Structure of Continental Margin off Mid-Atlantic States

(Baltimore Canyon Trough)

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Introduction

Increasing interest in the Atlantic continental margin as a future petroleum province has resulted in several recent papers (Emmerich, 1974; Burk and Drake, 1974) that attempt to summarize the structure and stratigraphic framework of this area. Most papers tend to portray the margin as a wedge of Mesozoic and Cenozoic sediment that thins at the outer edge of the shelf over a "basement ridge" and then thickens again under the continental rise. Off the northeastern United States, the sediment wedge under the shelf attains a thickness of 8-11 km in the Georges Bank basin (Schultz and Glover, 1974; Mattick and others, 1974; Sheridan, 1974b; Behrendt and others, 1974) and 12 km in thickness in the Baltimore Canyon trough off the middle Atalntic states of Delaware, Maryland, Virginia and New Jersey (fig. 1). Seaward of the continental shelf and its sediment prism, Emery and Uchupi (1972, figs. 133-135) infer slump deposits (eroded in some areas) covering a buried ridge thought to extend from the Laurentian Channel to Cape Hatteras, where it splits in two. The lower slope and continental rise are inferred by Drake and later investigators to be a thick prism of deep sea sediment (turbidites, hemipelagic clays, slump deposits) overlying oceanic basement in a welt that parallels the continental edge and reaches a maximum thickness of 6 km (Emery and Uchupi, 1972, fig. 188).

Our purpose is to present the results of a geophysical survey across the margin seaward of the middle Atlantic states that comments on the structural - stratigraphic framework of the margin.

During the summers of 1973 and 1974, we contracted with Digicon, Inc. to collect multichannel continuous seismic reflection profiles in 7 lines across the shelf, slope, and continental rise; three were taken across the Baltimore Canyon trough, three across Georges Bank, and one across the Hatteras margin. They form the initial effort in a continuing program by the Geological Survey to look at deep structure on the Atlantic continental margin. Their contribution lies in the depth of sonic penetration (about 7 seconds two-way travel time on the shelf) achieved through computer enhancement of returns recorded on 24-channel tape recorder. This report focuses on two multichannel profiles collected and processed in 1973 across the Baltimore Canyon trough; it ties in the profiles with single-channel data collected farther offshore in an effort to outline the broad regional framework of the trough and discusses its evolution.

In 1973, data were collected aboard the M/V GULF SEAL (a 50m offshore supply vessel)using twenty air guns (total volume of 1260 cu. in.) fired simultaneously, and towed 17 m behind the ship; the air guns were towed 9 m below the sea surface, and were operated at a pressure of 1800-2000 psi. The array of air guns was fired once every 50 m (about once every 20 seconds assuming a speed of 5 kts). Returning signals were received by a 24-group (100 m) hydrophone array 2.3 km long and towed 356 m behind the ship at a depth of approximately 12 m below the sea surface. The signals received by the streamer were recorded on one of two 48-channel tape recorders and a single-channel analogue recorder. Tapes were later processed to include true amplitude recovery, normal moveout correction, vertical summation of 2 on 1, common depth point gather, velocity analysis, time variant filtering, and horizontal stack. Six-fold processing was done on that part of the profiles where water was greater than 1000 m, whereas 12-fold processing was done on the parts shallower than 1000 m; in addition, 24-fold processing was done on the outer shelf-slope-upper rise section (55 km long) ~~see figure 12)~~ on the line off New Jersey and 12-fold processing was done on the slope-upper rise part of Georges Bank and Maryland lines to enable better delineation of deep structure.

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Just prior to the multichannel profiling, a cooperative effort was mounted with personnel from the Naval Oceanographic Office, aboard the R/V LYNCH to collect 2770 km of single-channel seismic reflection profiles, magnetics, and gravity along the same cruise track as the multichannel lines, but extending the lines farther seaward and adding other ones. A 80 cu. in. air gun (with shaper) was operated at a pressure of 1950 psi on a 12-second firing rate. Incoming signals were received on a 100-element hydrophone towed 120 m behind the ship.

Figure 1 near here

The LYNCH single-channel profiles made using an air gun were recorded with a 4-second sweep rate and filtered with a setting of 25 to 125 or 160 hz. A proton magnetometer and a stable platform LaCoste Gravimeter were used to obtain magnetic and gravity data. A satellite navigation system was used to track the ship's position. In addition, we used 3650 km of track lines from earlier cruises 602-72 and 708-73 of R/V LYNCH and from part of R/V CHAIN 73 (CHAIN data were kindly suppled by Elazar Uchupi) to supplement our data in estimates of depth to Horizon A and oceanic basement. On these cruises of the LYNCH, an 18 Kj sparker was used along the 1570 km of track; the sparker was fired at a 10-second repeat rate, and incoming signals (filtered at 50 to 100 cps) were received by a 200-element hydrophone array towed 75 m behind the ship. Data from the one additional multichannel profile taken in 1974 was used to infer depth to acoustic basement and to Horizon A obtained from the deep ocean part of the line (fig. 1).

From both the single-channel and multichannel records, overlays were made to bring out the arrangement of reflectors, to highlight key reflectors and to show apparent unconformities. Magnetic profiles plotted above the seismic data in Figures 4 and 5 had the IGRF removed. Using the velocity scans and standard methods of interpretation, the root-mean square velocities (RMS) determined were converted to interval velocities since the length of the streamer cable (2.3 km) is much less than the depths to basement (of the order of 10 km). The errors are progressively greater in the lower parts of the section, since adequate refraction data exists only along Line 3 to be discussed in another paper. We used the interval (?) velocities determined from the velocity scans in constructing the generalized depth sections presented here in Figures 4 and 5.

Figure 1. Index map of continental margin off the middle Atlantic and northeastern United States.

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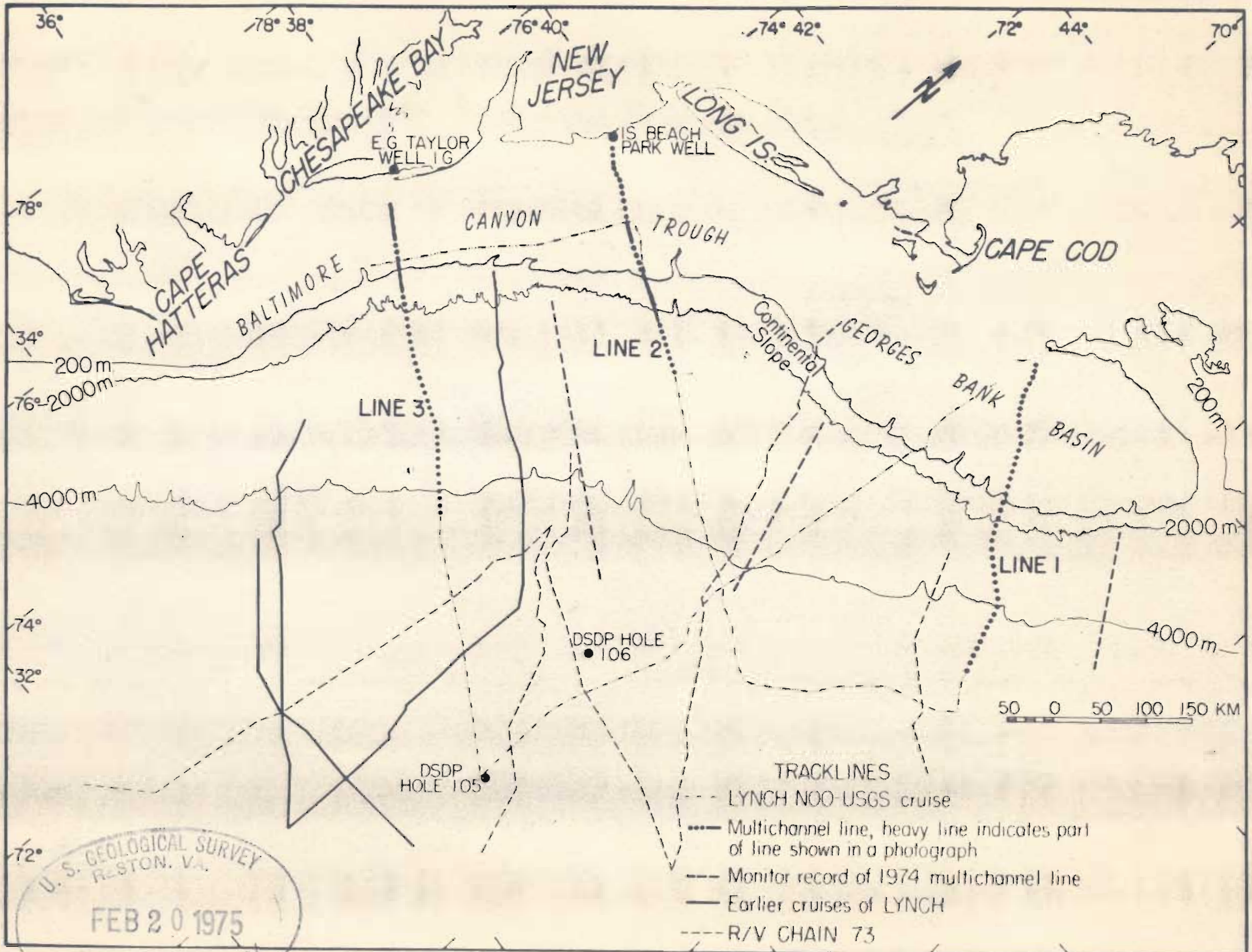
36°
78° 38°
76° 40°
74° 42°
72° 44°
70°
78°
34°
76°
74°
32°
72°
NEW JERSEY
CHESAPEAKE BAY
LONG IS.
CAPE COD
CAPE HATTERAS
E.G. TAYLOR WELL I G
IS BEACH PARK WELL
BALTIMORE CANYON TROUGH
GEORGES BANK BASIN
Continental Slope
200 m
2000 m
4000 m
LINE 1
LINE 2
LINE 3
DSDP HOLE 106
DSDP HOLE 105
50 0 50 100 150 KM
TRACKLINES
LYNCH NOO-USGS cruise
Multichannel line, heavy line indicates part of line shown in a photograph
Monitor record of 1974 multichannel line
Earlier cruises of LYNCH
R/V CHAIN 73

Fig. 1

Results

Baltimore Canyon Trough

The two profiles (figs. 2, 3, 4, and 5) taken off New Jersey and Maryland (lines 2 and 3) reveal a seaward thickening sedimentary section of presumed Mesozoic age in excess of 13 km under the continental shelf. At the seaward edge of the shelf, the sediment wedge appears to be interrupted by a group of deeply buried fault blocks overtopped by what may be reef deposits that extend from under the shelf to under the upper continental slope. This zone of block faulting plus the change in sediment thickness mark the transition to the deep ocean.

The shelf sediment prism differs between the two profiles in that it is folded and intruded off New Jersey and not farther south. Off Maryland (line 3), the section thickens seaward (fig. 3) where beneath the shelf edge, acoustic penetration exceeds 7 seconds (>12 km in figure 5). A few broad discontinuous reflectors (some real) can be seen below acoustic basement (fig. 6); they are most common as the shoreward part of the line, but they also occur as scattered reflectors that tend to dip gently offshore. Acoustic basement deepens from 4-1/2 km to >12 km over a horizontal distance of 77 km. It is irregular and less distinct toward the outer part of the shelf and at least one small basin (?), about 16 km in apparent width, appears to be nestled between basement and the main sedimentary wedge.

On the Maryland profile (line 3, figs. 3, 4, 5, and 6), the main sedimentary wedge shows subhorizontal reflectors dipping gently seaward. Three broad groupings of reflectors (fig. 6) are evident though boundaries between them can be indistinct; an upper sequence of discontinuous subhorizontal weak reflectors (0.7 seconds at the inner shelf to 1.3 seconds under the upper continental slope); a middle sequence of stronger discontinuous reflectors (encompassing an interval 1.6 to 2.9 seconds from the inner shelf to the upper slope) suggestive of stratigraphic discontinuities; a lower sequence similar to the upper one in that most reflectors are weak and discontinuous. The general characteristics are similar to those in the Georges Bank profile. Reflectors in the upper sequence indicate

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Figures 2, 3, 4, 5, and 6 near here

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a progradation of the outer shelf and upper slope. The sequence also exhibits much lower velocities (2.0, $\pm$.1 km/sec) than the middle and lower sequences. Values are similar to those in the Georges Bank profiles and similar to what Drake and others (1959, Table 1) indicate for unconsolidated sediment in their Cape Henry section.

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Figure 2. Interpretive section along the New Jersey (line 2) multichannel line. Heavy lines indicate a prominent reflector or group of reflectors. Lighter lines give the general arrangement of less obvious reflectors. Letters are referred to in the text. Vertical exaggeration of bottom topography approximately 4:1.

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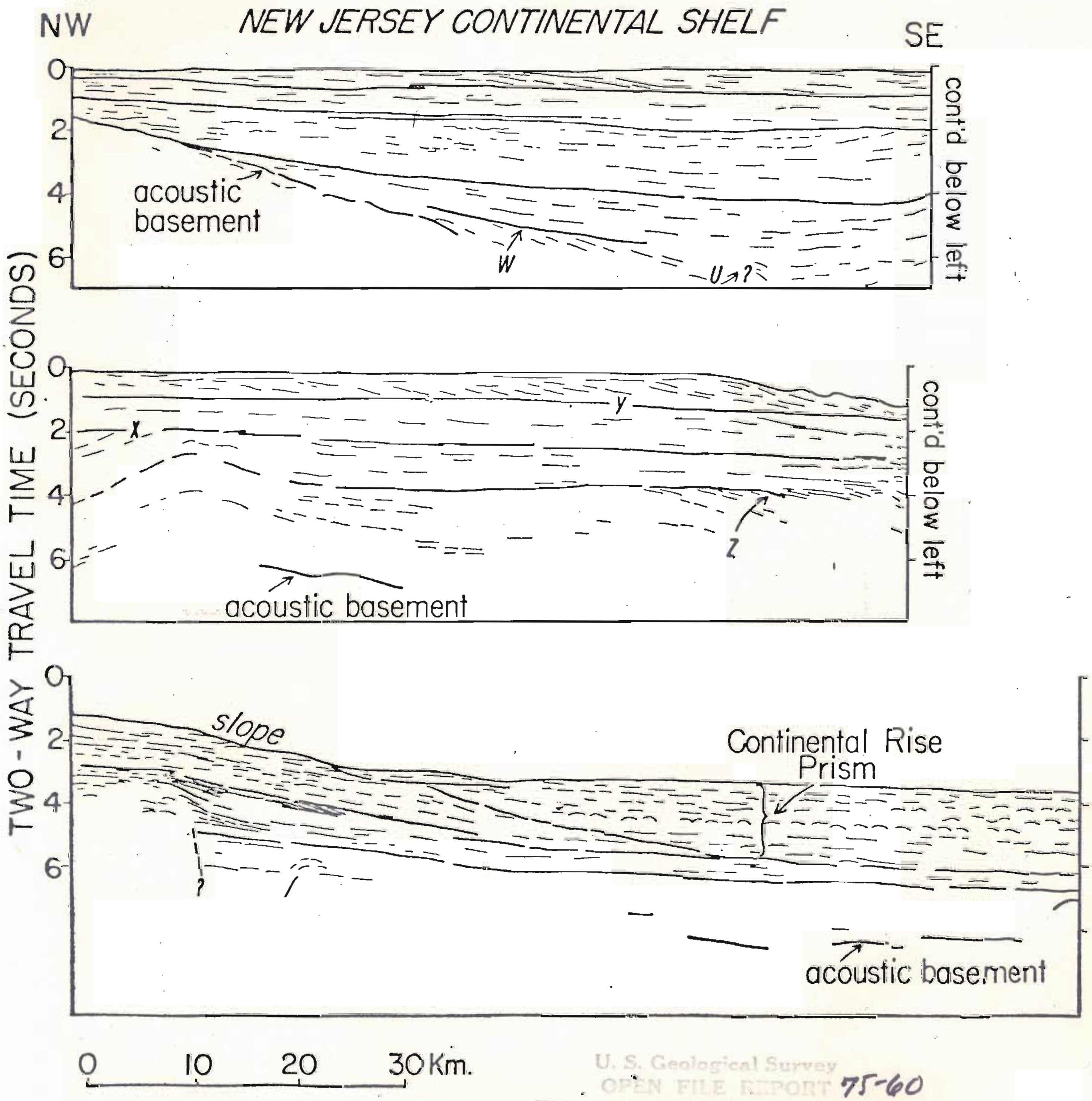
NEW JERSEY CONTINENTAL SHELF
NW
SE
TWO-WAY TRAVEL TIME (SECONDS)
0
2
4
6
acoustic basement
W
U ?
cont'd below left
X
Y
Z
acoustic basement
cont'd below left
slope
Continental Rise Prism
acoustic basement
0 10 20 30 Km.

Fig. 2

Figure 3. Interpretive section along the Maryland (line 3) multichannel line. Heavy lines indicate a prominent reflector or group of reflectors. Lighter lines give the general arrangement of less obvious reflectors. Vertical exaggeration of bottom topography approximately 4:1.

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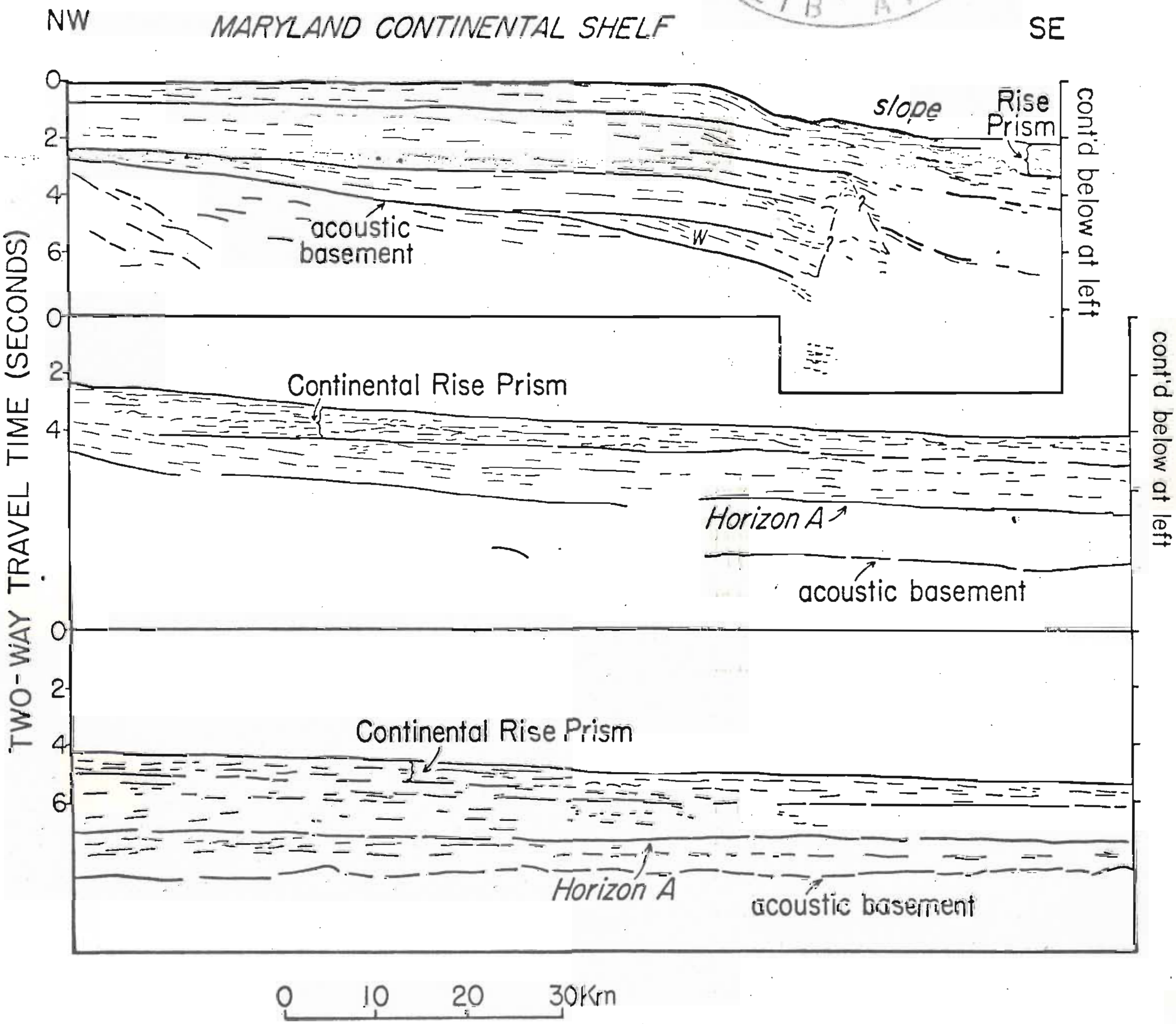
NW
MARYLAND CONTINENTAL SHELF
SE
slope
Rise Prism
cont'd below at left
acoustic basement
W
Continental Rise Prism
cont'd below at left
Horizon A
acoustic basement
Continental Rise Prism
Horizon A
acoustic basement
TWO-WAY TRAVEL TIME (SECONDS)
0 2 4 6
0 2 4
0 2 4 6
0 10 20 30Km

Fig. 3

Figure 4. A generalized structural profile across the New Jersey margin (line 2), using the CDP stacking velocities tied to some of the prominent reflectors shown in figure 2. Note rapid thickness change under the New Jersey shelf.

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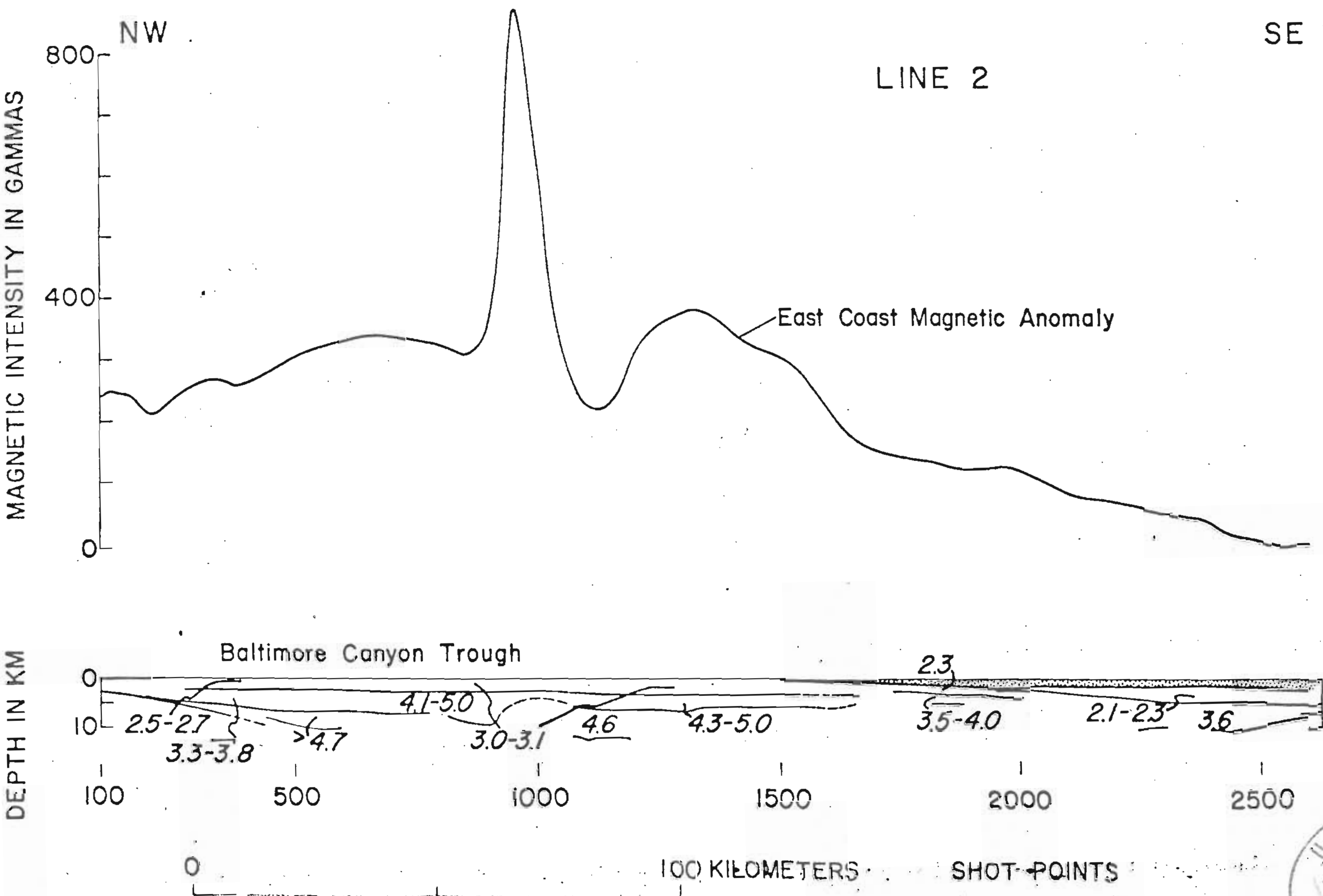
NW
SE
LINE 2
MAGNETIC INTENSITY IN GAMMAS
800
400
0
East Coast Magnetic Anomaly
DEPTH IN KM
0
10
Baltimore Canyon Trough
2.3
4.1-5.0
2.5-2.7
3.3-3.8
>4.7
3.0-3.1
4.6
4.3-5.0
3.5-4.0
2.1-2.3
3.6
100
500
1000
1500
2000
2500
0
100 KILOMETERS
SHOT POINTS

Fig. 4

Figure 5. A generalized structural profile across the Maryland continental margin (line 3), tied to some of the prominent reflectors shown on figure 3. Note the high velocities of the oldest acoustic unit and how much it makes up of the total Baltimore Canyon trough wedge.

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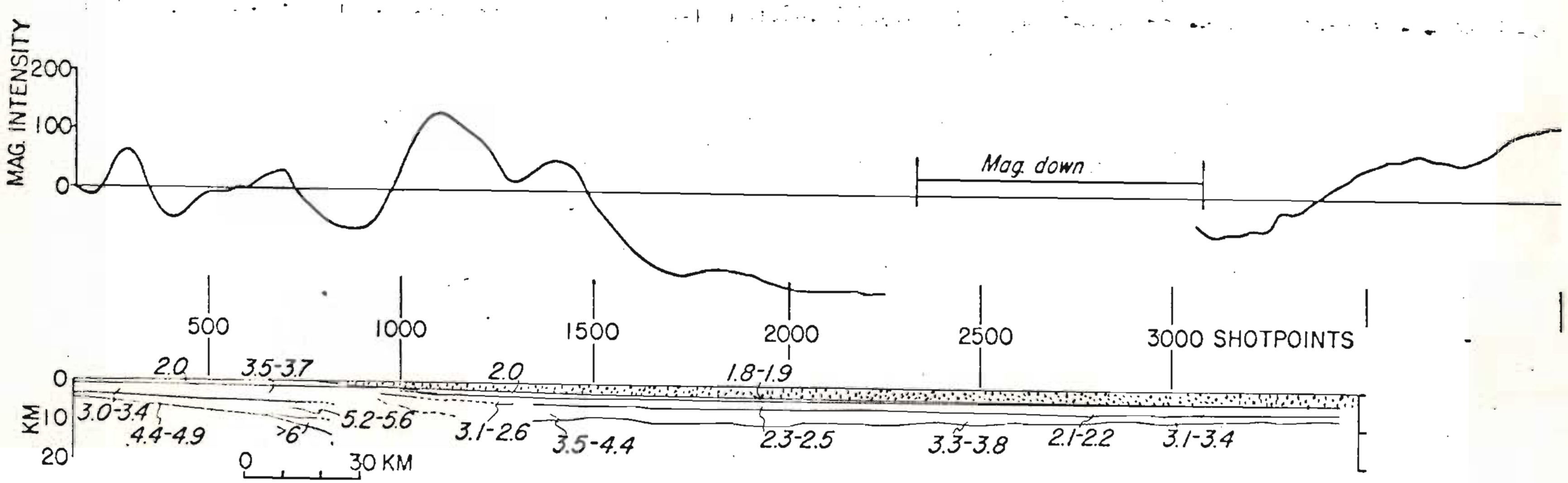
MAG. INTENSITY
200
100
0
Mag. down
500
1000
1500
2000
2500
3000 SHOTPOINTS
KM
0
10
20
2.0
3.5-3.7
2.0
1.8-1.9
3.0-3.4
4.4-4.9
>6
5.2-5.6
3.1-2.6
3.5-4.4
2.3-2.5
3.3-3.8
2.1-2.2
3.1-3.4
0
30 KM

LINE 3

Fig. 5

Figure 6. Multichannel seismic reflection profile across the inner shelf off Maryland. Acoustic basement appears to deepen more rapidly (point X) to the southeast.

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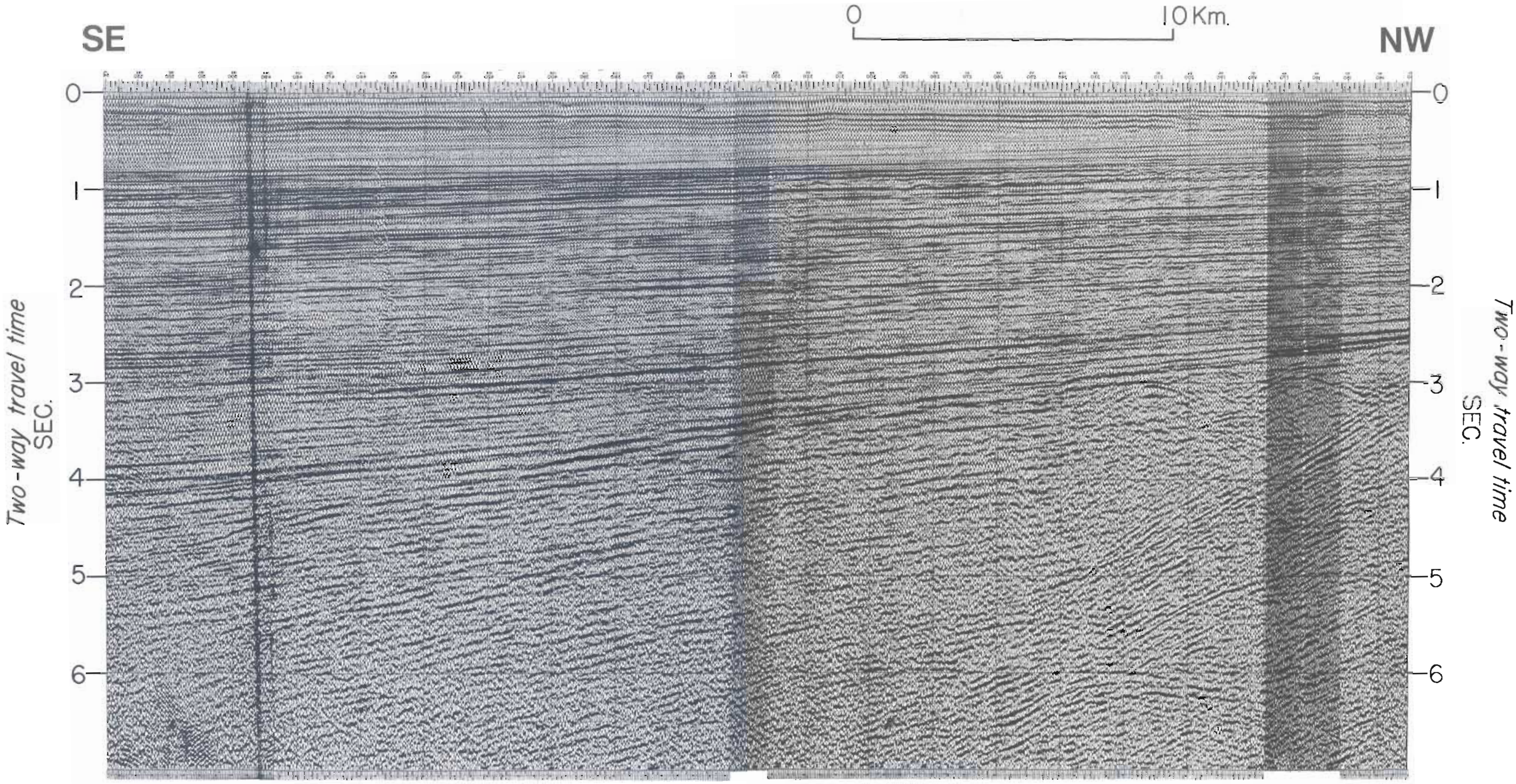
R290
no. 75-60



The upper boundary of the middle sequence is a strong group of fairly continuous reflectors that extend to the upper continental slope where they are lost in a jumble of discontinuous reflectors -- probably slump deposits. The lower boundary (fig. 6) is another set of strong reflectors approximately 1.8 seconds below the upper ones and not nearly as continuous. In between, the reflectors are weaker, marked by minor irregularities and discontinuous. Velocities (average, 3.5, $\pm$0.4 km/sec) are higher than the overlying sequence and broadly overlap the range Drake and others (1959, Table 1) indicate for consolidated sediment. Assuming the reflectors give a generalized representation of sedimentary section, the major response to a regional subsidence of the margin has been an upbuilding of the shelf. Subsidence in excess of 13 km is indicated beneath the outer shelf off Maryland.

The lowest acoustic unit inshore extends from 2.3 sec to the basement at 2.7 seconds. It is characterized (fig. 6) by fairly even weak and locally strong subhorizontal reflectors. They dip at a low angle seaward and the unit occupies the lowest 2.3 seconds (above acoustic basement) of the sedimentary section beneath the outer edge of the shelf. The velocity data (fig. 5) indicate a thickness change of 1.1 km to 6-1/2 km across the shelf. Acoustic basement dips more steeply beneath the outer shelf - upper slope because of the addition of an irregular sedimentary wedge (fig. 3, point W) at the base of the lowermost acoustic unit.

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Farther north in the New Jersey line, the sedimentary wedge is much broader (about double the 70 km width off Maryland) and the lower part of it is folded (fig. 2). The three-fold subdivision of reflectors noticed on the Maryland line is present here on the inshore part, but offshore the sequence is more complex. Inshore the upper and lower zones of seaward dipping uniform reflectors are separated by a strong zone of anastomosing reflectors whose boundary is poorly defined. A pronounced acoustic basement (probably gneiss as encountered at 1115 m in the Island Beach, New Jersey well (Gill and others, 1963) drilled 12 km west of the end of the line) deepens to at least 11-1/2 km, 55 km seaward of the inshore end of the line. As on the other line, arcuate reverberations mark the record below acoustic basement in places, but other reflectors (some with reversed dip) about 2 seconds below "basement" suggest layering within the metasedimentary crystalline rocks underlying the sedimentary section. The main thickening of sedimentary section seaward seems to occur mainly through the addition of reflectors immediately above acoustic basement (fig. 3).

Figure 7 near here

Figure 7. Multichannel seismic reflection profile across the central part of the New Jersey shelf (line 2). Note broad warp, beveled at 2 seconds by an unconformity.

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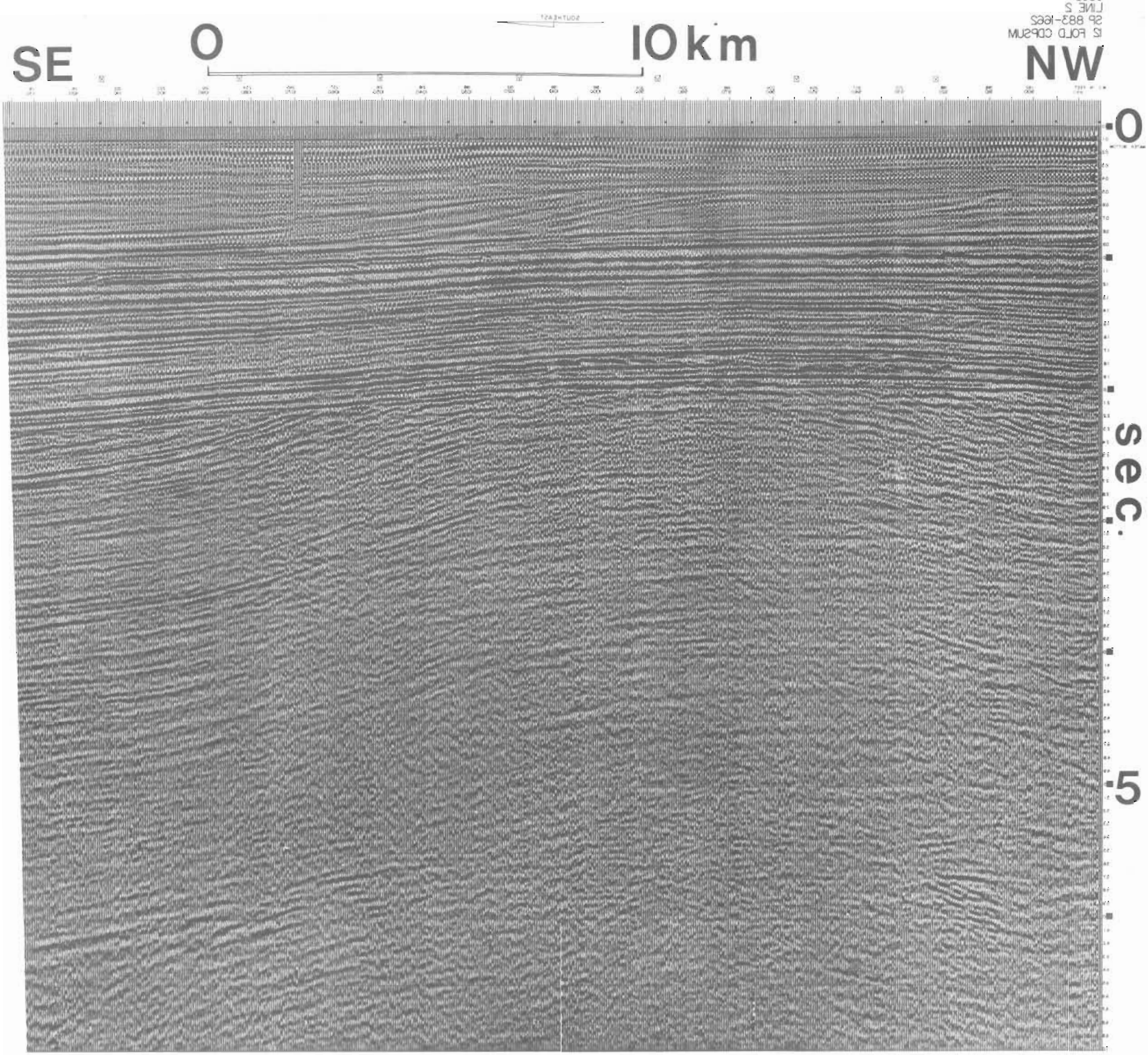
USGS
LINE 2
SP 883-1662
12 FOLD CDPSUM
SE
0
10 km
NW
0
sec.
5

The mid-shelf part of the New Jersey profile (line 2) shows (1) three obvious unconformities, and (2) warping the lower part of the section, likely in response to a circular intrusive at depth (figs. 2 and 7). Of three hiatuses, shown in figure 2, the lowest is a low angle truncation of a deeply buried sequence situated immediately above basement (point W, fig. 2). The unconformity deepens from 7 to 11 km below the seafloor over a distance of 20 km before it is lost among other reflectors of the inner shelf. Seismic velocities at these depths are high (fig. 4) -- in the range of 3.7 - 6.3 km/sec. The next higher break is centered in the middle zone of anastomosing reflectors and is most obvious (fig. 2, point X) as the truncating horizon over the domal structure under the middle part of the shelf. This "unconformity" deepens from approximately 1 km at the landward part of the shelf to 3 km below the outer edge of the shelf. The break continues as a major reflector under the continental slope to the point where it is lost beneath the lower slope. It marks a significant velocity change from 2.9, $\pm$.3 km/sec above to 4.1 $\pm$.8 km/sec below; velocity values average in between what Drake and others (1959) show for semiconsolidated and consolidated sediment on one hand, and consolidated sediment and continental crust on the other.

The shallowest break is distinguished by even nearly horizontal reflectors below, and extremely low-angle foresets reflectors above (point Y, fig. 3). This break also marks the base of the uppermost acoustic unit, and it deepens from about 0.4 km at the inshore end of the line to about 1 kilometer at the shelf break; seaward of the shelf, it appears to continue under the upper slope and to intersect the seafloor in approximately 1500 m of water. In the uppermost acoustic unit, the main arrangement of reflectors suggests an outbuilding shelf, and if the actual record is examined (fig. 8), there is a faint suggestion that the foreset sequence buildings upward and outward into the zone under the slope where reflectors become discontinuous and disrupted. Contrast this unit, characterized by low-angle foresets, to the uppermost acoustic unit off Maryland (line 3) where reflectors are subhorizontal, perhaps indicating a more uniform buildup of the shelf. As in the case of the middle discontinuity, this one marks a velocity change from 1.8, $\pm$.1 km/sec above to 2.9, $\pm$.3 km/sec below. Prograding reflectors (fig. 2) are most evident immediately above the break, whereas reflectors tend to be subhorizontal near the shelf floor.

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Domal warping is about 20 km across and affects strata 2-1/2 km or more down (figs. 2 and 7). Deep acoustic basement returns are fragmentary, hence inferences about igneous rocks at depth come mainly from a strong magnetic anomaly over the structure (figs. 4 and 9). A suggestion of acoustic basement is present on the seaward flank of the dome.

Seaward of the dome, subhorizontal reflectors dip gently offshore and one of them (fig. 2, point Z) shows a crude foreset arrangement to secondary reflectors. This reflector (fig. 8, point X) is slightly deeper than the one that truncates the dome; the "foresets" appear to have a clinoform shape (Rich, 1951) on the profile -- as though they were part of units that prograded seaward over a gentle slope, there to merge gradationally with what may be a reef under the continental slope (see next section, Slope Transition).

Figure 8 and 9 near here

Figure 8. Multichannel seismic reflection profile of line 2 across the outer part of the New Jersey Shelf and the continental slope. Note the low-angle foresets in the upper one second of section under the shelf and the foresets at 4 seconds under the shelf and slope. Letters are referred to in the text.

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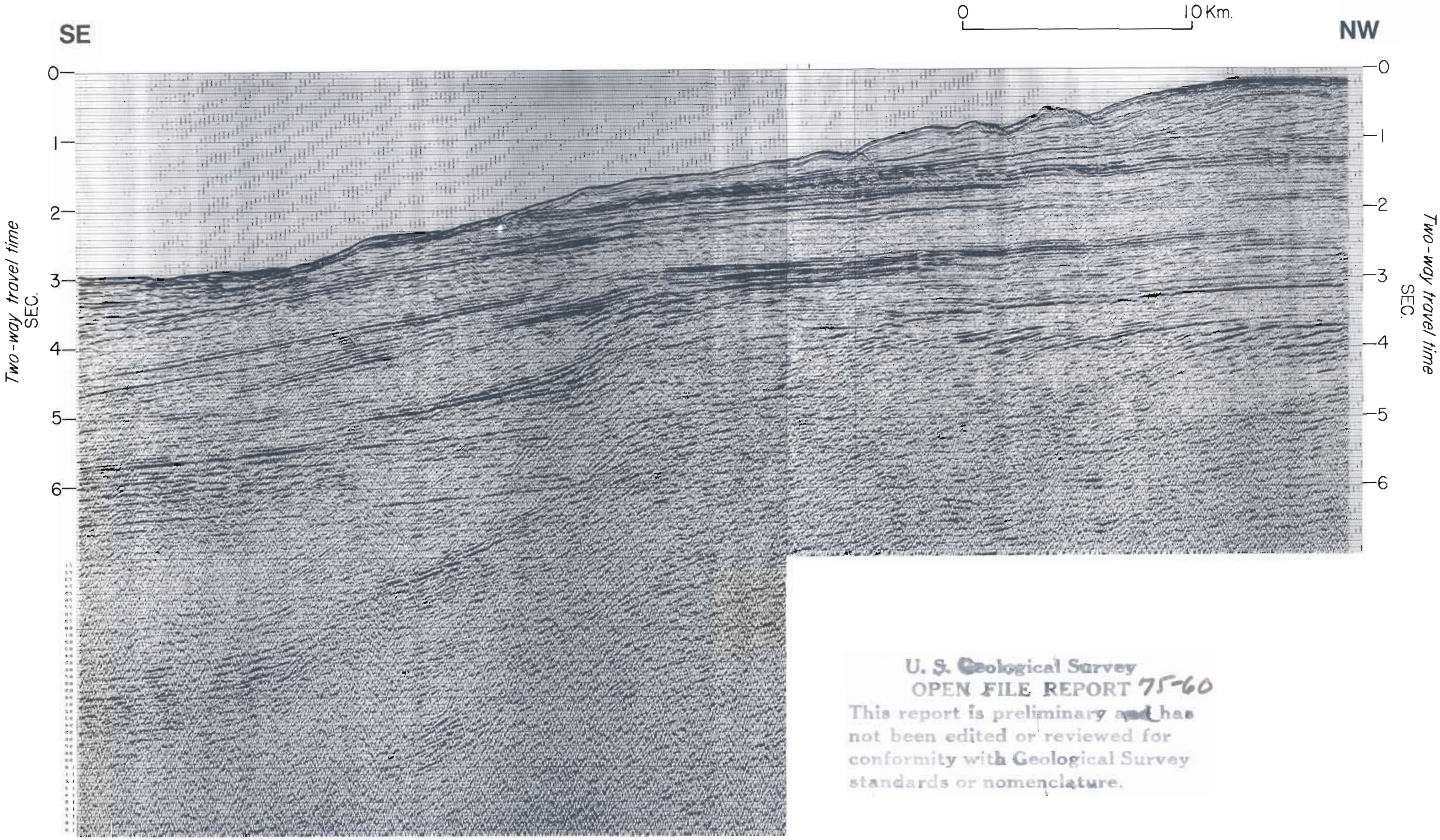

Fig. 8

Figure 9. Residual total intensity magnetic contour map. IGRF removed. Contours based on data indicated, guided by additional data not shown.

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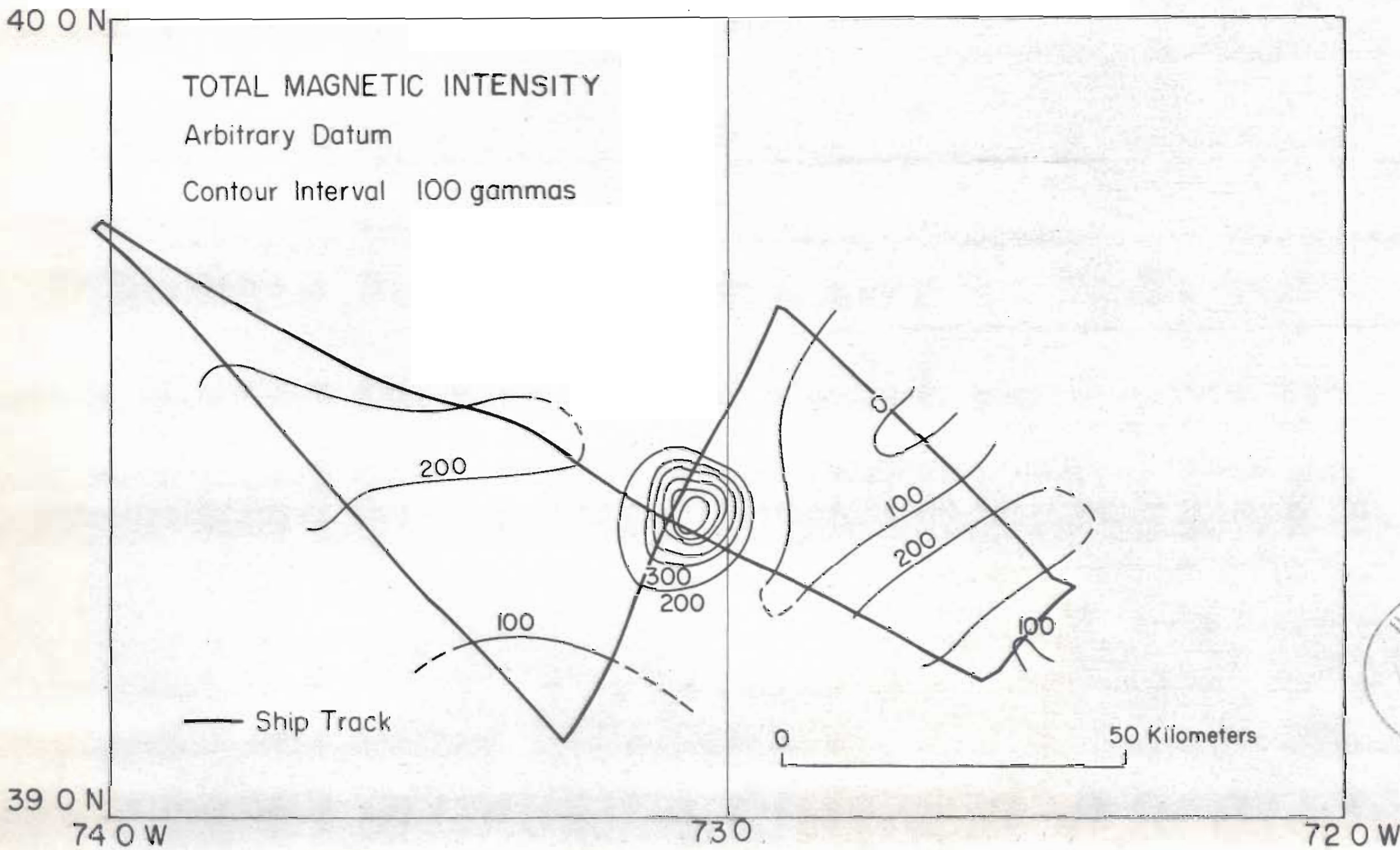
40 0 N
TOTAL MAGNETIC INTENSITY
Arbitrary Datum
Contour Interval 100 gammas
200
0
100
200
300
200
100
100
Ship Track
0
50 Kilometers
39 0 N
74 0 W
73 0
72 0 W

Fig. 9

Slope Transition

The seaward side of the Baltimore Canyon Trough lacks an obvious bounding ridge. We interpret both sections to show an eastward thickening of the sedimentary wedge beneath the shelf; it appears to be draped across broken crustal blocks beneath the upper slope (figs. 2 and 3). On the slope part of the New Jersey profile (fig. 8), the evidence for deeply buried fault blocks shows up as an interruption of reflectors, and a "draping" of reflectors across the faults; two deeply buried steeply dipping faults are inferred with apparent downward displacement toward the ocean basin (fig. 2). The amount of apparent offset is difficult to figure because seaward dipping reflectors appear to end against the blocks (point Y, fig. 8). The distance between faults on the figure is about 10 km and the internal structure within the blocks is mainly faint discontinuous seaward dipping reflectors. The shallowest of the blocks on figure 8 is about 2 sec below the sea floor and the deeper one is at least 4 sec below the sea floor. Curiously, the deep, fairly strong subhorizontal reflectors so easily projected seaward from beneath the outer part of the continental shelf (point Z, fig. 8) become faint, discontinuous and bowed adjacent to the first fault zone. In addition, reflectors are splayed seaward of the presumed fault. The ramp-like zone where internal reflectors are absent (point W, fig. 8) is close to the deep "foreset" horizon already discussed -- indeed almost leads in to the ramp. These relations look suspiciously like a reef is built over the buried fault block.

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Above the structural-biostratigraphic (?) feature described above, other reflectors can be traced out across the slope with only a slight increase in apparent dip; many of these reflectors appear to intersect the sea floor, or to be buried by only a thin veneer of sediment (fig. 2). The steeply (4-6 degrees) truncating nature of the slope floor points up the recency of the continental slope as a bathymetric feature, and its largely erosional character. Except for the vicinity of the shelf-slope boundary, the surface of the continental slope is cut into older units, most deeply as small canyons but also over broad surfaces.

The lower part of the slope is constructional as a lobate fan of sediment that thickens beneath the continental rise to over 3 km; this fan leaps onto the lower slope and buries many of the older reflectors that can be traced out from the shelf. Velocity scans give values that average 2.0, $\pm$.4 km/sec for this sediment prism; the average compares favorably with values obtained by the DSDP-Leg 11, of 1.73 km/sec for the upper sand silty clay, and 1.94 km/sec for compacted hemipelagic mud, at hole 106 (the Shipboard Scientific Party, 1972, p. 319) for a 900 m section.

Deep structure under the continental slope and rise on the Maryland (line 3) profile (fig. 3 and 10) shows a similar though less obvious pattern of fault zone to that shown off New Jersey (line 2). Without a change in dip, some reflectors continue out under the upper

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Figure 10 near here

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slope where they lessen dip or bend upward slightly (fig. 10, point X) and stop. A few hyperbolic returns mark the zone of reflector loss. The zone (fig. 10, point Y) of loss of deep coherent returns is about 4 km wide and extends from 2 seconds below the sea floor on down. The data indicate velocities of about 2.5 - 2.8 km/sec above this structure; some weak reflectors with flattened dips, are draped over it. To the seaward, however, their continuity is lost. The loss of some reflectors and the change of attitude and acoustic character of others, mark this area as a zone of faulting.

Figure 10. Multichannel seismic reflection profile (line 3) across the outer part of the Maryland shelf and continental slope. Note low angle foresets in upper one second of section under the shelf and the eroded slope underlain by slumped strata; continental rise prism thickens to the southeast seaward of the slumping (point Z). Letters are referred to in the text.

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(200)
R29o
no.75-60

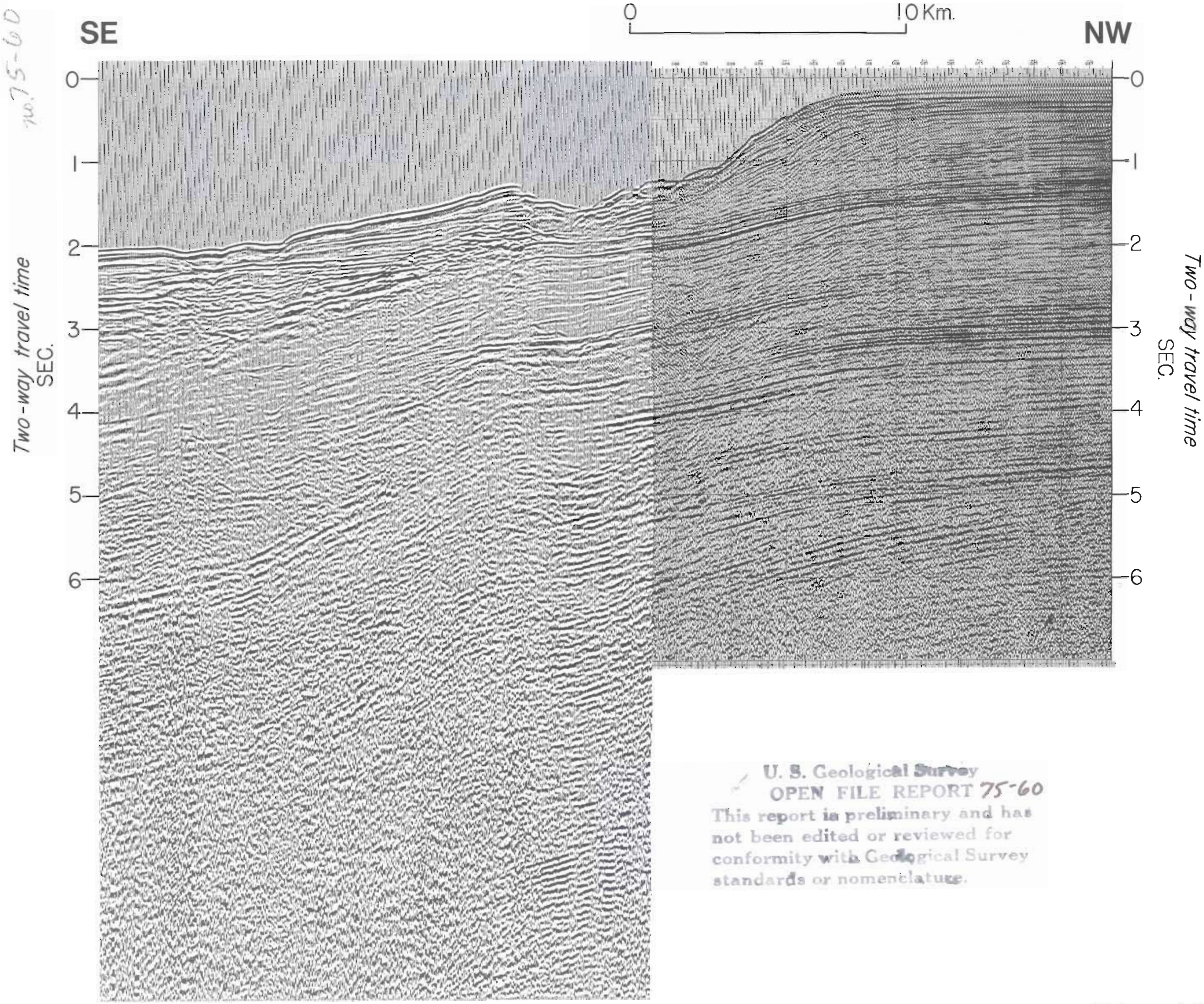

Fig. 10

The shallowest acoustic unit distinguished on the shelf part of the Maryland line 3 (see previous section) has a strong reflector at the base that carries under the continental slope where it gives way to a zone of anastomosing reflectors (fig. 10, point Z) thought to be slump deposits; these deposits also mark the upslope beginning of a sedimentary sequence characterized by strong discontinuous crenulated reflectors, that becomes more even beneath the continental rise. The lower boundary of the sequence is characterized by a loss of strong subhorizontal reflectors, and by the low angle truncation of older seaward dipping even reflectors. This prism of slope-rise sediment is the same one that cuts older reflectors beneath the lower slope and rise of line 2 (the New Jersey line). On line 3 (the Maryland line), the prism starts much higher up on the slope, attains a maximum thickness of 1.4 km under the rise before thinning across the lower rise; sound velocity averages 1.85, $\pm$.17 km/sec.

The continental slope is less of the erosional feature than it is off New Jersey. It is erosionally sculptured in the upper part (fig. 10) but appears constructional below that area. Intersection of older horizons with the slope sea floor so obvious to the north, is almost entirely lacking here. Instead, outbuilding shelf sediments seem to give way to an area of slumping that results in a hummocky sea floor.

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Rise - Abyssal Plain

The profiles across the lower continental rise and the Hatteras Abyssal Plain, seaward of the Baltimore Canyon trough, reveal a hummocky oceanic basement, Horizon A, and the seaward pinchout of the continental rise sediment wedge against the lower continental rise hills (fig. 11A). Two of the profiles (fig. 11) (based on single-channel seismic data) are seaward extensions of Lines 2 and 3; they show a gradual pinchout of evenly layered sediment of the lower continental rise against slump topography -- the lower rise hills. Indeed, the sediments are built across a floor of slump deposits

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Figure 11 near here

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as noticed by Emery and others (1970) and the sediments appear ponded by the lower continental rise hills which act as a barrier and an obvious topographic break to the Hatteras Abyssal Plain to the southeast. The sedimentary cover is probably in part the Hudson submarine delta (Heezen and others, 1959) though it is best formed southwest of the canyon, where the damming influence of the lower rise hills is greatest. Northeast of the canyon toward the Caryn Seamount, the seaward edge of the sediment wedge is not well defined; broad overlapping wedges are present, but the lower rise hills are absent. Drill hole data offer some support for the inference that the sediment prism is composed in part of turbidites, much as Emery and others, 1970) postulated. DSDP hole 106 encountered approximately 340 m of hemipelagic clay with a few beds of gray quartzose sand of Holocene-Pleistocene age. Though sedimentary structures are not preserved, the Shipboard Scientific Party (1972) still infer that the coarse-grained material (largely terrigeneous detritus) was emplaced by turbidity currents in an interval of rapid sedimentation (20 cm/1000 years). The Tertiary clays are thought to make up the lower rise hills, and are also the transparent interval sonically between Horizon A and the evenly layered strong reflectors near the sea floor inferred to be turbidites.

Figure 11. Interpretation of single-channel seismic reflection profiles that extend two of the multichannel profiles into the lower continental rise. The extension of line 3, has its seaward terminus near DSDP Hole 105 (Leg 11).

Note seaward terminus of the continental rise prism against slump deposits of the lower rise hills (11A).

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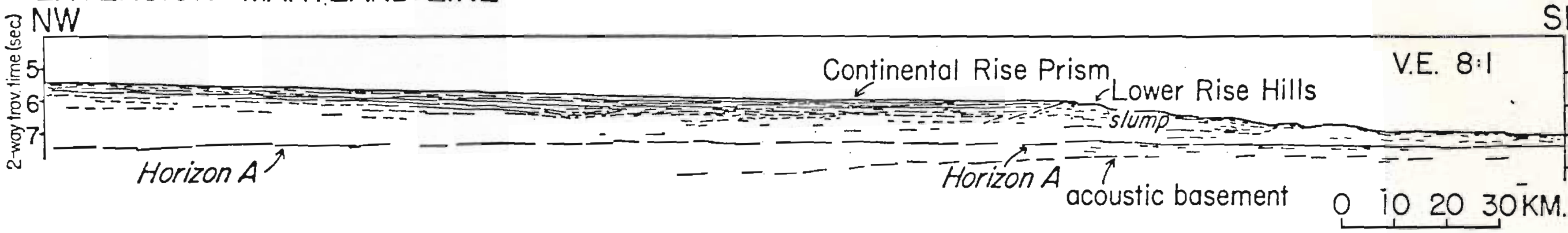
A. EXTENSION- MARYLAND LINE



B. EXTENSION-NEW JERSEY LINE

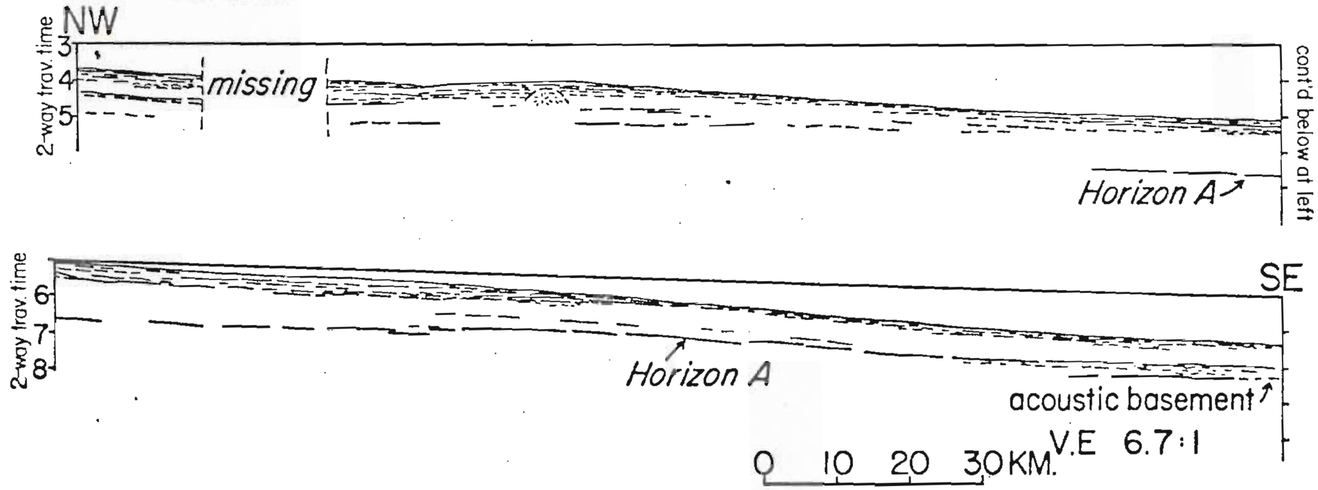


Fig. 11

Horizon A (figs. 3 and 11) is covered by as much as 2-1/2 km of sediment (assuming a velocity of 2.1 km/sec) beneath the upper continental rise seaward of the Baltimore Canyon and by lesser amounts away from there (fig. 11). It is an even horizon in the

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Figure 12 near here

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deep ocean basin that passes uninterrupted beneath the lower continental rise hills and is covered by the thickening rise prism landward. The horizon actually rises towards the lower continental slope so that it is 5 km below sea level as compared to 5.6 km below sea level ~~(93% water)~~ under the Hatteras Abyssal Plain, at the end of the extended Maryland line. On the two multichannel profiles across the Baltimore Canyon trough, Horizon A appears to collate with a significant change in sediment-sound velocity (fig. 5) from about 2 km/sec above it to 3.6 km below it.

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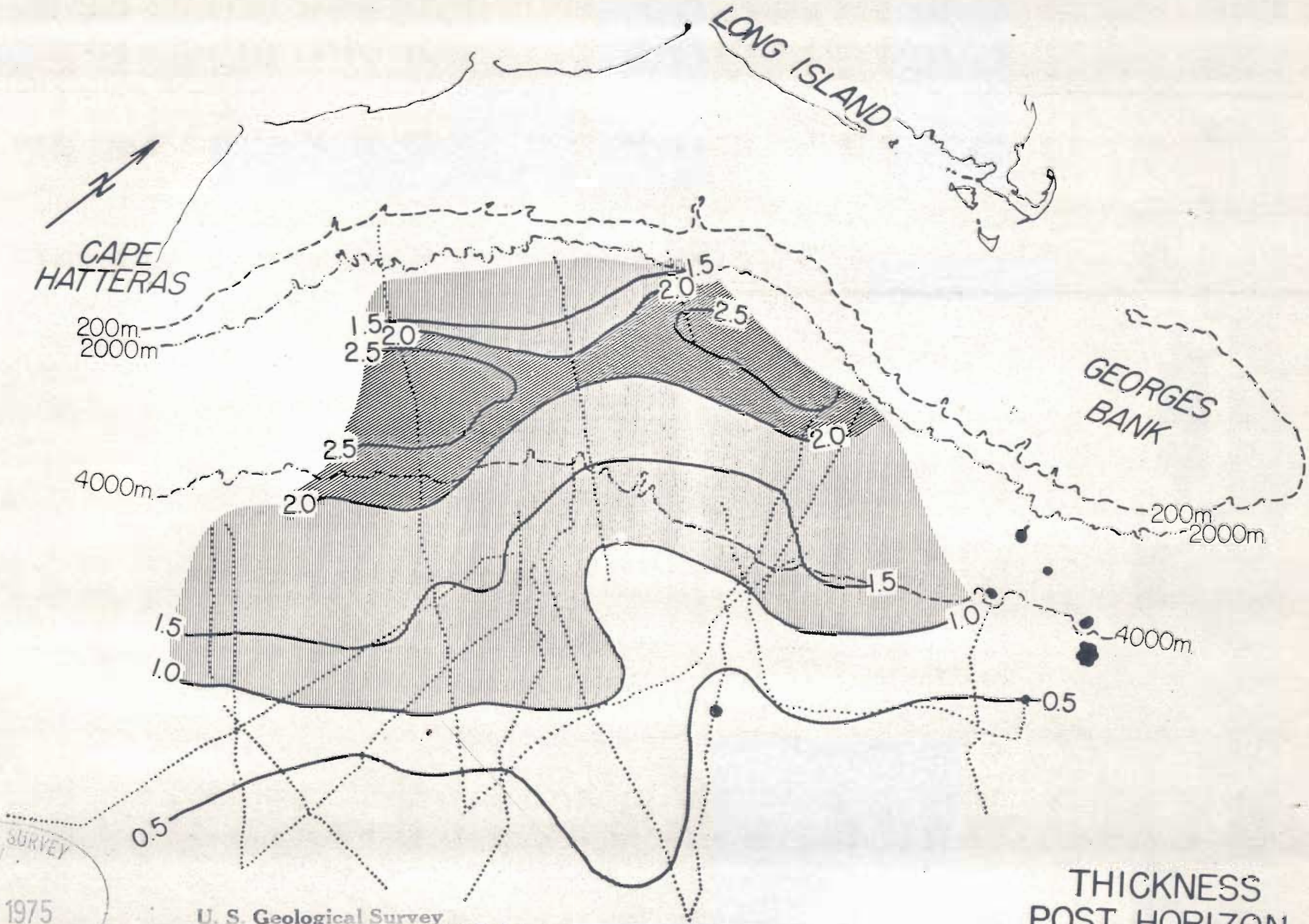
Figure 12. Isopach map of sediments above Horizon A. Dotted lines are cruise tracks used to obtain estimates (every 7 - 12 km) of the sediment thickness. Dark areas are seamounts.



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THICKNESS
POST HORIZON
A
in Kilometers

Fig. 12

On the multichannel profiles (figs. 2 and 3), Horizon A continues as a poorly defined group of reflectors, no one of which carries completely through. Hence, the interpretive line drawing shows Horizon A as a discontinuous reflector(s). It is well below the well-layered near surface reflectors and can have a more or less transparent layer in between, as on the Maryland line. The reflector is discontinuous below the upper rise and is lost entirely near the edge of the fault zone. On the New Jersey line (line 2), Horizon A is not as easily identified because the transparent layer is lacking; strong even reflectors characterize the entire continental rise sediment prism. We chose a strong group of reflectors near the base of the rise prism and can trace it to the upper part of the continental rise where it merges with a low angle "unconformity" that marks the base of the prism. In the multichannel profiles (lines 2 and 3), Horizon A appears to be restricted to the deep ocean sediments and not to carry through to the continental shelf.

Also obvious from the profiles, particularly line 3, Horizon A here probably is not a time-synchronous zone. Instead, it appears to be a diagenetic phenomena, more as a zone of alternating hard and soft siliceous clay stones and hemipelagic mud. This type of a section helps best to explain the fact that on the records, Horizon A appears as a group of reflectors, no one of which carries all the way through. It may also explain why Horizon A seems to be different ages in different places (Ewing and others, 1966, Ewing and others, 1970; Saito and others, 1966; Ewing and Hollister, 1972).

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Acoustic basement is a gently undulating irregular reflector that is buried by at least 7 km of sediment beneath the upper continental rise (fig. 13). It is more deeply buried to the south, seaward of the Baltimore Canyon trough than it is to the northeast off Georges Bank basin. In a curious way, the inferred sediment thickness on the shelf is a guide to the off-shelf sediment thickness. Oceanic basement can be traced on the Georges Bank line right up to the base of the continental slope (fig. 2) where the sediment cover is estimated to be about 4 - 4.5 km thick.

Figure 13 near here

Acoustic basement on line 3 is a gently undulating reflector that can be traced to within about 65 km of the base of the slope. Farther seaward, acoustic basement can be traced with relative ease on several single-channel profiles. The seaward extension of the Maryland line (fig. 11) shows a discontinuous acoustic basement, less deeply buried to the southeast. The line end near DSDP hole 105 and indicates acoustic basement approximately 1130 meters below the sea floor -- a figure that is nearly double the figure that basalt was encountered (623 m) in the hole. Detailed seismic profiler recorders of the drill sites (The Shipboard Scientific Party, 1972a, p. 221) show a hummocky basement, hence the discrepancy may indicate that the hole happened to center over a basement high.

Figure 13. Isopach of sediments above acoustic basement. Cruise tracks used to make the estimates are shown as dotted lines. Bathymetry at 200, 2000 and 4000 m is indicated. Dark areas are seamounts.

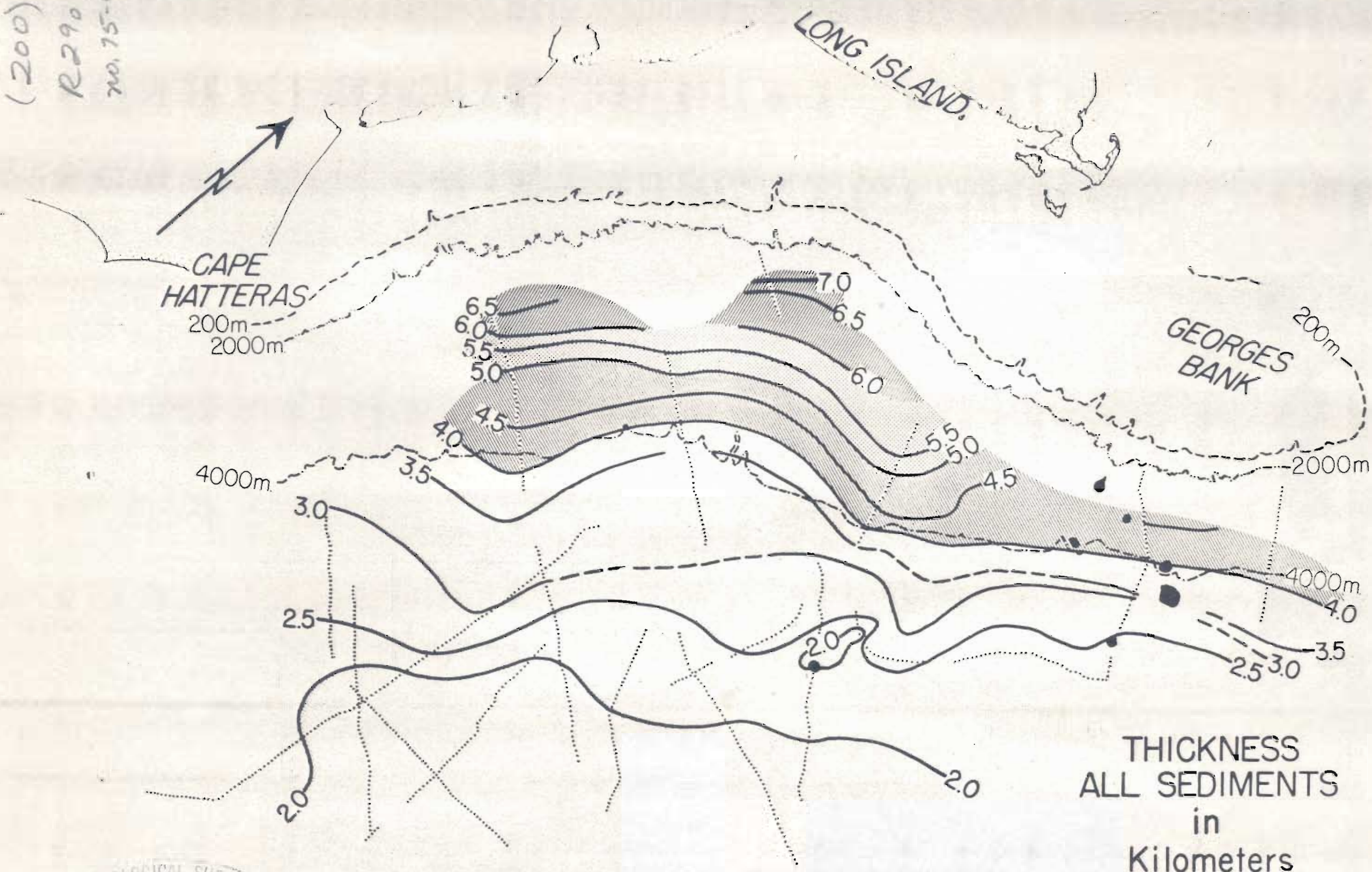

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Fig. 13

We interpret the two profiles in a similar manner but without the basement horst beneath the outer continental shelf. The Maryland line (line 3) (fig. 4) shows no evidence of it, and the data on the New Jersey line (line 2) are equivocal. Velocity scans suggest a structural high of dense rock (below 4 seconds 2-way travel time) below the outer shelf off New Jersey, but is it crystalline rock or a refractory sedimentary rock such as dolomite or siliceous limestone? We think that the rocks are sedimentary because of the foresets evident at the 4-second level (fig. 8), and because we see no evidence in the seismic data of the fault along which the horst was uplifteed. Data show a steep gradient along the northwest edge of the "east coast magnetic anomaly" but computer analyses of the data indicate a complex source and a good depth solution could not be obtained. What may exist are a deeply buried carbonate platform and reef deposits that formed atop a block-faulted margin immediately following the separation of Africa and North America (fig. 14). Reefs may have begun to grow on one of the blocks and continued to do so as the margin gradually subsided. If so, they migrated with time seaward to occupy what is now the area under the upper continental slope. They appear to have acted as sediment dams to a thick sedimentary sequence that filled in behind them. Eventually, the reefs were overwhelmed by the infilling sediment prism which built over them and spread sediment directly onto the deep ocean floor. The broad tectonic framework for the Baltimore Canyon trough is similar to what Beck and Lehner (1974)have pictured for the foundered margin of west Africa sans diapirs, and what Mayhew (1974) has envisioned for the western Atlantic margin of North America. Figure 14 is modified from the Beck and Lehner paper to indicate how to view the Baltimore Canyon part of the margin.

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Figure 14 near here

The age of the acoustic units on the profiles is probably similar to what was inferred for Georges Bank -- namely the uppermost unit is equivalent to sediment of Cenozoic age, the middle one is equivalent to the Cretaceous section, and the lowest (a mjaor part of the section, figures 4 and 5) is equivalent to the Jurassic section. In the Baltimore Canyon trough, the problem of inferring the age of units offshore is complicated by the substantial thickness change (over 5 times from the coast to the deep part of the basin) and the complex facies changes that take place along the strike of the formations of the Atlantic Coastal Plain (Minard and others, 1974). On line 2 (fig. 2, point Y) the uppermost interval (inferred as Cenozoic) changes from 0.3 km (inner shelf) to 1.2 km (outer shelf). The inner shelf figure compares to 0.36 km of Cenozoic sediment encountered on the Island Beach well at the New Jersey coast, 12 km away. A thickness of 1.2 km for the Cenozoic deposits beneath the outer shelf (assuming a velocity of 2 km/sec) agrees well with Emery and Uchupi's isopach map (1972, figure 190) which shows 1.4-1.6 km of Cenozoic sediment there. The projection of this unit out on to the continental slope (fig. 12, point V) shows it to give out at 1500 m water depth, a figure that is about 200 m less than what Weed and others (1974) infer. The prograded nature (figs. 7 and 8) of this uppermost acoustic unit agrees well with the inferred deltaic complexes of Tertiary age described by Garrison (1970) from a sonic survey of the shelf immddiately north of the New Jersey and south of New England. Garrison was able to distinguish several prominent reflectors at the base of and within the Cenozoic section.

Figure 14. Schematic cross section of the Baltimore Canyon trough.

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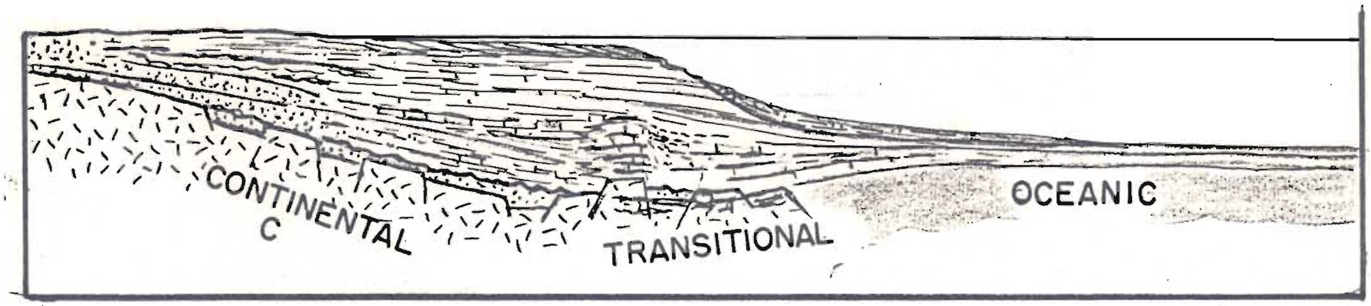

Fig. 14

In the Maryland line (line 3), the equivalent acoustic unit changes in thickness from approximately 0.6 km inshore to 1.3 km beneath the shelf edge; closest land well (E.G. Taylor 1G, 37 km from inshore end of the profile) cored slightly more than 0.4 km of Cenozoic sediment (Minard and others, 1974, fig. 5).

By comparison with coastal land wells, the middle acoustic unit is inferred to correlate with the Cretaceous system. On the inner shelf of New Jersey this figure would include about 1.8 km of section; this figure compares with 0.8 km of Cretaceous rocks drilled in the Island Beach well. Farther south, on the inshore part of the Maryland line, the interval would include 2.6 km of the section (compared to 1.5 km in the Taylor well) and leave about 1.1 km of sedimentary rock inferred to be preCretaceous in age; a thin sequence (200 m) of Triassic or Jurassic rocks were encountered in the Taylor well (Perry and others, 1974).

On the New Jersey profile (line 2), a prominent unconformity occurs within the presumed Cretaceous section. The work of Perry and others (1974) and Minard and others (1974), show that the most pronounced disconformity occurs within strata of late Cretaceous age (Raritan-Magothy), but that one between the Lower and Upper Cretaceous is not evident. The Raritan-Magothy unconformity appears regional in extent, and marks a major marine transgression over a deltaic complex that formed during the Early Cretaceous (Gill and others, 1969). It seems likely that the hiatus seen on the New Jersey line with an associated circular magnetic anomaly (figs. 4 and 9) is a local one formed in response to uplift of the shelf during emplacement of the igneous intrusion; the substantial thickness of sediment both above and below the unconformity within the middle acoustic unit, makes suspect that the hiatus may be down in the section, perhaps within the sequence of Lower Cretaceous age. Depth estimates to the source of the magnetic anomaly suggest, however, that the top of the intrusion must not be very deep below the deepest reflector ($\pm$ 5 km).

We infer the third and lowest acoustic unit to be equivalent to Jurassic (?) and older sedimentary rocks. The lack of a well zoned Jurassic section closeby makes it difficult to project stratigraphic trends offshore. Maher (1971) and Perry and others (1974) indicate a Jurassic (?) age for some of the red, brown, and gray arkosic sandstone and shales in the Salisbury embayment. Beneath the shelf, the closest described section is off the Canadian Maritimes where up to 6 km of marine carbonates (with evaporites) and non-marine clastics have been drilled in a series of structural basins (McIver, 1972; Amoco Canada Petroleum Company Ltd. and Imperial Oil Ltd., Offshore Exploration Staffs, 1974). They are separated by an unconformity from rocks of early Cretaceous age on the Grand Banks; southwest off Nova Scotia, unconformities are within the Jurassic system, and the sequence shows a lateral gradation north to south, from nonmarine to marine conditions. If similar change occurred in the Baltimore Canyon trough, the unfossiliferous shale and fine-grained feldspathic sand deposited in a continental milieu (Brown and others, 1972, p. 37) might be expected to give way to evenly bedded marine shale and carbonates. Further, the faint suggestion of a diapir (point V, fig. 3) could be evidence of a deeply buried evaporite sequence under the Baltimore Canyon trough area. Sheridan (in press) has speculated on the possibility of such a structure to account for a dome he located on the Delaware outer continental shelf. The age of the reef beneath the outer shelf-upper slope would appear to bridge the interval from Late Jurassic to early Cretaceous, to judge from

(paragraph continues)

its position the upper part of the lower acoustic sequence; the tendency for the "foreset" sequence to build upward and seaward into the anomalous "reef" mass under the continental slope suggests reef development may have taken place over an indetermined interval and migrated. The possibility that this structure could be early Cretaceous in age would match with shallow water carbonate shown by Paulus (1972) for the Gulf of Mexico and Blake Plateau region. Here a more or less continuous barrier reef system is thought to have extended from the Blake Plateau, down through the Bahamas and northern coast of Cuba, around the Gulf of Mexico to the Yucatan Platform. Sheridan (1974b) speculates on the existence of such an aged reef off New Jersey as does Mayhew (1974) for the east coast margin in general. Further north under the Scotian Shelf and the Grand Banks (McIver, 1972; Amoco Canada Petroleum Company Ltd. and Imperial Oil Ltd, Offshore Exploration Staffs, 1974) some shallow marine platform carbonates of Late Jurassic age have been drilled.

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