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GEOLOGICAL SURVEY

GEOLOGY AND POTENTIAL HAZARDS OF THE CONTINENTAL SLOPE BETWEEN LINDENKOHL AND SOUTH TOMS CANYONS, OFFSHORE MID-ATLANTIC UNITED STATES

James M. Robb, John C. Hampson, Jr., John R. Kirby,

and David C. Twichell

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Woods Hole, Massachusetts

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Illustrations

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SUMMARY

Because sediment instability, or slumping, has been identified as a potential hazard to petroleum development of the east-coast Continental Slope, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management, began a detailed study of a segment of the Continental Slope between Lindenkohl and South Toms Canyons off New Jersey. This 40-km x 35-km area was chosen for study because it lies within the area of high interest for petroleum development (Lease sales 49 and 59), and because it includes several wells which provide stratigraphic control. This report discusses the results of geologic mapping, using seismic-reflection data acquired in 1978 and 1979. Some initial results from more recently acquired data are included.

The Continental Slope in the study area has a complex surface with ridges, canyons, and valleys. Three slump or slide features were observed in the heads and on the walls of canyons and valleys, and two slides were identified on an intercanyon area. The identified slumps or slides are found in Quaternary sediments and total about 1.3 percent of the Continental Slope area mapped.

The slope is generally mantled by less than 2 m of Holocene sediments. Pleistocene sediment (primarily silty clay) is about 450 m thick at the top of the slope and thins to nearly zero or is absent on much of the mid and lower slope, where sediments of Miocene to Eocene age are exposed. Ridges on the midslope (water depths of 800-1,500 m) and parts of the lower slope (1,500-2,150 m) result primarily from Pleistocene and older deposition. The intervening valleys show evidence of erosion along the deepest parts of their courses. Mid-range sidescan-sonar data show evidence that processes of bottom-current erosion and downcanyon transport of material may be active in the present day. However, major features of the sea floor appear to be unchanged since late-Pleistocene time.

CONCLUSIONS

1. We have identified five slump or slide deposits on the Continental Slope in this study area. These total about 1.3 percent of the Continental Slope area mapped. There are substantial amounts of material on the uppermost Continental Rise that may have originated from mass wasting of the adjacent Continental Slope, probably during Pleistocene time.

2. Hazards of slope failure (slumping, sliding, or creep) are probably limited to areas with substantial thicknesses of Quaternary sediment. There are large areas of the lower slope where Quaternary deposits are very thin or absent. These areas are probably stable.

3. Steep slopes (10^o to 25^o) are common on the Continental Slope along the sides of canyons and valleys. Slopes greater than 12^o total about 17 percent of the Continental Slope area mapped in this study.

4. Several faults below the Continental Slope were mapped, but they show no evidence of activity since pre-Pleistocene time. Although their seismic risk appears to be minimal, they may represent constraints for drilling operations.

5. The general scarcity of slump or slide deposits on this portion of the Continental Slope implies either: a) that slump or slide features are too small, or thin, to be detected by our present seismic methods; or b) if slumping is widespread, that a nearly concurrent process, possibly turbidity currents, removes and redistributes material quickly after failure. The frequency of occurrence of small-scale slope failure in the present day and the effect downcanyon of such possible failure remains to be established.

6. Questions for engineering purposes of the stability of the Continental Slope will have to be addressed on a site-specific basis with a knowledge of the general area using high-resolution tools of acoustic profiling (probably deep-towed systems) and geotechnical testing of carefully located samples.

BACKGROUND OF STUDY

Slumping of the sediments on the Continental Slope off the Mid-Atlantic United States has been identified by Rona and Clay (1967), Uchupi (1967), Rona (1969), and more recently by Embley and Jacobi (1977), McGregor and Bennett (1977), Knebel and Carson (1979), MacIlvaine and Ross (1979), and others. The reported slump features were located by seismic profiling and range in area from about 2,000 km^2 (Embley and Jacobi, 1977) to perhaps 3 km^2 (estimated from data of Knebel and Carson, 1979).

The distance from shore and the deep water of the Continental Slope have limited the detail of previous fine-scale bathymetric and geologic mapping of the area. Little is known of the nature of the Continental Slope that can be applied with confidence to analyses of geologic hazards or to engineering design in specific terms. In spite of their number, the reported studies are largely topical, and there has been no detailed mapping of an entire slope segment so that such studies can be placed in an areal perspective. In 1978 and 1979, the U.S. Geological Survey (USGS) in cooperation with the U.S. Bureau of Land Management (BLM) collected detailed bathymetric and subbottom seismic-reflection data between Lindenkohl and South Toms Canyons on the Continental Slope off New Jersey (fig. 1). The segment of Continental Slope mapped for this study was chosen because it lies within the area of high interest for petroleum development (Lease Sales 49 and 59) (fig. 1), and because it includes several wells that provide stratigraphic information.

The goals of our program are to determine the sizes and areal distribution of slumps or slides or features of instability on the Mid-Atlantic Continental Slope, to determine the age of any such features, and to identify any peculiarities or particulars of their occurrence that will allow prediction of future slope failures. Copies of the seismic-reflection data used for this study are available from the National Geophysical and Solar-Terrestrial Data Center, Boulder, Colorado, 80303 (Robb, 1980a, 1980b). An initial interpretation of the seismic-reflection data dealt with in this report was discussed by Robb and others (1981a).

METHODS

More than 2,250 km of seismic-reflection profiling (40 cubic-inch airgun, 800 J sparker, and 3.5 kHz echo sounder) was completed in 1978 and 1979 aboard the R.V. COLUMBUS ISELIN (cruise CI 7807-1) and R.V. JAMES M. GILLISS (cruise GS 7903-4). The data cover a 40- x 35-km area with a 900- x 1,700-m grid (fig. 2; tracklines are also shown on plate 1). We also acquired 97-kHz sidescan-sonar images over 22 km of trackline and deep-towed hydrophone profiles (Robb and others, 1981c) over 60 km of ship track. Prime navigation for both cruises was Loran-C. Satellite fixes and checks of water depths and subbottom structures at trackline crossing points indicate that positions are generally accurate to 200 m or better. Long-range sidescan-sonar data (GLORIA) acquired by the USGS in cooperation with the Institute of Oceanographic Sciences (IOS), United Kingdom, in October 1979, provided an overall view of this study area as it compares with other parts of the Continental Slope between Baltimore Canyon and Hudson Canyon.

Partial analysis of 550 km of mid-range sidescan sonar acquired by the USGS in cooperation with the BLM and the Lamont-Doherty Geological Observatory of Columbia University (LDGO) in September 1980, has also contributed to this report.

A bathymetric map (fig. 3 and plate 1; Robb and others, 1981b) was contoured from 3.5-kHz soundings. Points were digitized from profiles at intervals of one-half minute or one minute of ship's travel (equivalent to about 60-m or 120-m distance). The wide-beam echo-sounder transducer used for this survey produces diffractions from canyon walls that obscure canyon floors (Krause, 1962); hence, canyons appear V-shaped in echo-sounding profiles. However, subsequent data from a deep-towed hydrophone (Robb and others, 1981c) and the mid-range sidescan-sonar data show that most canyon and valley floors are flat, a condition not represented on the map.

A geologic map (fig. 4 and plate 2) was constructed based on stratigraphy interpreted from seismic-reflection profiles. Paleontological dates from six wells and 20 piston cores within the area provided stratigraphic control. Isopachous and structural contour maps (figs. 9, 10) were made assuming a sound velocity of 1,676 m/s through Pleistocene deposits (Carlson, 1979).

RESULTS AND DISCUSSION

Bathymetry

The bathymetric map (fig. 3, plate 1; Robb and others, 1981b) shows the complexity of the surface of the Continental Slope in considerably greater detail than older bathymetric maps of this area. The Continental Shelf break occurs near the 130 m isobath. The Continental Slope extends down to the Continental Rise at depths near 2,150 m. Lindenkohl, Carteret, Berkeley, and South Toms Canyons are the major features on the Continental Slope. They show a sigmoid pattern as they bend left then right in their downslope trend from an initial southerly direction at the edge of the Continental Shelf. The surface of the upper Continental Slope between Lindenkohl and Carteret Canyons is smoother than the highly dissected area between Carteret and South Toms Canyons. Large numbers of small valleys or gullies are tributary to the submarine canyons on the upper Continental Slope. (To define terms for purposes of this report, canyons indent the edge of the Continental Shelf, whereas valleys do not; gullies are short valleys on steep slopes). The pattern of valley and canyon talwegs is not dendritic on the Continental Slope, although gullies may be dendritic in some areas around canyon heads. Deep-towed hydrophone and mid-range sidescan-sonar data show that the canyons and valleys are flat-floored in cross section, and that there appears to be an abrupt transition between floors and walls. The walls of the canyons and larger valleys are extensively gullied. Valleys begin and terminate at various places on the Continental Slope; they do not always lead into a larger valley or extend to the Continental Rise. For example, Berkeley Canyon terminates at a depth of about 1,900 m on the Continental Slope, whereas Lindenkohl Canyon extends to the base of the slope and continues seaward across the Continental Rise.

The overall declivity of the Continental Slope ranges from 4^o to 7^o. The average declivity varies from place to place, however. For example, the area between Lindenkohl Canyon and Carteret Canyon averages 7^o, while the Carteret to South Toms area averages 4^o to 5^o. The general slope angle becomes a relatively meaningless figure for engineering or stability purposes, however, because slopes on canyon or valley walls are commonly 25^o or 30^o, and vertical walls may be found at some places along canyon axes. Slopes determined at specific sites from this bathymetric map (plate 1) will be minimum values because the wide-angle echo-sounding equipment used shows only hyperbolic diffractions at many canyon walls (Krause, 1962).

Structure and Stratigraphy

Seismic profiles show strong, continuous, slightly seaward-dipping reflectors below the Continental Slope that are truncated and overlain by material having less continuous reflectors. A generalized cross section of the Continental Slope is shown in figure 5; typical airgun profiles are shown in figures 7 and 8. (Figure 6 shows the locations of profiles used for illustrations in this report. Note that illustrations used for this report are taken from seismic profiles and are vertically exaggerated. Note also that seismic-reflection profiles show subsurface structures as slightly distorted from their true attitudes because of sound velocity differences from water to sediment and within the sediments and rocks.)

Paleontologic ages from AMCOR 6021, ASP 13, ASP 14, and ASP 15 (Poag, 1979, 1980; Ruth Todd, personal commun., 1980) (locations on fig. 4 and plate 2) indicate that the surficial deposits which dip generally parallel to the present slope surface are Pleistocene in age. The unconformity at their base may be of early Pleistocene or of Pliocene age. It truncates Miocene deposits below the midslope (ASP 14 and ASP 15, Poag, 1979) and may truncate Pliocene deposits below the upper slope. Wash samples from the shallower parts of the COST B-3 well contain Pliocene foraminifera (C. W. Poag, oral commun., 1980). A stratigraphically similar unconformity to the southwest, near Wilmington Canyon, was inferred to be of Pliocene age by McGregor and Bennett (1977).

The Tertiary sedimentary rocks, Eocene, Oligocene, Miocene, and Pliocene, which make up the bulk of the material underlying the Continental Slope in this area (Poag, 1979), are nearly flat lying and slightly seaward dipping (Grow and others, 1979). A delta-front sequence of channeled and crossbedded sediments exists within the mid-Miocene (Poag, 1979), that should not be confused in seismic outcrop with slump or slide deposits (figs. 5, 7). A zone of faulting is observed within the Tertiary sediments of the lower slope which does not appear to extend through the pre-Pleistocene unconformity (fig. 4, plate 2); hence these faults probably do not constitute a present-day hazard. The faults displacing Tertiary rocks trend northeast. An older fault set is observed within the Cretaceous and lowermost Eocene sequences which appears to trend northwest.

Samples from piston cores show that Holocene (post-Pleistocene) sediments are very thin on the bottom surface, generally not more than

2 m thick. Resolution of our seismic profiles (>10 m) is generally inadequate to distinguish them. Most samples from the piston cores in the area, which average 6 m in penetration, contain foraminiferal faunas of Pleistocene age (C. W. Poag, written commun., 1979)

The Pleistocene sediments are about 450 m thick at the top of the Continental Slope and are distributed in lobate ridges that extend down over the midslope and parts of the lower slope (fig. 4). Figure 9, an isopach map, shows the variation in the thickness of the Pleistocene deposits on the upper Continental Slope. Depth contours on the pre-Pleistocene surface are shown in figure 10. The general conformity of contour lines of the pre-Pleistocene and present surfaces suggests that the Pleistocene sediments were deposited over a slope terrain somewhat similar to that of the present.

Profile 37 (fig. 11), along the upper Continental Slope, shows Pleistocene sediments at the surface which generally have reflectors conformable to the present sea bottom. Below the Pleistocene sediments are the nearly flat-lying, much more continuous horizons of Pliocene and older rocks. Filled valleys and crossbedding are visible within the Miocene, but in comparison, the Pleistocene deposits show a much greater degree of complexity from localized depositional and erosional processes. When investigated in detail, using a deep-towed hydrophone, the Pleistocene deposits are shown to be largely conformably deposited (figs. 12, 13).

Pleistocene strata are truncated in the heads of canyons and over parts of their outcrop area on the upper slope and midslope. Areas of truncated strata can be recognized on mid-range sidescan-sonar data as well as on seismic-reflection profiles. The truncations are not visible from research submersible except in a few places within canyon heads, however. At intercanyon dive sites the sea floor consists of undisturbed, fine-grained Holocene sediment (R. A. Slater, written commun., 1980). Clay beds have been observed from research submersible in the heads of Carteret Canyon and South Toms Canyon which dip at the same angle (approximately 35^{o}) as the canyon wall (R. Slater, written commun., 1980). Slater infers that the clay is late Pleistocene in age and is draped over a surface which truncates middle- or early-Pleistocene deposits. Slater also reports small (1-2 m) scarps and blocks of clay which are probably the result of local slumping in the heads of Carteret and South Toms Canyons (water depths less than 360 m). Features of this size are too small for detection with conventional seismic-profiling systems.

On the upper slope, the walls of Lindenkohl, Berkeley, and South Toms Canyons show a history of early canyon erosion, subsequent filling, and recutting during Pleistocene time. These canyons are now slightly southwest of their former positions; old canyon fill forms their northeastern wall (left bank), whereas the right bank is cut into early Pleistocene sediments. Concordant reflectors show that Berkeley Canyon was maintained as a canyon during some interval of Pleistocene time while deposition occurred both in the canyon and on its left bank (fig. 14).

Intercanyon and intervalley ridges of Pleistocene sediments on the midslope and lower slope appear from their internal stratigraphy to be largely depositional features, rather than erosional forms. Although strata are truncated on the lower parts of valley and canyon walls the reflectors are mainly conformable with the topography (figs. 15, 16). In some places parallel strata are draped over the pre-Pleistocene unconformity (fig. 15); in other places strata are thicker over the highs and thin toward the lows (fig. 16). Some of the ridges resemble levees, thinning away from the major valleys or canyons (fig. 16). On the lower slope, the ridges were deposited over a nearly flat surface (fig. 17).

Profile 92 (fig. 17), across the lower slope, shows that several valleys between Lindenkohl and Carteret Canyons are clearly eroded into nearly flat-lying rocks which were determined at Deep Sea Drilling Project (DSDP) site 108 (Hollister and others, 1972) to be of Eocene age. These valleys are part of a pre-Pleistocene surface because they can be traced below the accumulation of sediments on the upper Continental Rise at the foot of the slope.

A sample from DSDP hole 107 in this sediment accumulation on the upper Continental Rise contained "displaced Pleistocene foraminifera" from a sublittoral environment (Hollister and others, 1972). These sediments may have originated from valley heads on the upper Continental Slope, or they may be material which bypassed the slope, transported by density flow from the shelf edge. Figure 18 shows Pleistocene sediment on the upper Continental Rise unconformably overlying Eocene rocks.

Potential Geologic Hazards

A map showing features of the Continental Slope that indicates potentially hazardous conditions is included as plate 3. These features include observed slumps or slides, canyon or valley axes which may act as conduits for downslope currents or transport of failed debris, area of Quaternary sediment cover greater than 10 m thick, topographic slopes greater than 12^{o}, filled valleys which have been intersected by present-day canyons, faults, and a probable debris field at the mouth of South Toms Canyon.

Most of the observed slumps or slides are relatively small features, intersected by one or two profiles within our survey grid. They are identified as deposits of surficial material up to 60 m thick which can be linked with a probable scar area upslope. The largest probable slump feature found in this area lies in Berkeley Canyon (figs. 4, 19, 20; plates 2, 3). Here an old, filled, canyon intersects Berkeley Canyon and part of that fill appears to have failed. Slumped material occupies about 5 km^2. A small slide scar (fig. 21) was observed on the wall of a small valley on the upper slope near $31^{o}51'$N., $72^{o}51'$W. on mid-range sidescan-sonar data, (plates 2, 3).

In this study area, slope instability, slumping, sliding, and creep, as geologic hazards, appear to be limited to within deposits of Pleistocene sediments. In our seismic profiles we have not observed mass failure in slopes made up of Tertiary materials. However, some canyons have steep, possibly near-vertical walls in some places along their courses, and in those places there are probably hazards of slumping or failure of Tertiary outcrops. Dillon and Zimmerman (1970) and Ryan and others (1978), from research submarines, observed fresh, steep outcrops that may represent faces of slump scars deep in other east-coast submarine-canyon axes.

In general, we have been able to identify remarkably little slump or slide material on the Continental Slope within the study area. Slumping appears to have been restricted to the steeper slopes of canyon and valley walls, especially in the heads of canyons. Although a few deposits of rubble are identified on some valley or canyon floors, the floors are generally quite clean. The shallow subsurface strata on the slope are generally smooth and conformable with regular layering and, where eroded, are clearly truncated. If slope failure is occurring, it involves small amounts of material that are swept rapidly away and apparently do not usually accumulate in identifiable volume on valley floors. Our data show no evidence of displacement of large, coherent blocks.

Most studies of potential hazards in the offshore have used seismic profiles. With the primary data of this survey, a grid of seismic profiles having dimensions of 900 x 1,700 m, the statistical probability of intersecting a single, quarter-mile circular target (a hypothetical single slump or slide) is 0.64 (calculated by the methods of McCammon, 1977). Intersecting such a target with two lines has a lower probability, and the necessity to identify any target so intersected lowers the probability of discovery still more. Sidescan-sonar data can give more complete areal coverage, but subbottom profiles using seismic-reflection equipment are still required for valid interpretation of sonographs.

We are unable to identify areas of creep (slow movement of surficial material downslope) from the data used for this study. Strata identified as Pleistocene or older in age appear to be conformable and undisturbed or truncated on most surfaces within our resolution limit of about 10 m. However, slow downslope movement should not be discounted as an engineering consideration, particularly on the walls or floors of canyons or valleys.

Our recently acquired mid-range sidescan-sonar data indicate that small-scale processes of bottom-current erosion and downcanyon transportation are active at the present day. Specifically, blocky debris is observed to be scattered over the upper Continental Rise at the mouth of South Toms Canyon (fig. 22). This debris implies that occasional strong currents carry material downcanyon, which may create hazardous conditions. The debris has not been sampled, and its lithologic nature and origin is undetermined.

Slopes greater than 12^{o} are shown on plate 3 as an indication of areas of greatest risk of failure. A slope value of 12^{o} was chosen for this map because the strength-vs.-depth profile of many piston cores tested (average penetration 6 m) indicates that failure may occur on slopes greater than 12^{o} (Dorothy Marks, personal commun., 1980). Slopes are greater than 12^{o} in about 17 percent of this mapped area. Slopes less than 12^{o} may also fail depending on local conditions and triggering forces, however.

Places where present-day canyons intersect old, filled valleys may present increased risk of failure of truncated valley fill. Such a failure in Berkeley Canyon has been described above (figs. 19, 20).

Two sets of faults below the Continental Slope were identified in this survey (fig. 4; plates 2, 3). Neither appears to have been active since pre-Pleistocene; hence they do not appear to offer any seismic risk, although they might represent a constraint to drilling operations.

In summary, we infer from the data available to us that the Continental Slope in this area represents a surface essentially developed in late-Pleistocene time, which has been mantled by thin, fine-grained Holocene deposits, and that present processes of modification are active, but at undetermined rates. Within the general framework we present, hazards must be assessed at specific sites, considering the nature of the substratum, topographic setting (including gradient at site and conditions upslope), and carefully located geotechnical samples.

ACKNOWLEDGEMENTS

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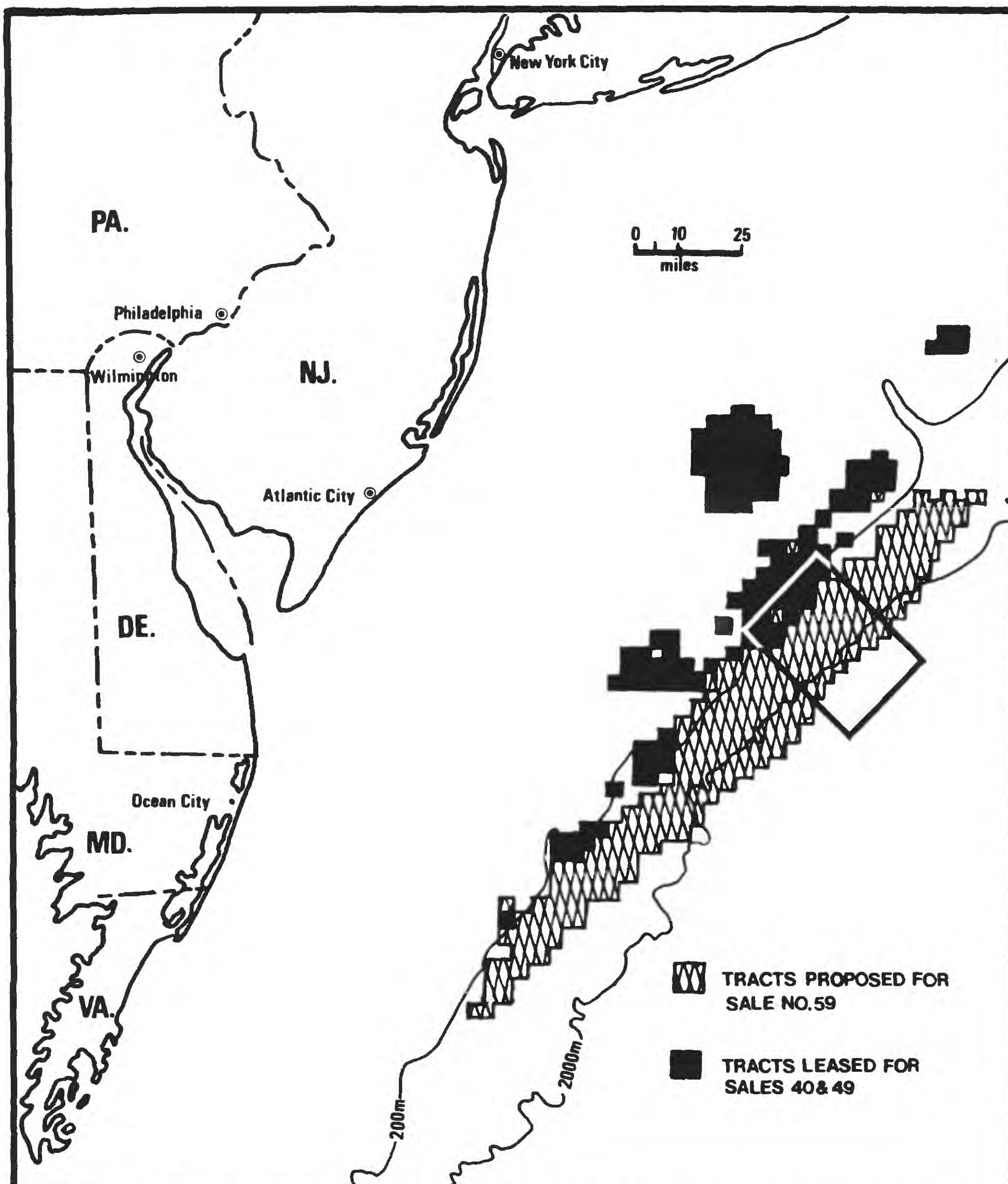

Figure 1. Map showing location of study area in relation to tracts leased or proposed for lease.

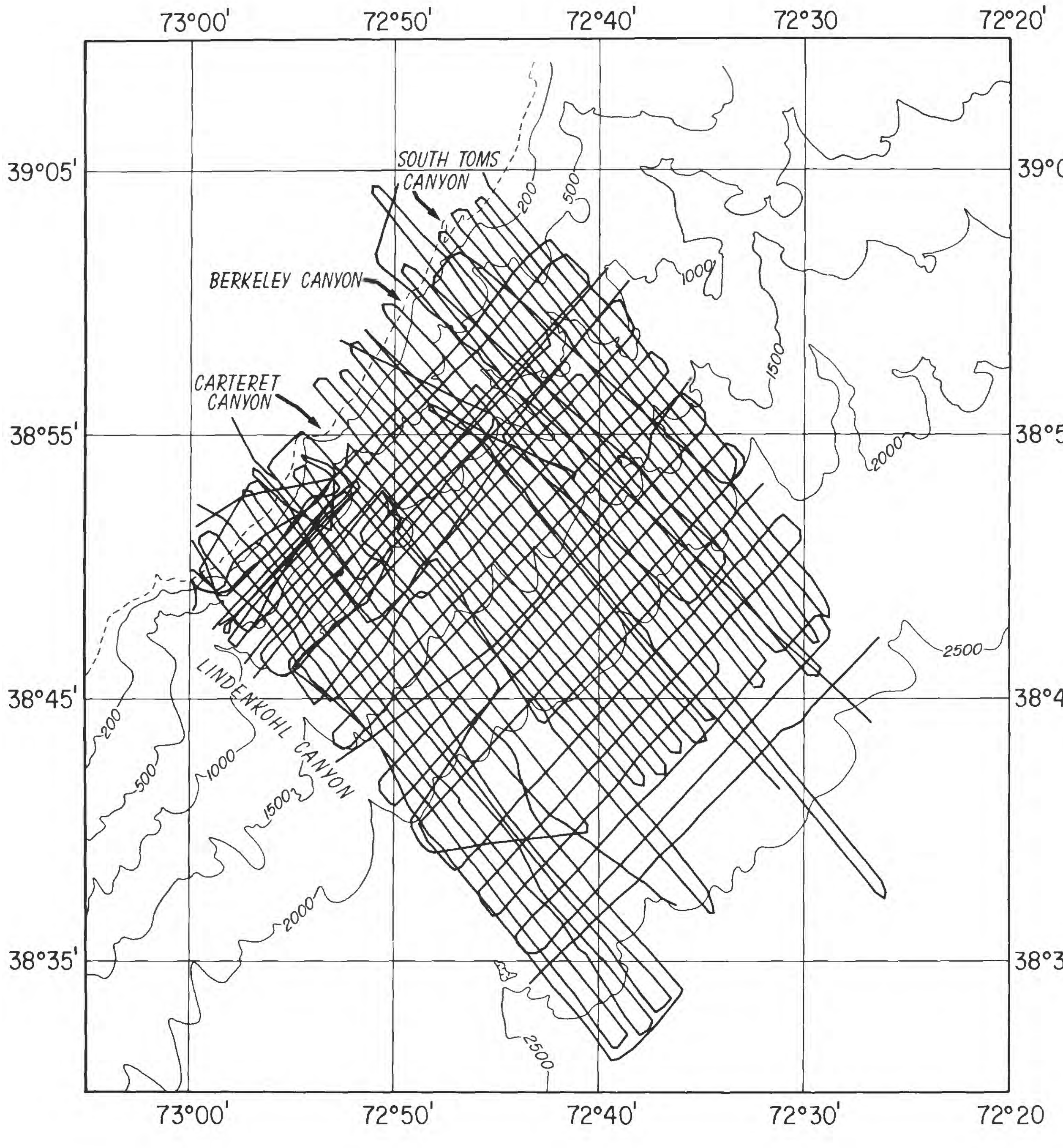

Figure 2. Track line locations of R.V. COLUMBUS ISELIN, 1978, and R.V. JAMES GILLISS, 1979.

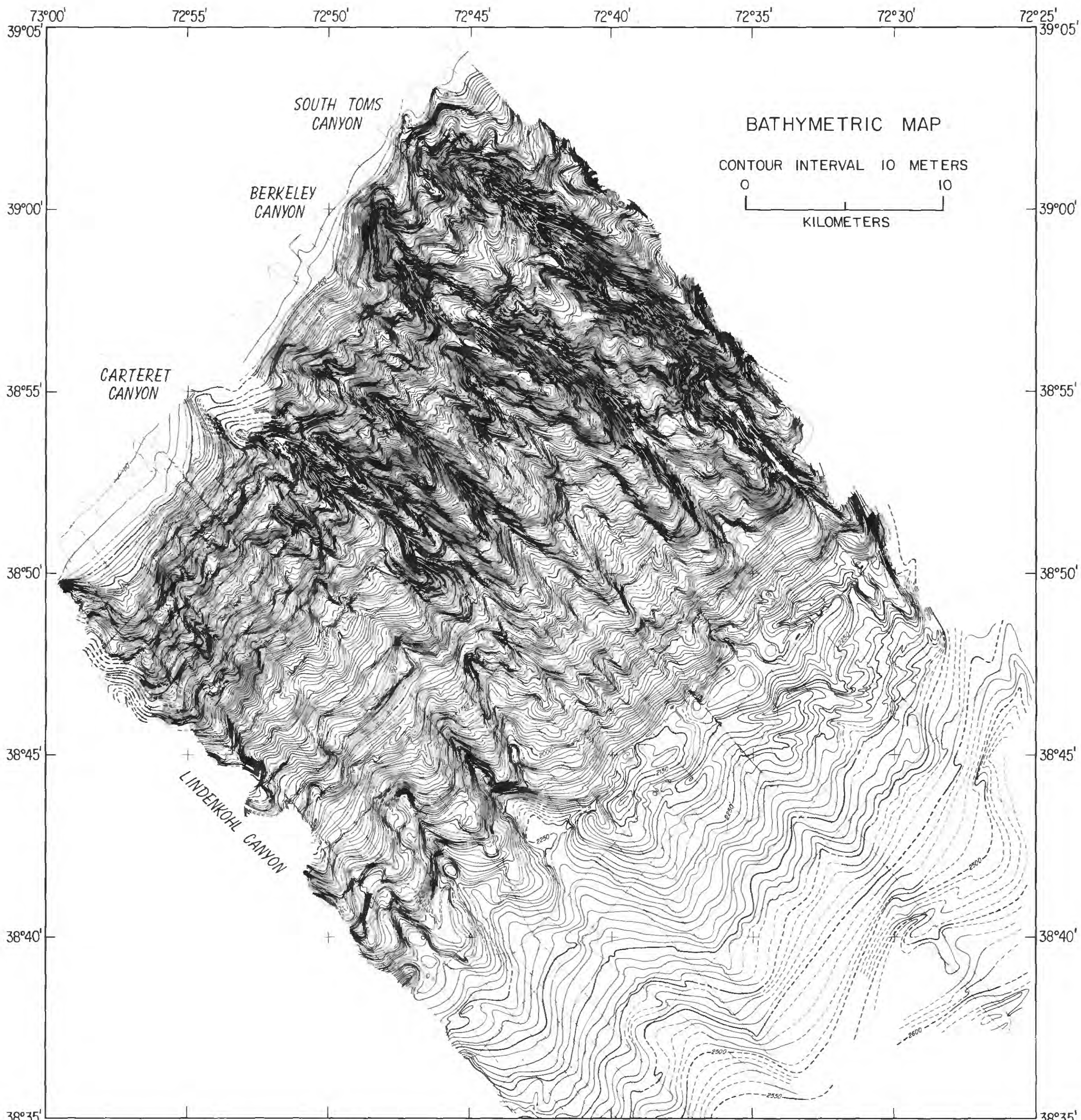

Figure 3. Bathymetric map of Continental Slope and uppermost Continental Rise. Contour interval 10 meters. See also plate 1.

A GEOLOGIC MAP OF THE CONTINENTAL SLOPE
BETWEEN LINDENKOHL AND SOUTH TOMS CANYONS

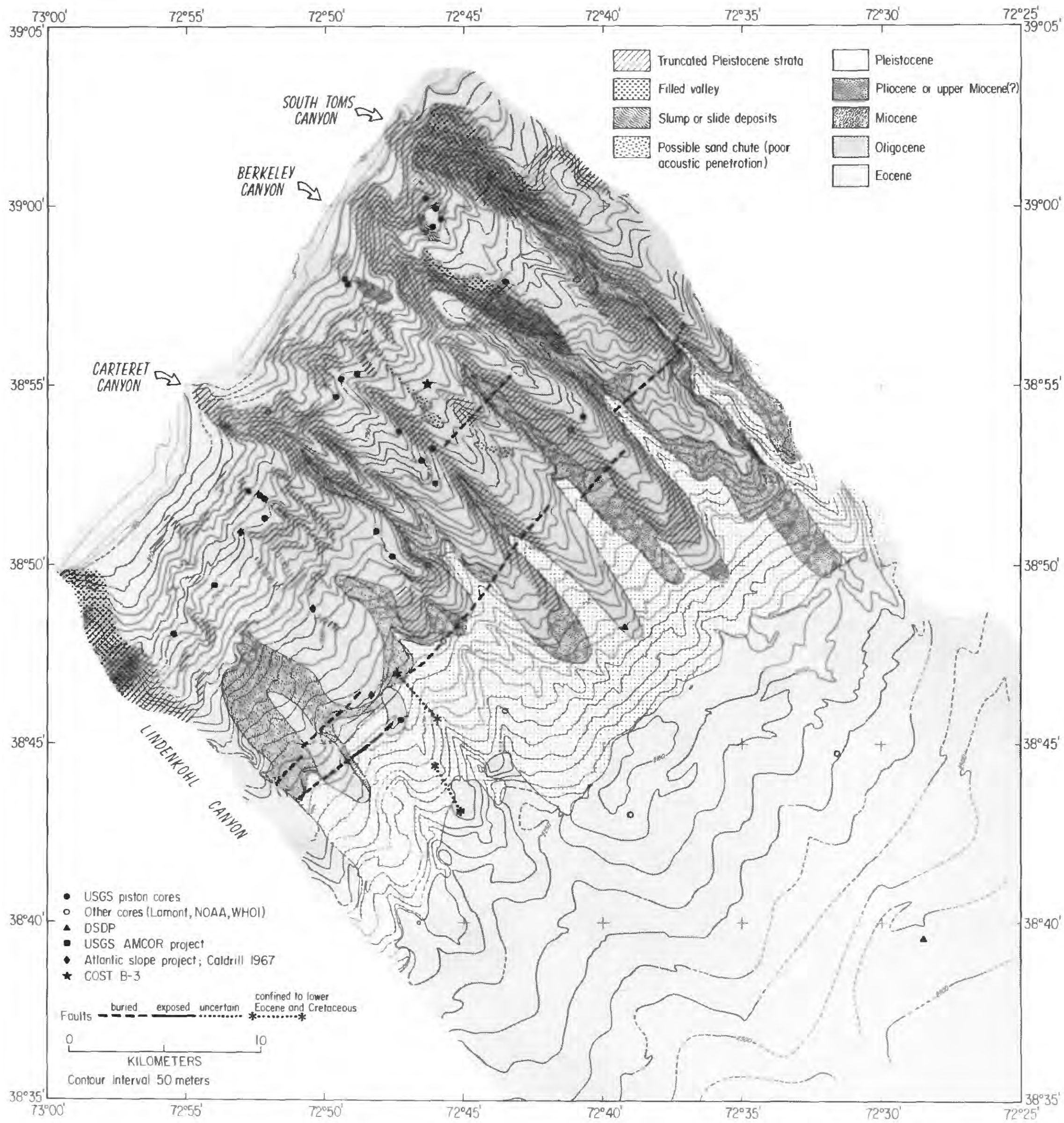

Figure 4. Geologic map of Continental Slope. See also plate 2.

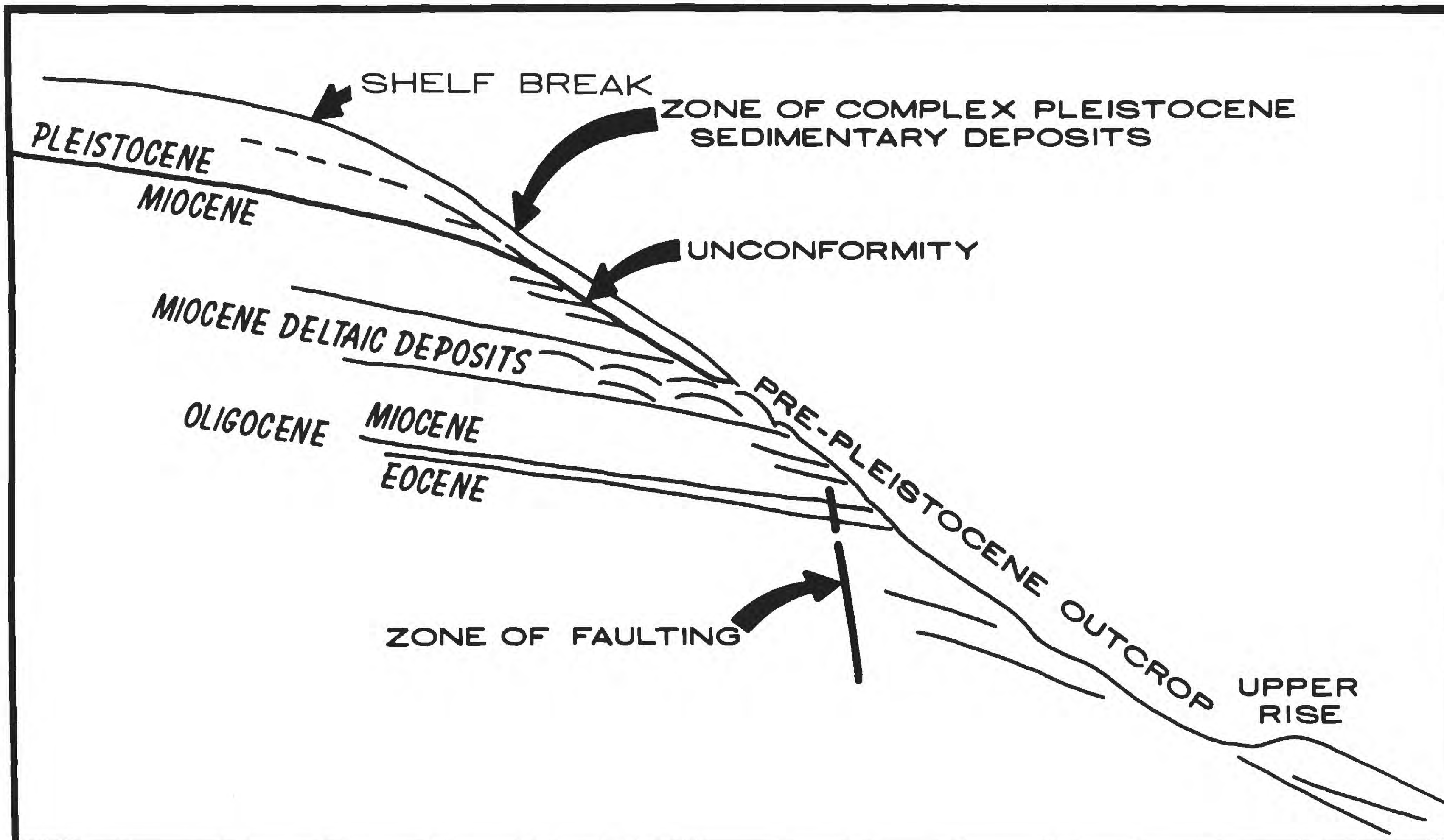

Figure 5. Generalized cross section of Continental Slope between Lindenkohl and South Toms Canyons.

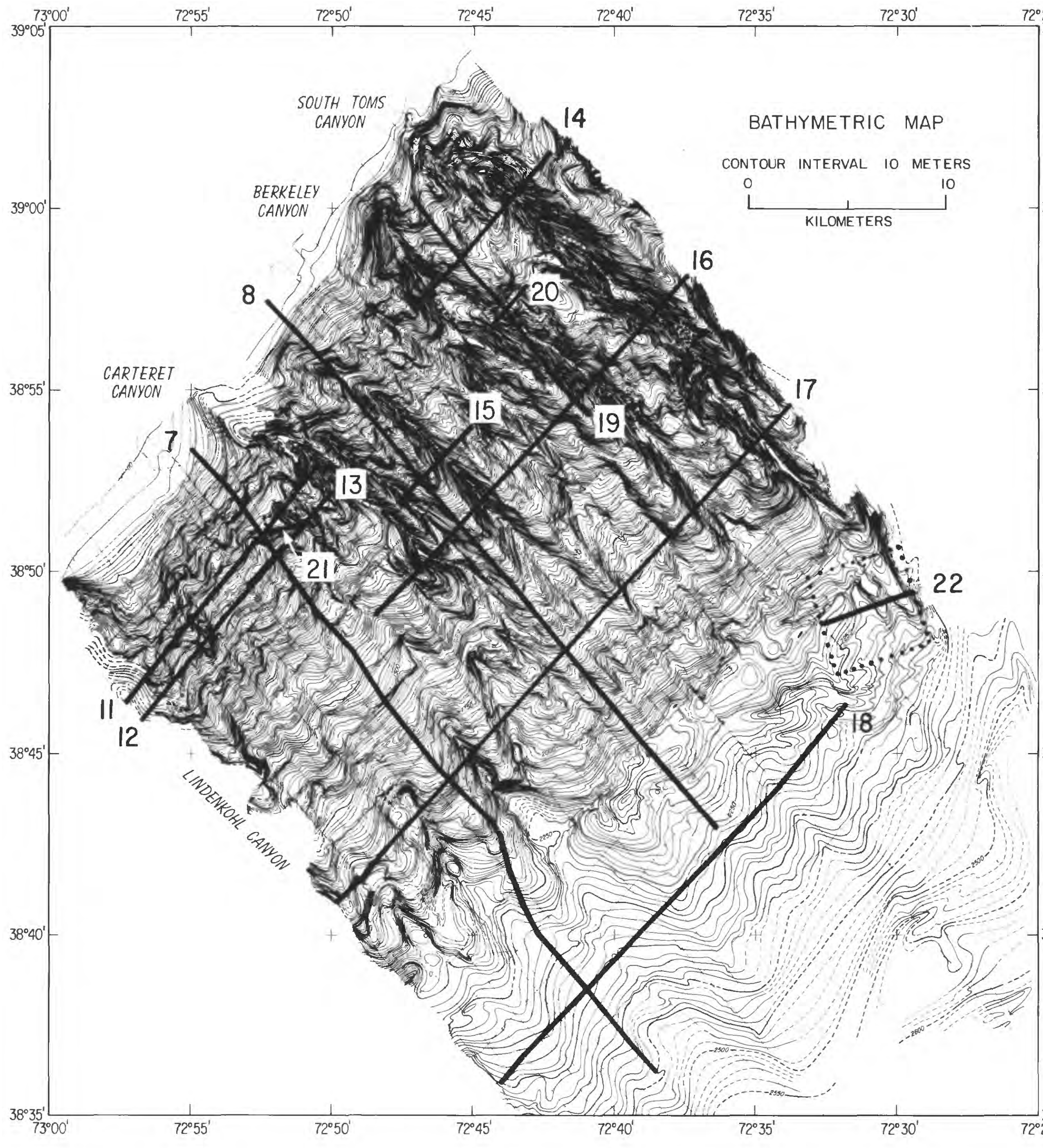

Figure 6. Locations of illustrated seismic-reflection profiles indicated by figure number.

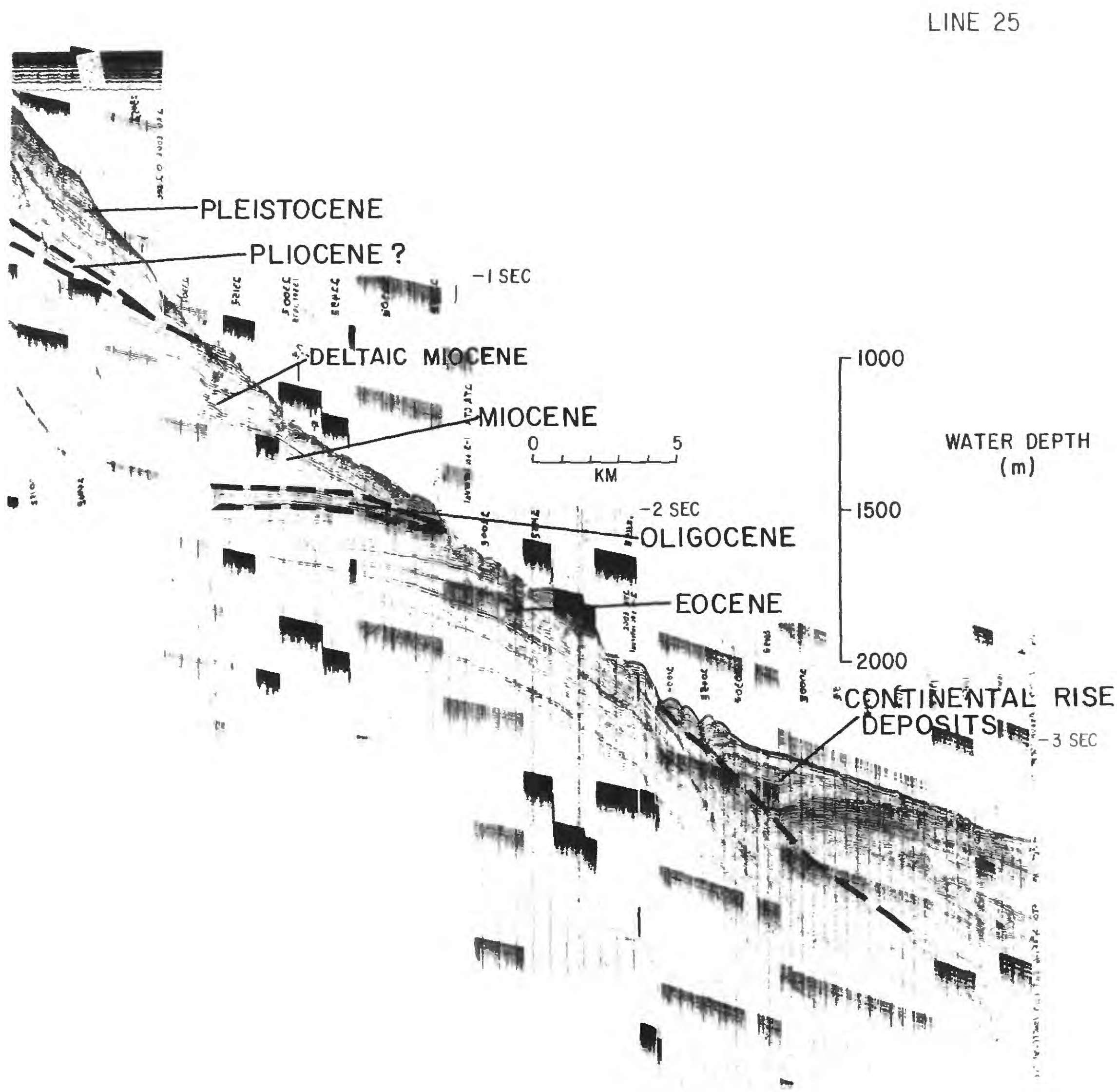

Figure 7. Airgun seismic-reflection profile (line 25) across Continental Slope. Vertical exaggeration 11 x. Location shown on figure 6.

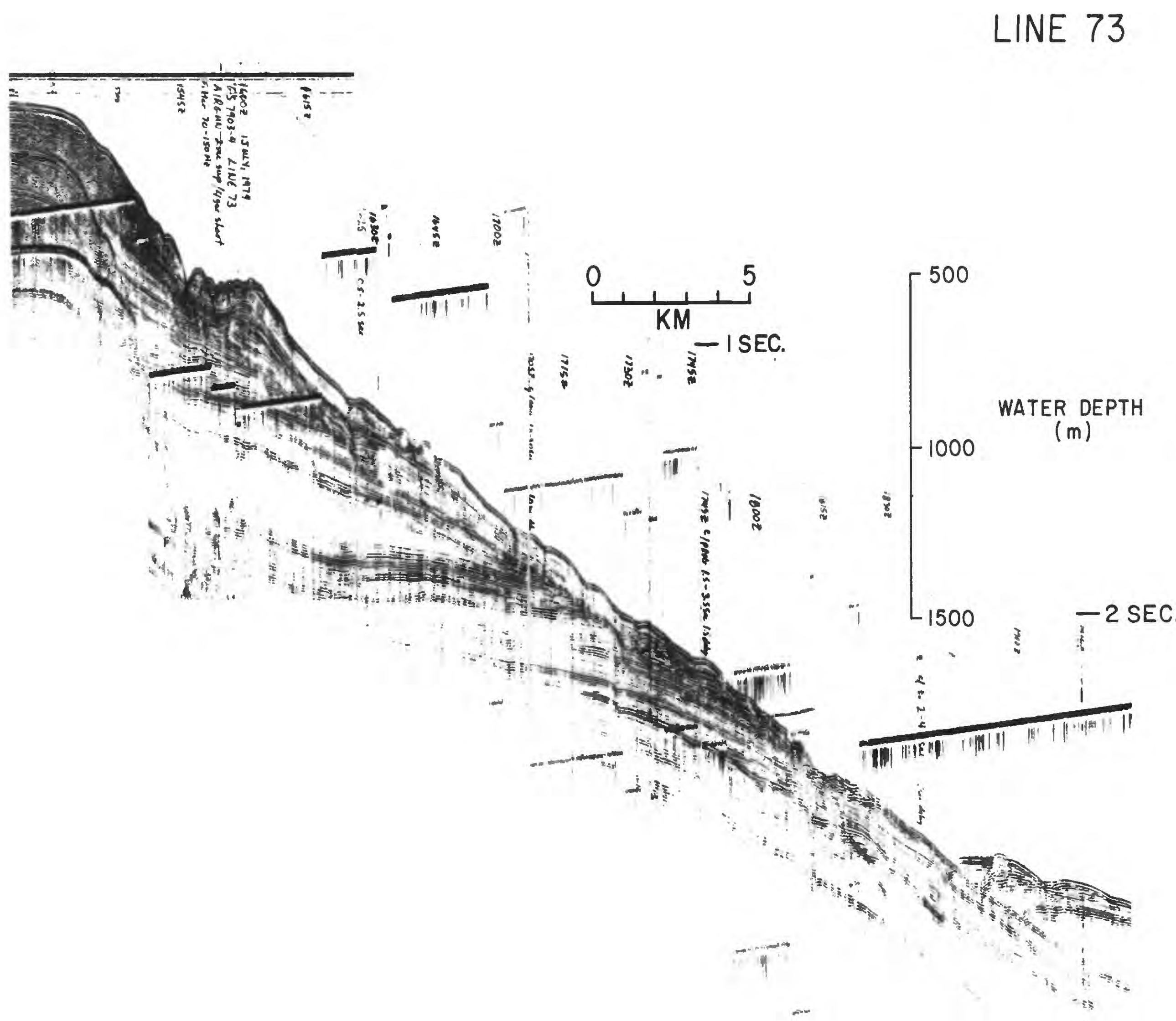

Figure 8. Airgun seismic-reflection profile across Continental Slope (line 73). Vertical exaggeration 12 x. Location shown on figure 6.

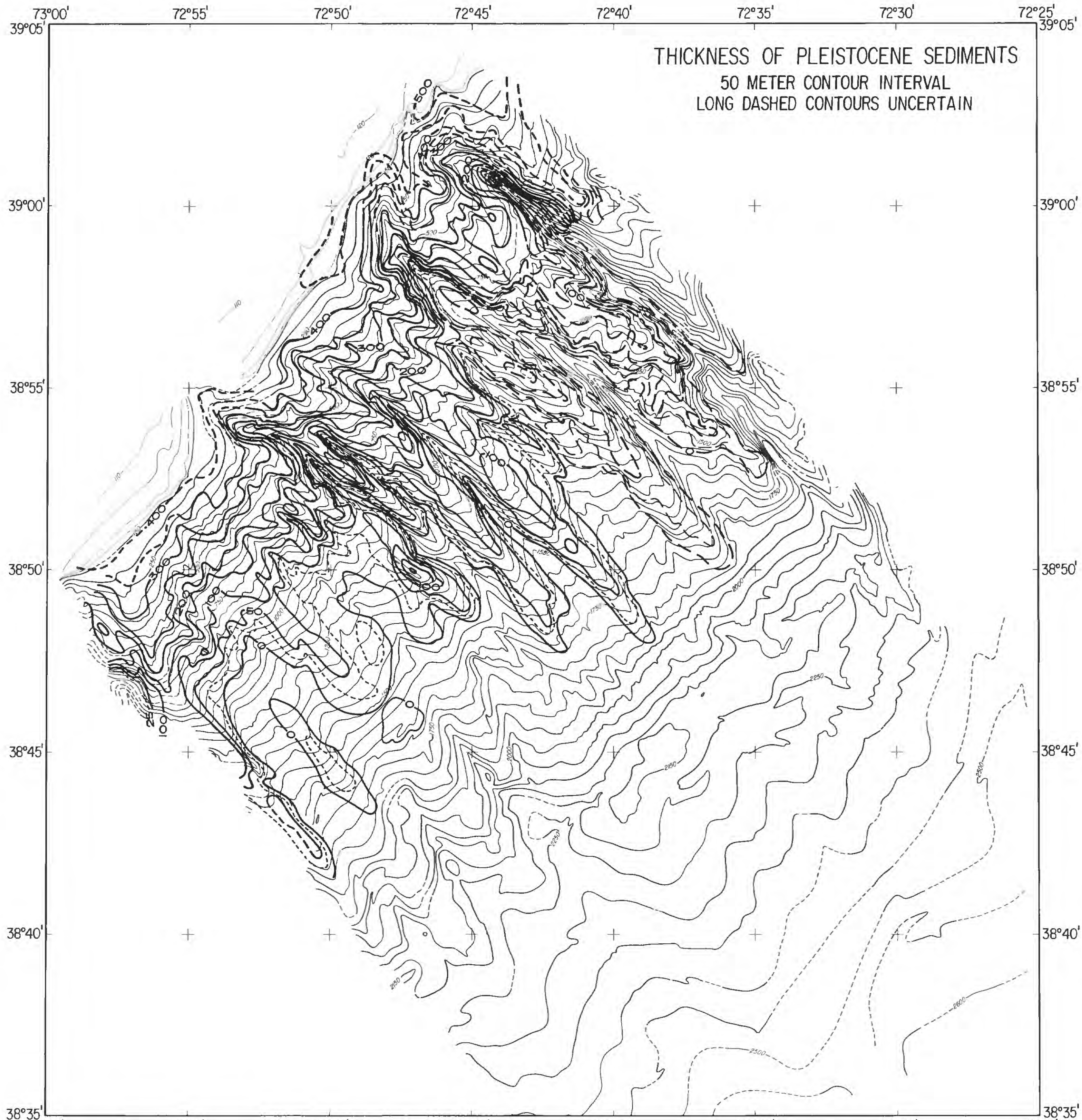

Figure 9. Thickness of Pleistocene sediments on Continental Slope. Contour interval 50 meters.

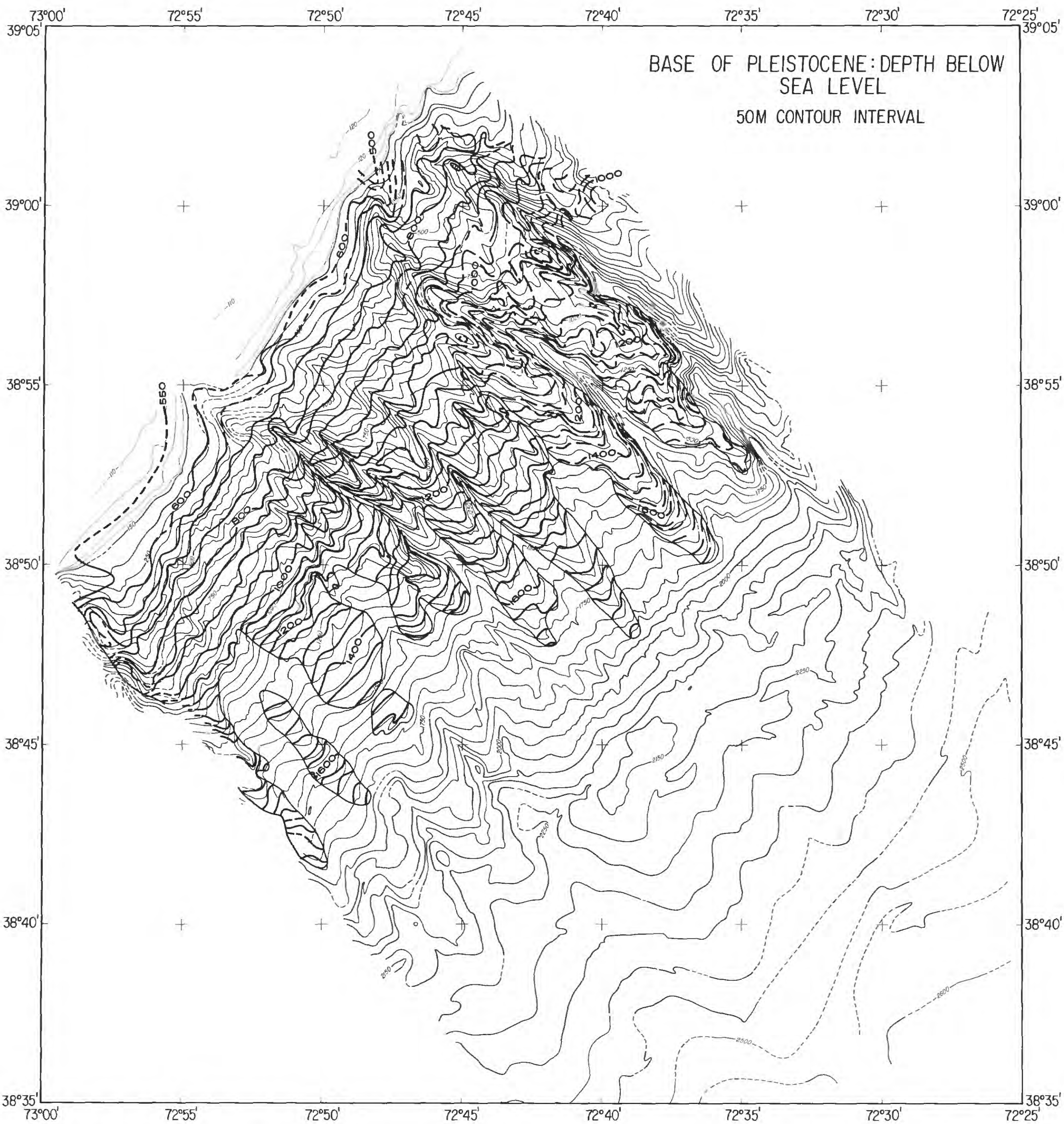

Figure 10. Depth below sea level of pre-Pleistocene unconformity. Contour interval 50 meters.

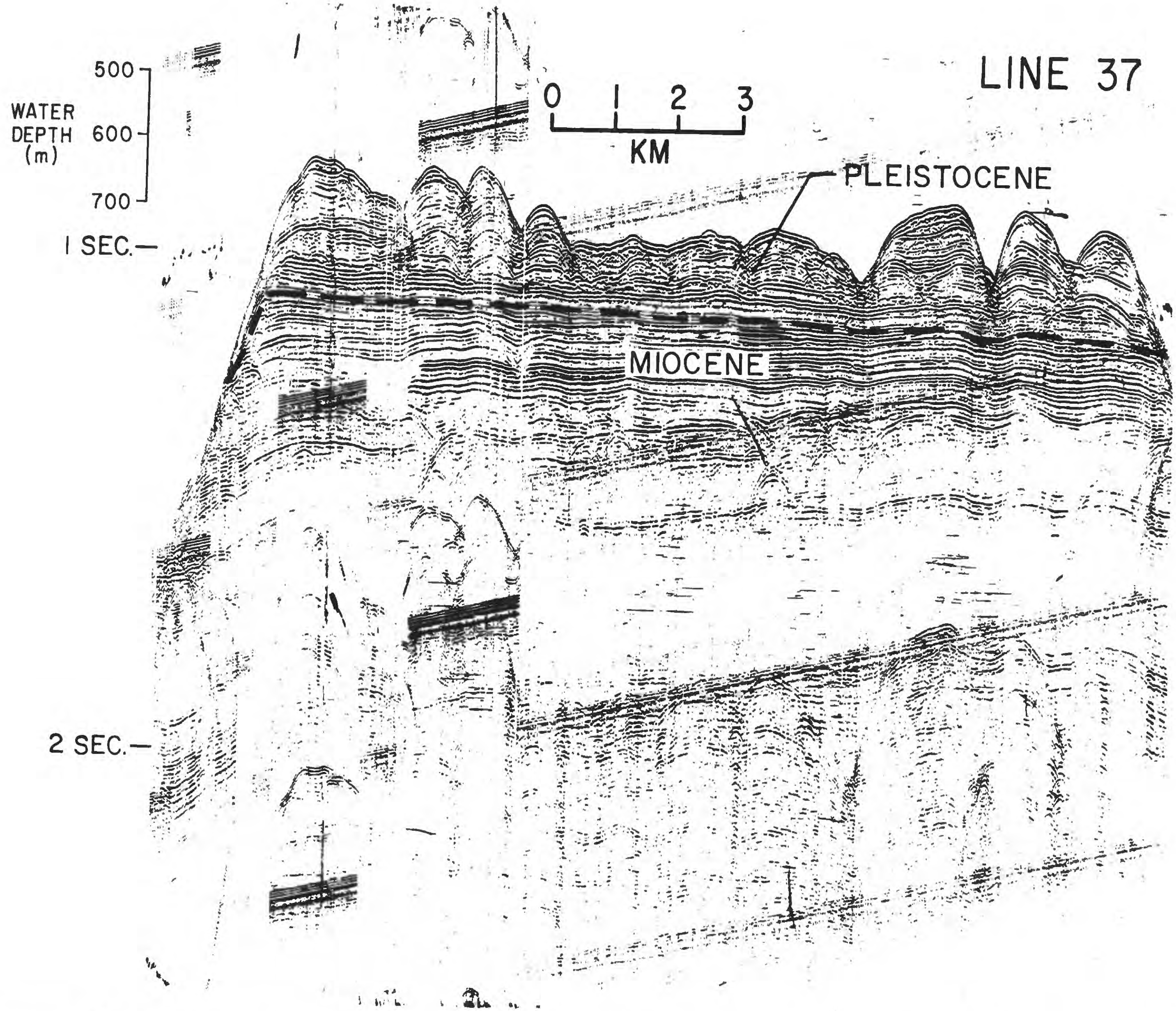

Figure 11. Airgun seismic-reflection profile along Continental Slope (line 37). Vertical exaggeration 10 x. Northeast to right. Location shown on figure 6.

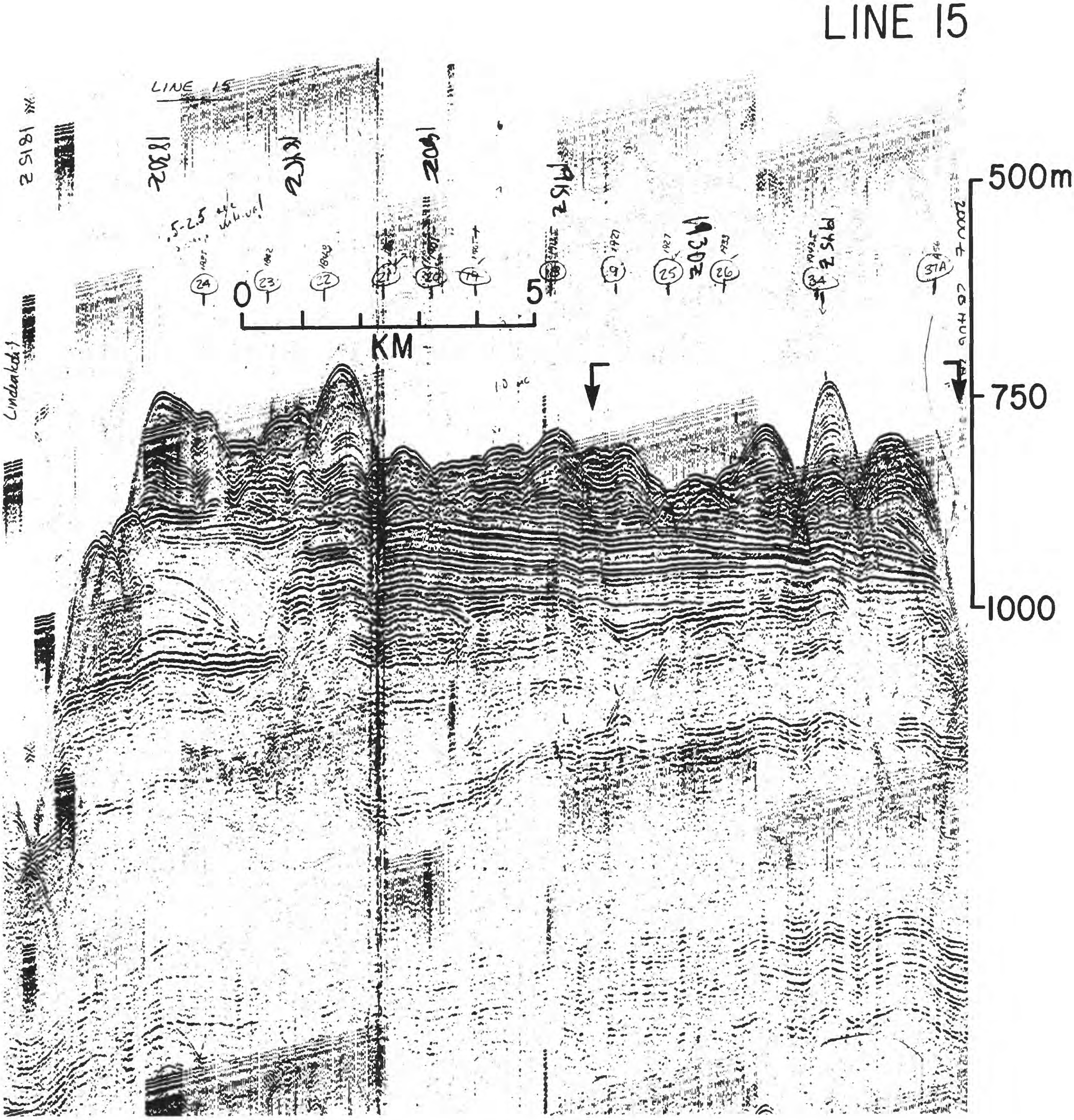

Figure 12. Airgun seismic-reflection profile (line 15) across upper Continental Slope between Lindenkohl and Carteret Canyons. Location shown on figure 6. Northeast (Carteret Canyon) to right. Vertical exaggeration 15 x. Compare record between arrows ("chaotic" Pleistocene in upper 75 to 100 m) to figure 13 which shows greater resolution.

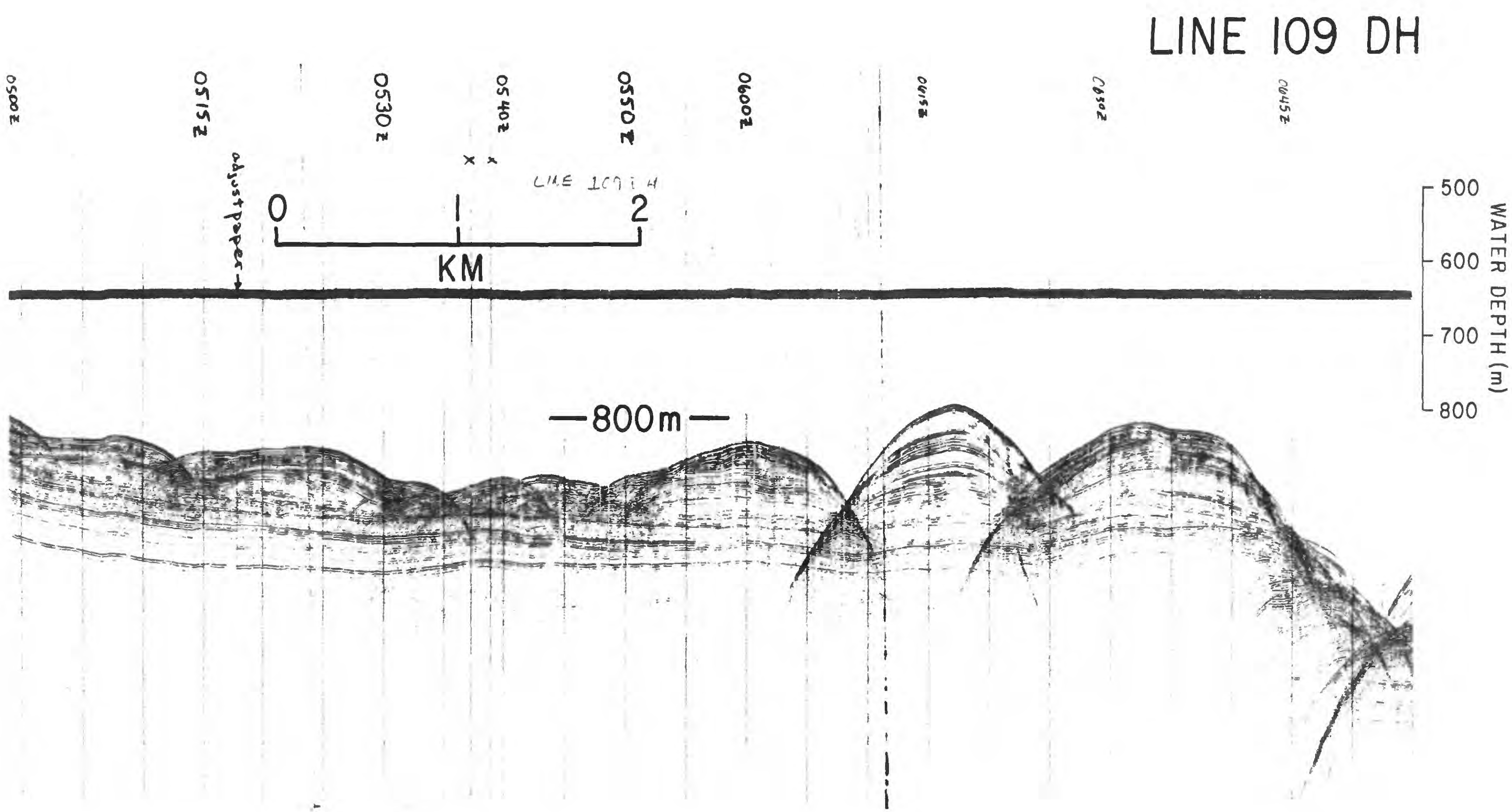

Figure 13. Sparker profile using deep-towed hydrophone across part of upper Continental Slope (line 109 DH). Location shown on figure 6. Vertical exaggeration 5 x. This record coincides with the area between arrows on figure 12. This deep-towed hydrophone record shows higher resolution and lower vertical exaggeration.

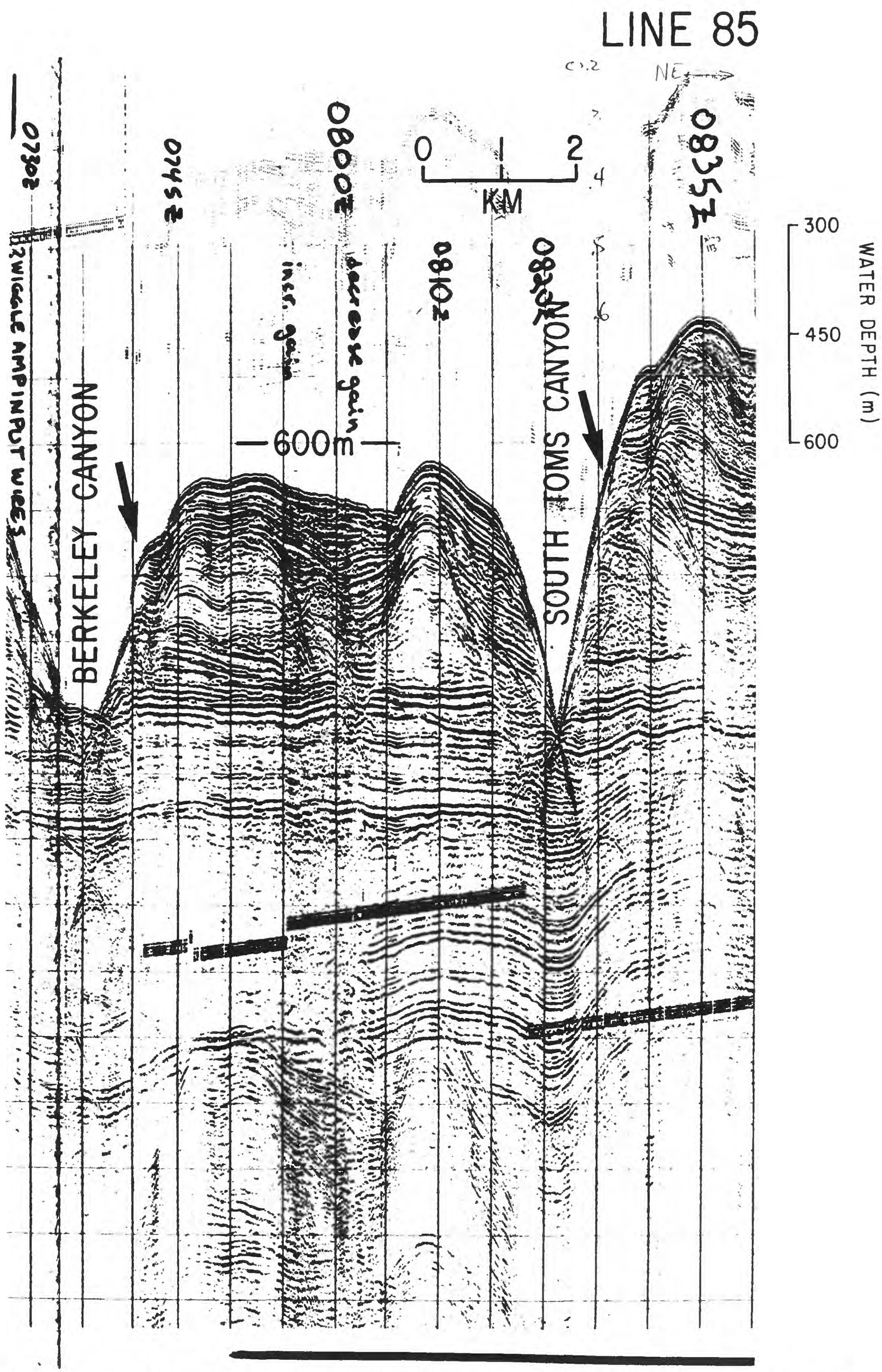

Figure 14. Airgun seismic-reflection profile (line 85) across upper parts of Berkeley and South Toms Canyons showing truncated fill of older canyons on northeast walls. Vertical exaggeration 12 x. Location shown on figure 6.

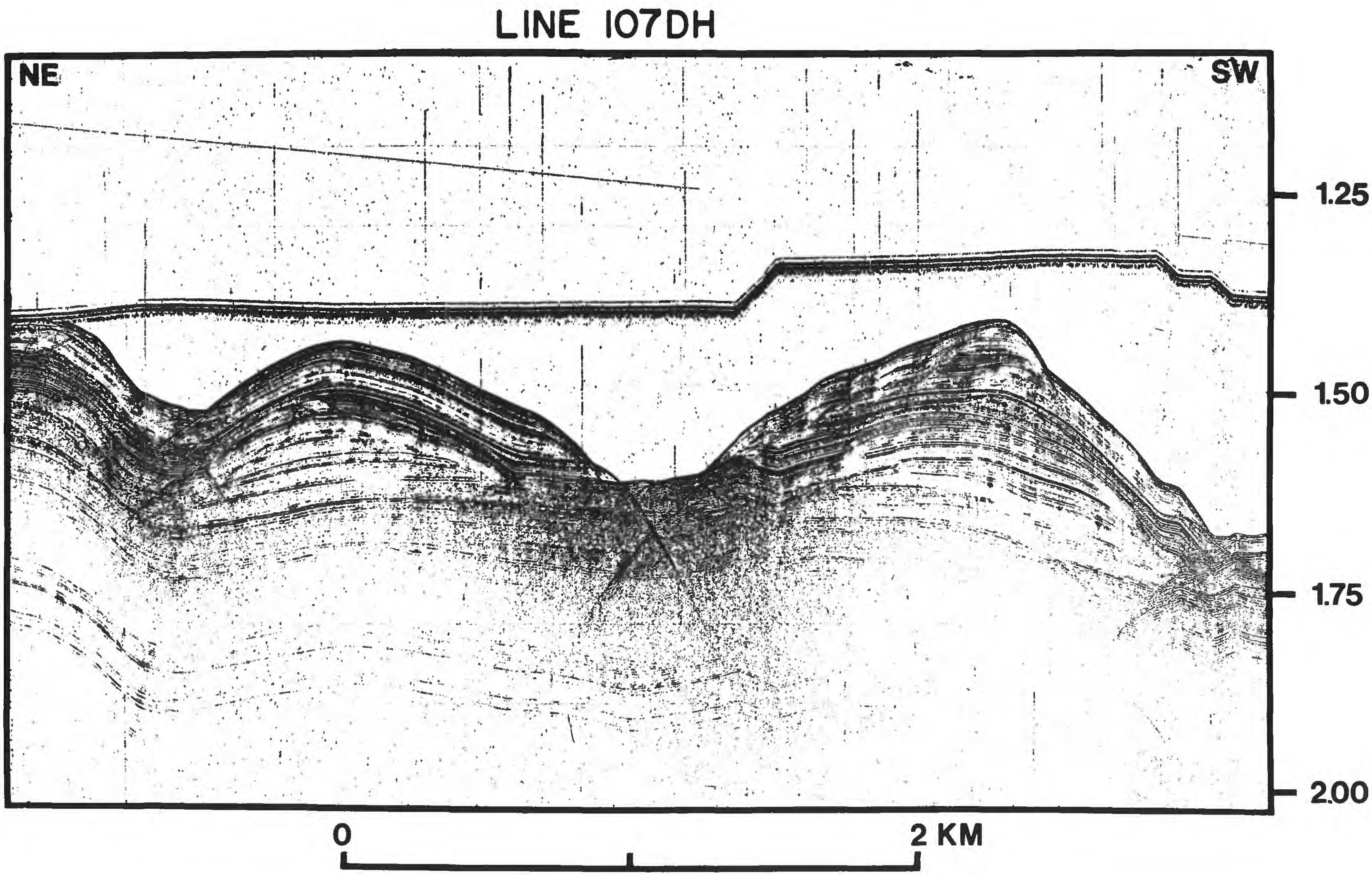

Figure 15. Sparker profile using deep-towed hydrophone along part of Continental Slope (line 107 DH). Vertical exaggeration 4 x. Location shown on figure 6. Hydrophone towed at depth using sparker sound source at surface provides higher resolution than surface-towed hydrophones achieve.

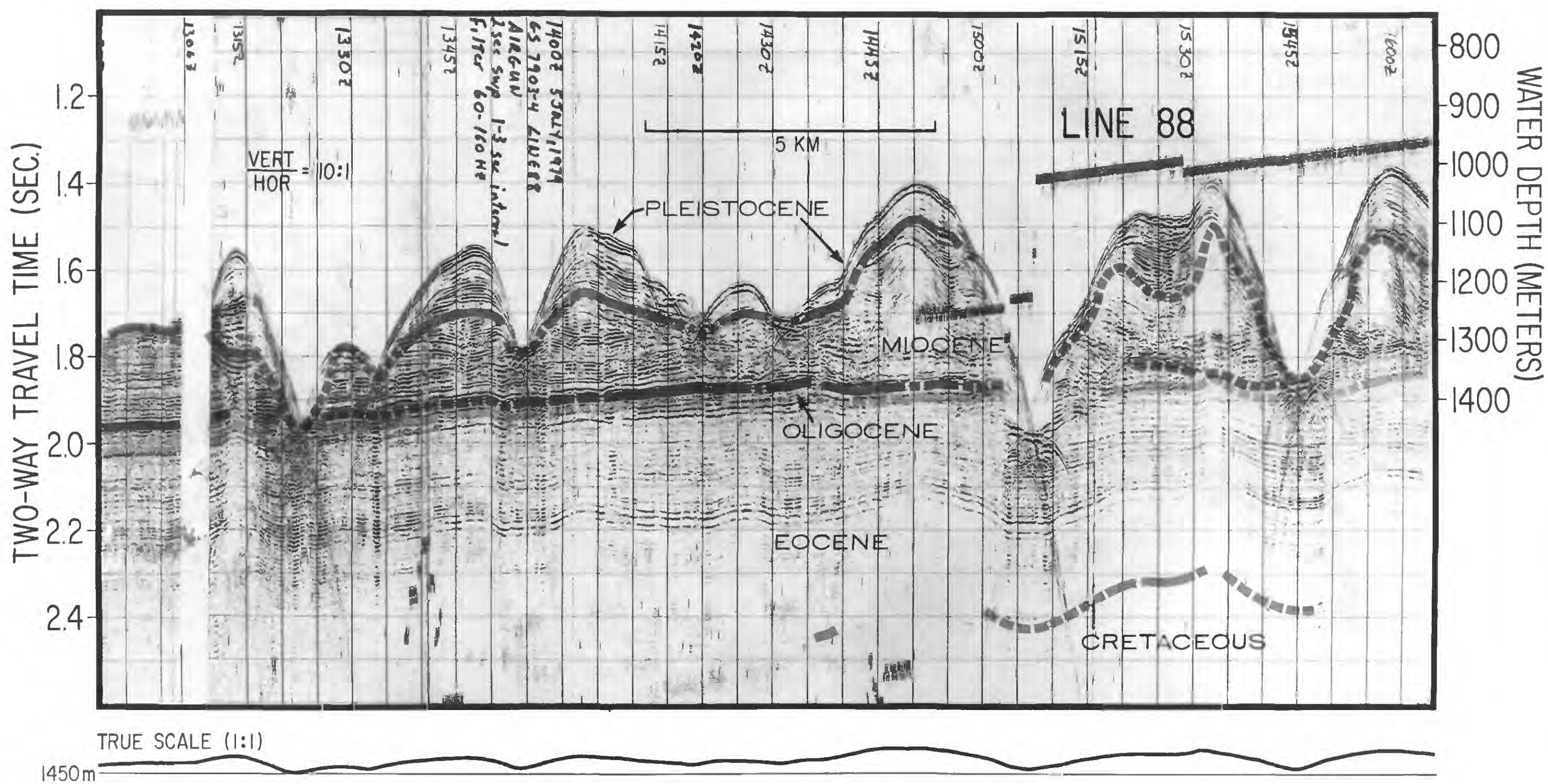

Figure 16. Airgun seismic-reflection profile (line 88) across part of lower Continental Slope. Vertical exaggeration 10 x. Location shown in figure 6.

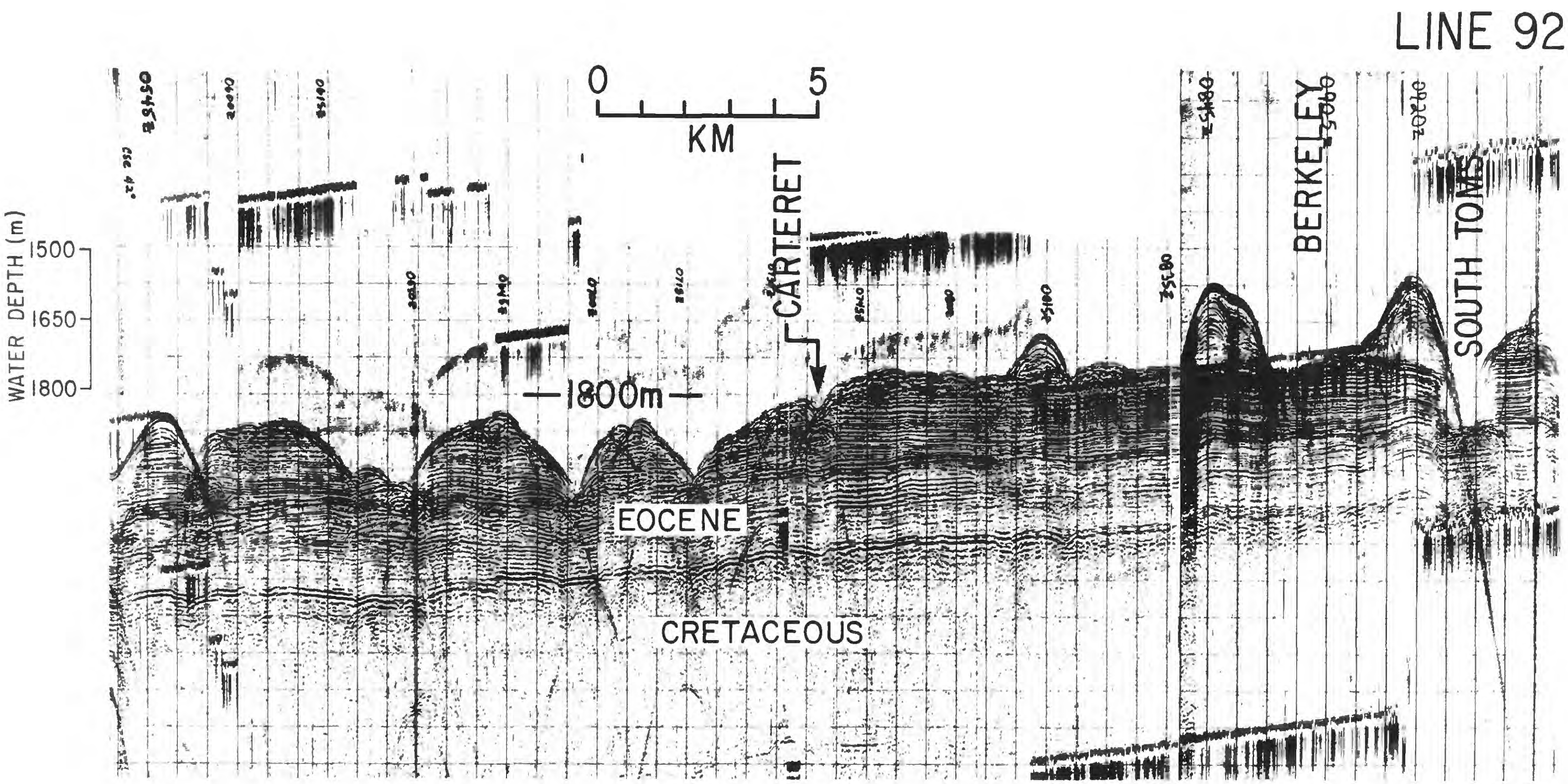

Figure 17. Airgun seismic-reflection profile along Continental Slope (line 92). Vertical exaggeration 11 x. Location shown on figure 6. Northeast is to the right.

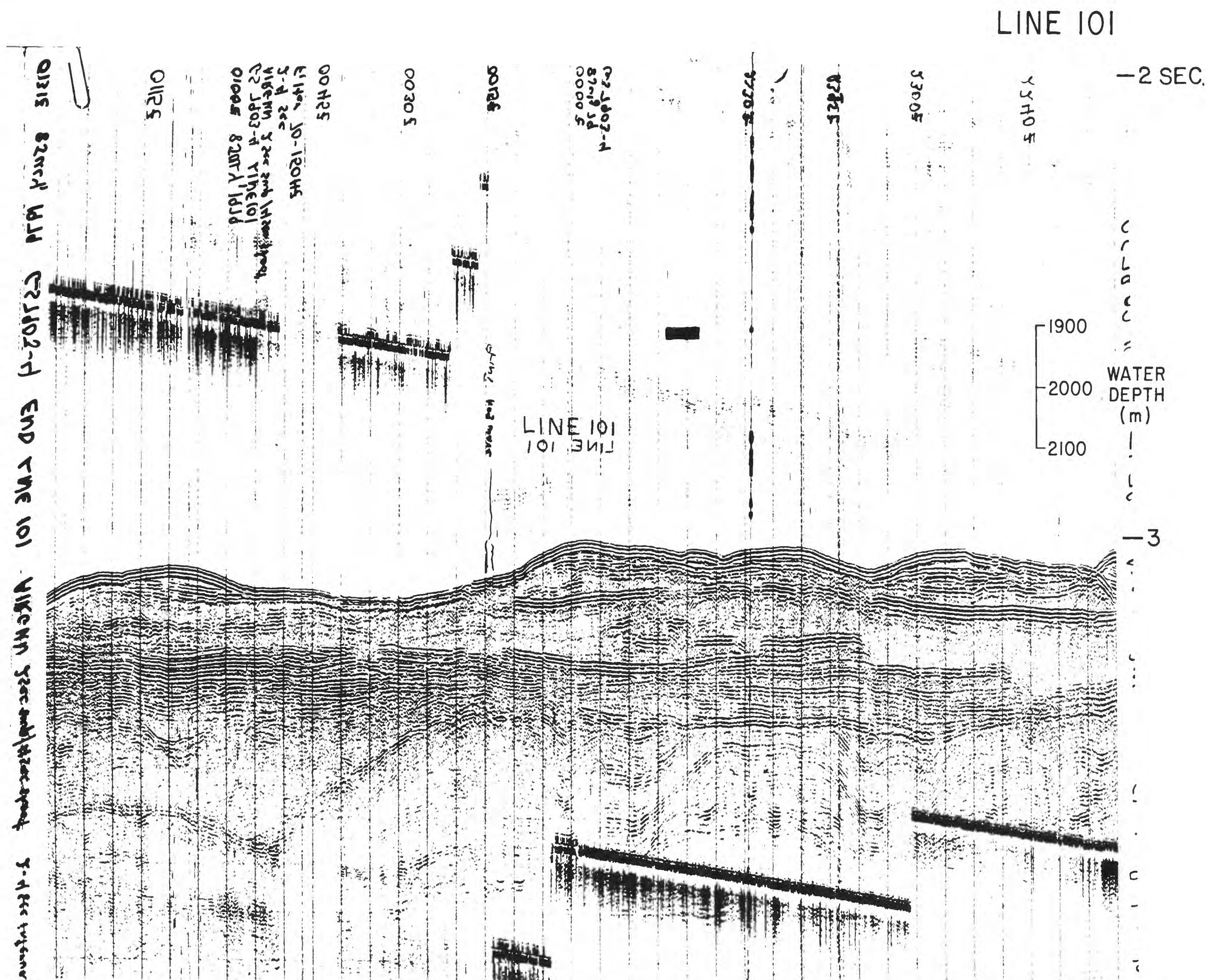

Figure 18. Airgun seismic-reflection profile (line 101) across upper Continental Rise. Vertical exaggeration 15 x. Location shown on figure 6. Northeast is to the right.

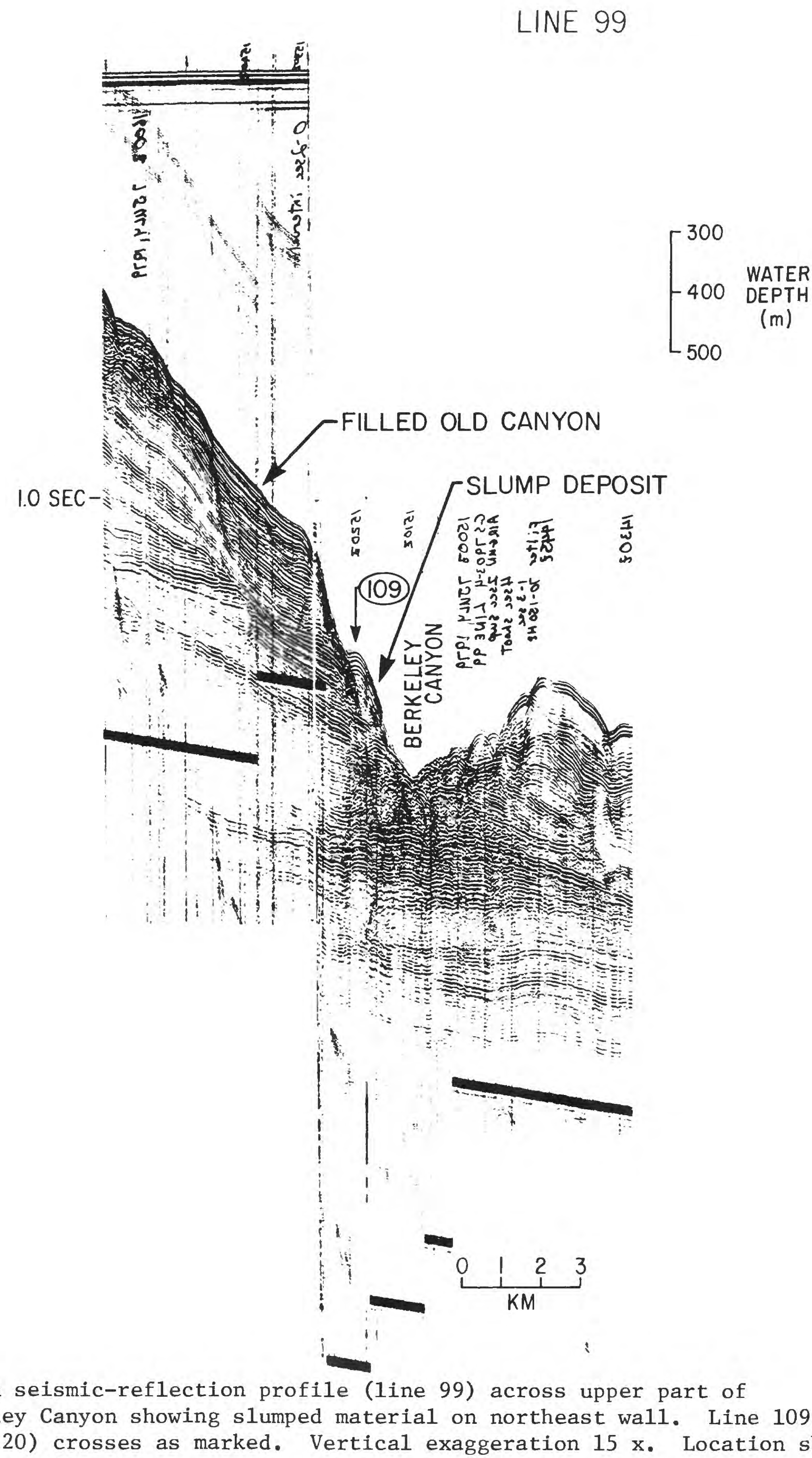

Figure 19. Airgun seismic-reflection profile (line 99) across upper part of Berkeley Canyon showing slumped material on northeast wall. Line 109 DH (fig. 20) crosses as marked. Vertical exaggeration 15 x. Location shown on figure 6.

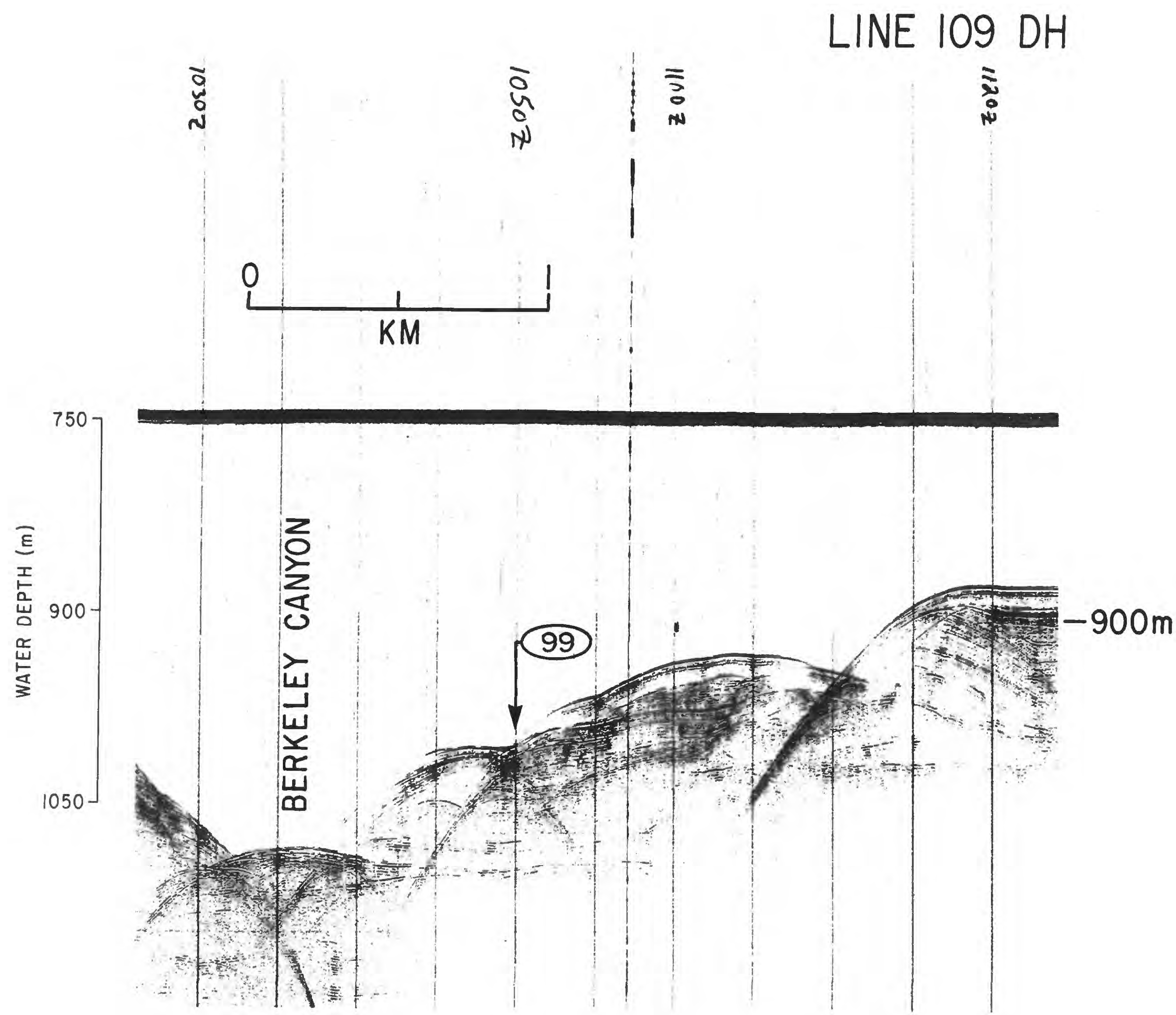

Figure 20. Sparker-reflection profile (line 109 DH) across slumped material in upper Berkeley Canyon line. Line 99 (fig. 19) crosses as marked. Vertical exaggeration 4 x. Location shown on figure 6.

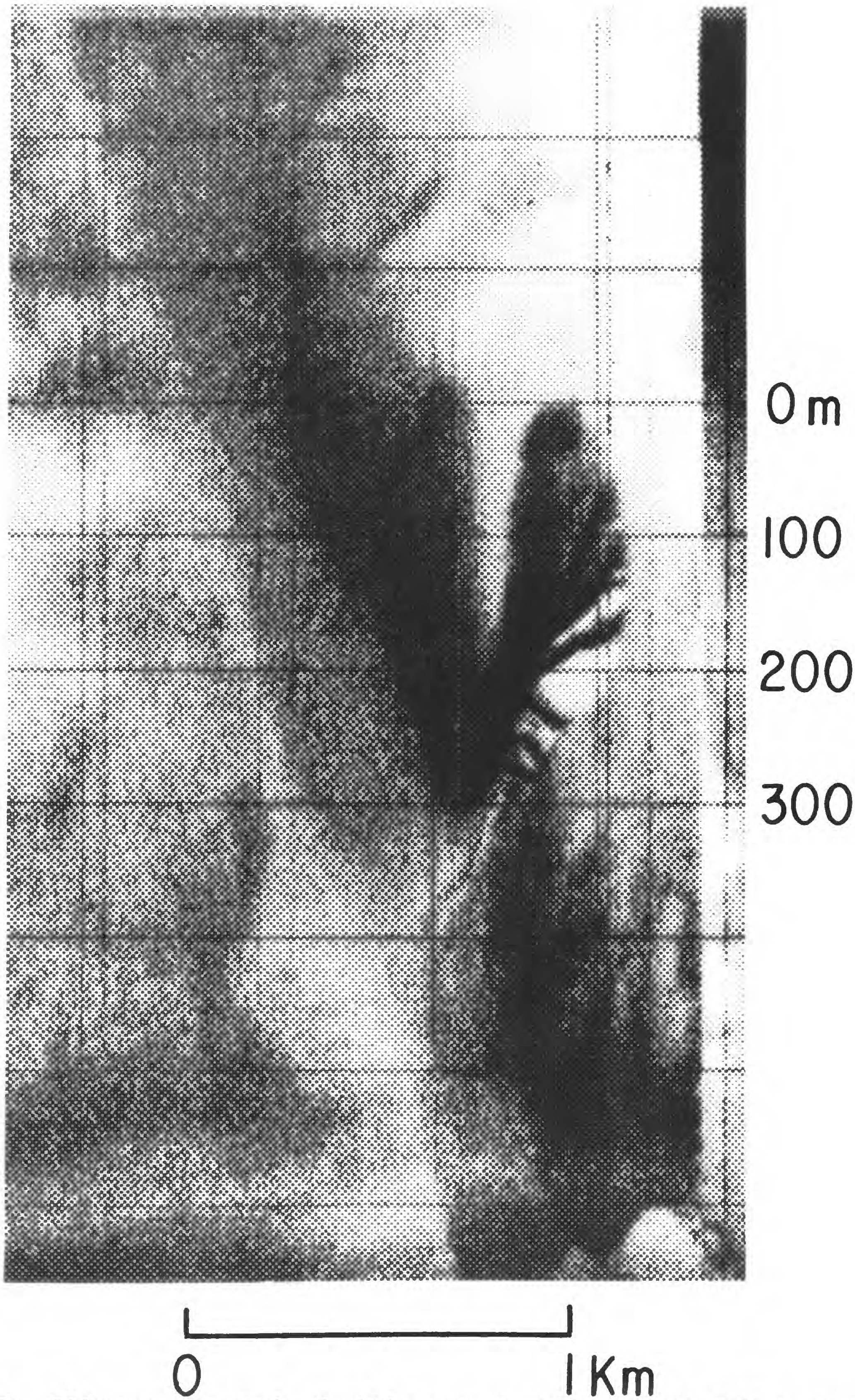

Figure 21. Sidescan sonograph of slide scar on wall of small valley on upper Continental Slope near 31°51'N., 72°51'W. (see plates 2, 3). Valley runs diagonally across figure, upper left to lower right. Downslope direction is toward lower right. Dark areas indicate strong reflections. Sidescan-sonar vehicle located downslope.

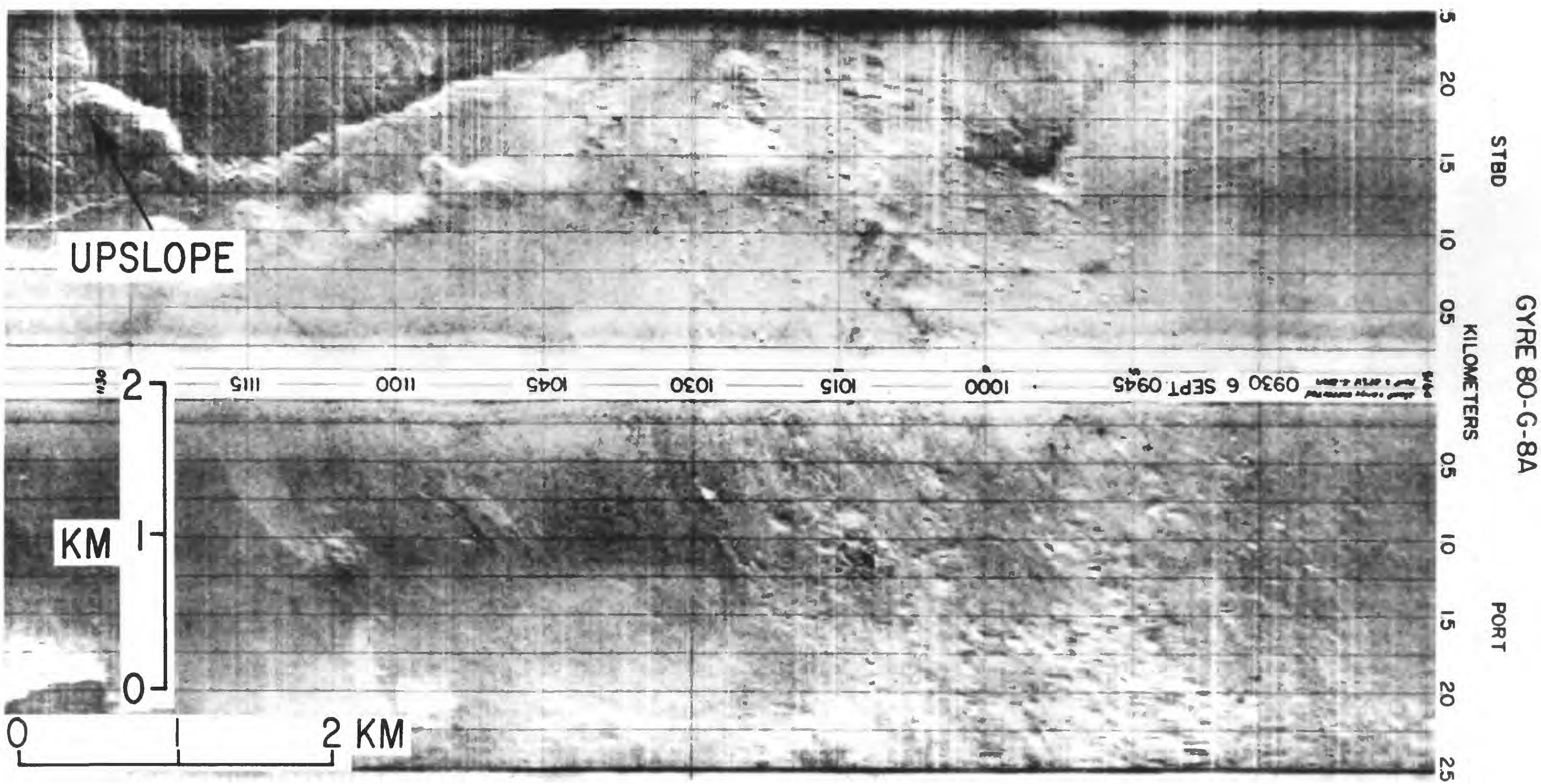

Figure 22. Mid-range sidescan sonograph of debris field on upper Continental Rise below mouth of South Toms Canyon (for location see fig. 6 and plate 3). This sonograph is corrected for slant range; width of swath is 5 km, 2.5 km either side of ship track at center line. Dark areas indicate strong reflections. Upslope is to the right.