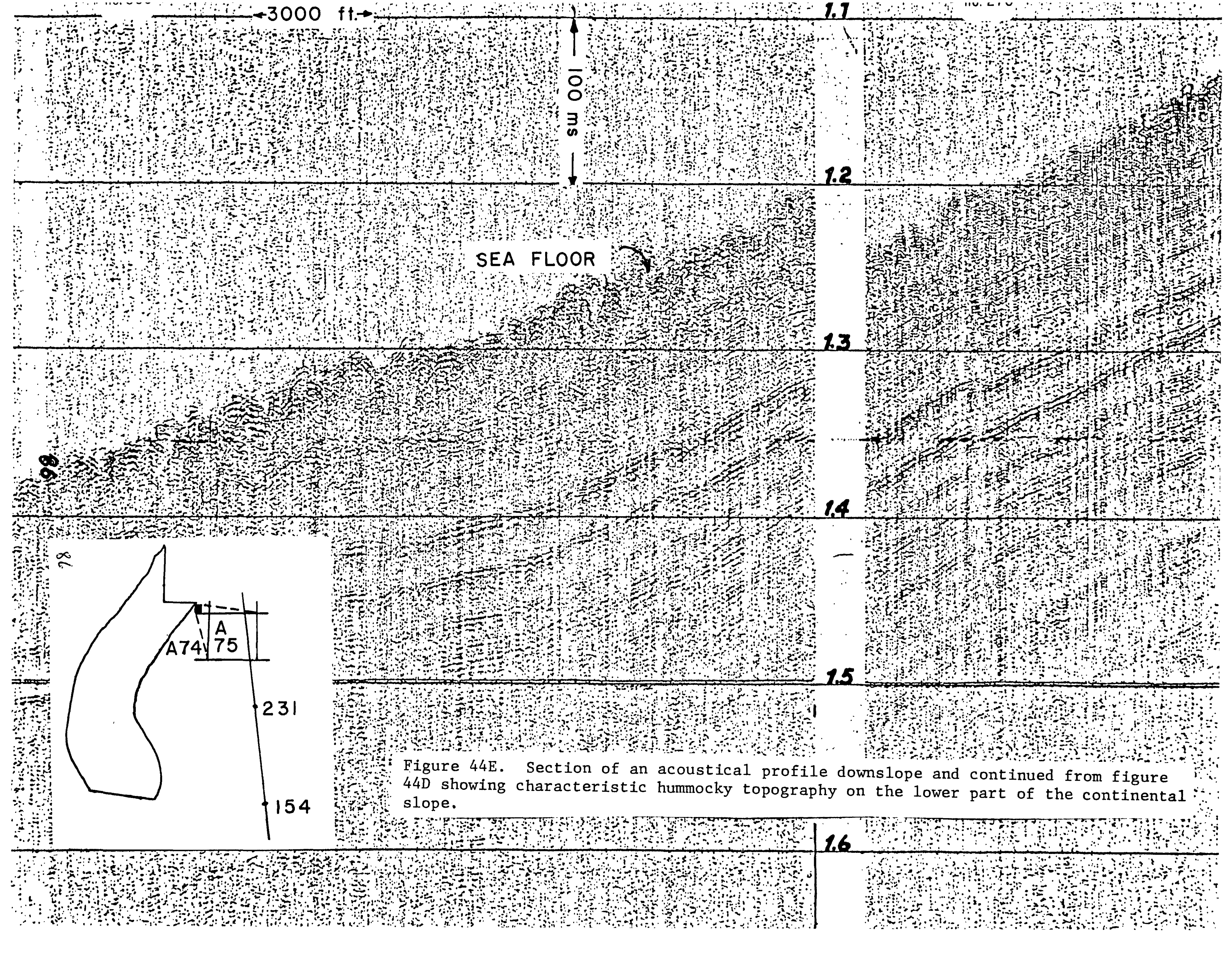


Figure 44E. Section of an acoustical profile downslope and continued from figure 44D showing characteristic hummocky topography on the lower part of the continental slope.

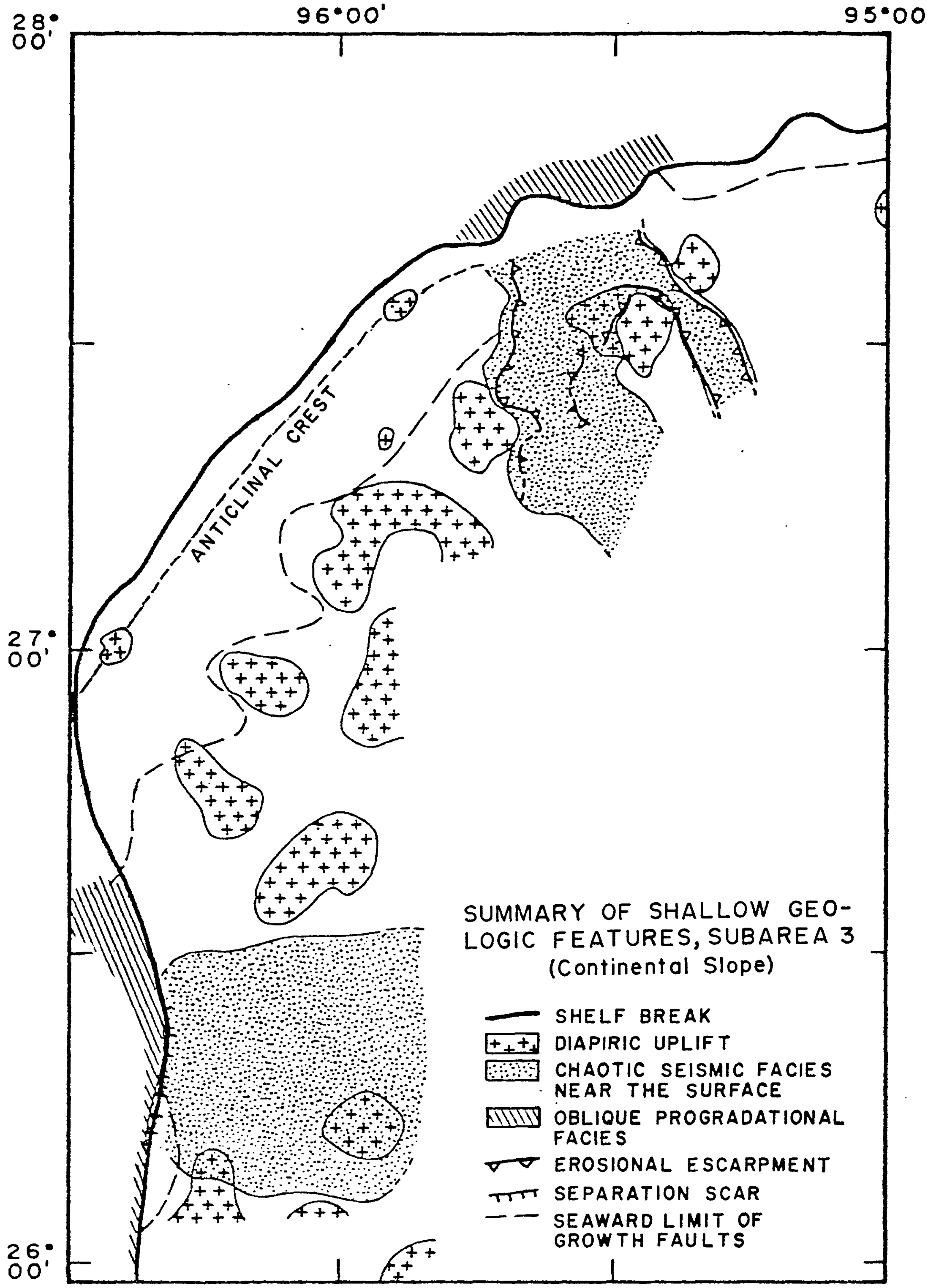


Figure 45. Shallow geologic features of the continental slope caused by deformational movements within the continental terrace. Modified from Tatum, 1977, p. 18.

the continental shelf where it merges with the continental slope.

(2) Long term and regionally high rates of deposition along the continental terrace in general which have caused isostatic adjustments and deep-seated gravity faulting.

(3) More localized high rates of sedimentation caused by deltaic outbuilding to the edge of the shelf where the combination of large volumes of unconsolidated sediments deposited on the increased topographic gradient leads to intensive slumping and sliding.

(4) Diapirism or the upward movement of less dense material such as salt and shale from depth. The movement of this material upward through the thick overlying sediment causes extensive deformation and the doming of the sediments above the diapiric material as it nears the surface.

(5) High gas content in rapidly deposited sediments.

REFERENCES
(A listing of both cited and supplemental reports)

*References cited

Amery, George B., 1976, Structure of continental slope, northern Gulf of Mexico in A. H. Bouma, G. T. Moore, and J. M. Coleman, (eds.), Beyond the shelf break: American Association of Petroleum Geologists Marine Geology Comm. Short Course, v. 2, p. H1-H16.

Antoine, John W., and Bryant, W. R., 1969, Distribution of salt and salt structures in Gulf of Mexico: American Association of Petroleum Geologists Bulletin, v. 53, no. 12, p. 2543-2550.

Antoine, John W., Martin, Ray G., Jr., Pyle, T. E., and Bryant, William R., 1974, Continental margins of the Gulf of Mexico in C. A. Burk, and C. L. Drake, (eds.), The geology of the continental margins: New York, Springer-Verlag, p. 683-694.

Bergantino, Robert N., 1971, Submarine regional geomorphology of the Gulf of Mexico: Geological Society of America Bulletin, v. 82, no. 3, p. 741-752.

*Berryhill, H. L., Jr., 1977, Integrated environmental studies, South Texas Outer Continental Shelf: approach, techniques, results in Proceedings: 1977 Offshore Technology Conference, v. 1, no. 2754, p. 239-248.

*Berryhill, H. L., Jr., Shideler, G. L., Holmes, C. W., Barnes, S.S., Hill, G. W., Martin, E. A., Bernard, B., Pyle, C. A., Roberts, K. A., Kindinger, J. L., and Wiley, G. D., 1977, Environmental studies, South Texas Outer Continental Shelf, 1976: Geology: National Technical Information Service, Springfield, VA, Pub. accession no. PB 277-337/AS, 626 p.

*Curray, Joseph P., 1960, Sediments and history of Holocene transgression, continental shelf, northwest Gulf of Mexico in Francis P. Shepard, Fred B. Phleger, and Tjeerd H. van Andel, (eds.), Recent sediments, northwest Gulf of Mexico: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 221-266.

Ewing, M., and Antoine, J. W., 1966, New seismic data concerning sediments and diapiric structures in Sigsbee Deep and continental slope, Gulf of Mexico: American Association of Petroleum Geologists Bulletin, v. 50, no. 3, pt. 1, p. 479-504.

Garrison, L. E., and Martin, R. G., Jr., 1973, Geologic structures in the Gulf of Mexico basin: United States Geological Survey Professional Paper 773, 85 p.

Gealy, E. L., 1955, Topography of the continental slope in northwest Gulf of Mexico: Geological Society of America Bulletin, v. 66, no. 2, p. 203-228.

Hardin, F. R., and Hardin, G. C., Jr., 1961, Contemporaneous normal faults of Gulf Coast and their relation to flexures: American Association of Petroleum Geologists, v. 45, no. 2, p. 238-248.

*Hill, G. W., 1976, Animal-sediment relationships in H. L. Berryhill, Jr., (ed.), Environmental studies, South Texas Outer Continental Shelf, 1975: Geology: National Technical Information Service, Springfield, Virginia, Pub. accession no. PB251341, p. 133-187.

*Hill, G. W., 1977, Animal-sediment relationships in H. L. Berryhill, Jr., (ed.), Environmental studies, South Texas Outer Continental Shelf, 1976: Geology: National Technical Information Service, Springfield, Virginia, Pub. accession no. PB277-337/AS, p. 285-389.

*Holmes, C. W., and Martin, E. A., 1977, Rates of sedimentation in H. L. Berryhill, Jr., (ed.), Environmental studies, South Texas Outer Continental Shelf, 1976: Geology: National Technical Information Service, Springfield, Virginia, Pub. accession no. PB277-337/AS, p. 230-246.

Holland, W. C., 1970, Bathymetric maps of eastern continental margin, U.S.A., northern Gulf of Mexico: American Association of Petroleum Geologists, sheet 3 of 3.

*Lehner, Peter, 1969, Salt tectonics and Pleistocene stratigraphy on continental slope of northern Gulf of Mexico: American Association of Petroleum Geologists Bulletin, v. 53, no. 12, p. 2431-2479.

Lewis, K. B., 1974, The continental terrace: Earth Science Reviews, v. 10, p. 37-71.

Martin, R. G., Jr., 1976, Geologic framework of northern and eastern continental margins, Gulf of Mexico in A. H. Bouma, G. T. Moore, and J. M. Coleman, (eds.), Beyond the shelf break: American Association of Petroleum Geologists Marine Geology Comm. Short Course, v. 2, p. A1-A28.

Martin, R. G., Jr., and Bouma, A. H., 1978, Physiography of Gulf of Mexico in A. H. Bouma, G. T. Moore, and J. M. Coleman, (eds.), Framework, facies, and oil trapping characteristics of upper continental margin: American Association of Petroleum Geologists, Studies in Geology No. 7, Tulsa, Oklahoma.

*Moore, D. G., and Curray, J. R., 1963, Structural framework of the continental terrace, northwest Gulf of Mexico: Journal of Geophysical Research, v. 68, no. 6, p. 1725-1747.

Poag, C. W., 1972, Shelf edge submarine banks in the Gulf of Mexico: Paleoecology and biostratigraphy: Transactions, Gulf Coast Association of Geological Societies, v. 22, p. 267-281.

*Pyle, C. A., and Berryhill, H. L., Jr., 1977, Late Quaternary geologic history of the south Texas continental shelf in H. L. Berryhill, Jr., (ed.), Environmental studies, South Texas Outer Continental Shelf, 1976: Geology: National Technical Information Service, Springfield, Virginia, Pub. accession no. PB277-337/AS, p. 390-453.

*Sangree, J. B., Waylett, D. C., Grazier, D. E., Amery, G. G., and Fennessy, W. J., 1976, Recognition of continental slope seismic facies offshore Texas-Louisiana in A. H. Bouma, G. T. Moore, and J. M. Coleman, (eds.), Beyond the shelf break: American Association of Petroleum Geologists Marine Geology Comm. Short Course, v. 2, p. F1-F54.

Shelton, John W., 1968, Role of contemporaneous faulting during basinal subsidence: American Association of Petroleum Geologists Bulletin, v. 52, no. 3, p. 399-413.

*Shideler, G. L., 1976, Sea floor sediments in H. L. Berryhill, Jr., (ed.), Environmental studies, South Texas Outer Continental Shelf, 1975: Geology: National Technical Information Service, Springfield, VA, Pub. accession no. PB251341, p. 51-105.

*Shideler, G. L., 1977, Sea floor sediments in H. L. Berryhill, Jr., (ed.), Environmental studies, South Texas Outer Continental Shelf, 1976: Geology: National Technical Information Service, Springfield, VA, Pub. accession no. PB277-337/AS, p. 142-166.

*Sidner, Bruce R., 1977, Late Pleistocene geologic history of the outer continental shelf and upper continental slope, northwest Gulf of Mexico: Ph. D. Dissertation, Texas A&M University.

*Sorensen, F. H., Snodgrass, L. W., Rebman, J. H., Murchison, R. R., Jones, C. R., and Martin, Ray G., Jr., 1975, Preliminary bathymetric map of the Gulf of Mexico region: United States Geological Survey open file map.

*Tatum, T. E., Jr., 1977, Shallow geologic features of the upper continental slope, northwestern Gulf of Mexico: Master's Thesis, Texas A&M University.

Uchupi, Elazar, and Emery, K. O., 1968, Structure of continental margins off Gulf Coast of United States: American Association of Petroleum Geologists Bulletin, v. 52, no. 7, p. 1162-1193.

Wilhelm, Oscar, and Ewing, Maurice, 1972, Geology and history of the Gulf of Mexico: Geological Society of America Bulletin, v. 83, no. 3, p. 575-600.

Woodbury, H. O., Murray, I. B., Jr., Pickford, P. J., and Akers, W. H., 1973, Pliocene and Pleistocene depocenters, outer continental shelf, Louisiana and Texas: American Association of Petroleum Geologists Bulletin, v. 57, no. 12, p. 2428-2439.

Woodbury, H. O., Spotts, J. H., and Akers, W. H., 1976, Gulf of Mexico continental slope sediments and sedimentation in A. H. Bouma, G. T. Moore, and J. M. Coleman, (eds.), Beyond the shelf break: American Association of Petroleum Geologists Marine Geology Comm. Short Course, v. 2, p. C21-C28.