United States Department of the Interior

Geological Survey

NEW YORK BIGHT FAULT

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Open-File Report 82 - 208

1982

INTRODUCTION

One of the persistent and puzzling aspects of recent earthquake activity in intraplate regions such as the northeastern United States has been the lack of evidence for young surface faults (for example, Yang and Aggarwal, 1981; Sykes, 1978). This paper describes a fault identified in the New York Bight area of the United States Atlantic continental margin which provides clear evidence for fault movements in the Cretaceous and tentative evidence for motion in the Tertiary and the Quaternary.

Identification of the fault is based on 633 km of single-channel and multichannel seismic-reflection data collected by the U.S. Geological Survey (USGS) aboard R/V GYRE in September, 1981, and on a 48-fold multichannel line contracted to Geophysical Services, Inc. (GSI) by the USGS in 1978. Our seismic profile grid and the location of the fault are shown in figure 1.

During the September GYRE cruise, we identified the fault on lines 2 and 3 while collecting multichannel data. We spent approximately one day collecting single-channel lines 11-16 to trace the fault, then had to resume other scheduled experiments. Lines 2 and 3 were shot using two 80 in^3 waterguns and a 6-channel 600-m-long hydrophone streamer. Because these data have not been processed, our interpretations are based on the single-channel near-trace analog monitor. Lines 11 and 13 were shot using one 80-in^3 watergun with a single-channel hydrophone streamer and recorded to 2 s depth (two-way travel time) with a sampling rate of 1 millisecond (ms). These data have been digitally processed using filters, deconvolution, and time-varying gain scaling. Line 16 was recorded identically to lines 11 and 13 except the source consisted of two 80-in^3 waterguns. Because line 16 has not yet been processed, our interpretations are based on the analog monitor record. USGS Line 24 is a 48-fold multichannel record shot and processed by GSI using techniques similar to those described by Grow and Markl (1977). This data set provides five crossings of the fault. A sixth crossing, an analog Uniboom record collected by the USGS in 1975, crosses the fault the same location as line 24. The poor quality of this record limits its usefulness to estimating the thickness of the Quaternary deposits.

DESCRIPTION OF THE FAULT

This report provides a preliminary descriptive analysis of the only apparent fault. The fault trends north-northeast, approximately 30 km offshore from and subparallel to the New Jersey coast (fig. 1). Our crossings indicate that the fault is at least 30 km long and maybe longer since we have no profiles with which to constrain its southward extension. The fault appears to die out by the northernmost profile, line 16, which is 7 km south of Long Island. The sense of motion is down to the west, with displacement decreasing upsection, indicating a growth fault.

To estimate the offset of reflectors across the fault in meters, we assumed a sediment velocity of 2.0 km/s, which is consistent with refraction data collected south of eastern Long Island (Oliver and Drake, 1951). Interval velocities calculated from multichannel seismic data south and east of the New York Bight suggest actual velocities may range from 1.8 to 2.2 km/s (Grow and others, 1979b). Hence, this estimate is probably accurate to about 10%. This velocity is also convenient since the conversion of milliseconds to meters is one to one: i.e., 30 ms = 30 m.

The magnitude of the displacement is large (figs. 2-6). The basement offset is from south to north: 30 m, 65 m, 75 m, 85 m, and 55 m. Interference from the direct arrival signal prevents resolving offset at the surface, but the shallowest identifiable offset on each profile is (excluding line 24): 15 m, 40 m, 45 m and 25 m. These values suggest that the maximum displacement is in the vicinity of line 11, with offset decreasing northward and southward. The 3.5-kHz echosounding records show no displacement on the water-bottom reflector.

The lack of apparent offset on line 16 suggests that the fault may terminate abruptly at its northern end (fig. 7), although future processing of these data may reveal fine structure that is unresolvable on the analog record.

AGE OF THE FAULT

The regional geology of the New York Bight consists of Paleozoic or Precambrian basement rocks overlain by Cretaceous and Tertiary Coastal Plain sediments (fig. 8) which are mantled by a veneer of Pleistocene and Holocene glacial and post-glacial deposits (Garrison, 1970; Weed and others, 1974; Rampino and Sanders, 1980). Four drill holes along the coastline provide the best existing stratigraphic control (fig. 1). These are the Island Beach Well in New Jersey, the Fort Hancock well on Sandy Hook, the Fire Island well on Long Island, and AMCOR site 6011, offshore from the Island Beach well (Maher, 1971; Brown and others, 1972; Liebling and Sherp, 1975; Perry and others, 1975; Petters, 1976; Hathaway and others, 1976, 1979). This map suggests that the youngest Coastal Plain sediments that could be offset by the fault are Middle Tertiary in age.

Resolving the age of the youngest reflector offset by the fault depends on the ability to extrapolate the stratigraphy from the four well sites to the vicinity of the fault. Unfortunately, there are no seismic ties to the three wells on the coast, and the only seismic ties to AMCOR site 6011 involve multichannel and airgun analog data which lack the resolution necesary to trace reflectors over long distances. Hence, we do not know the age of the reflectors on the seismic profiles.

However, we projected our seismic profiles onto a cross-section of the New York Bight constructed by Perry and others (1975), (fig. 9). This cross section runs between the Island Beach and Fire Island wells. Lines 2, 3, and 24 intersect the cross-section profile; lines 11, 13 and 16 terminate west of the profile and can only be projected into its plane. These extrapolations suggest that lines 2, 3, and 24 cross Upper Cretaceous and Lower Tertiary beds and that lines 11, 13 and 16 cross Upper Cretaceous but little or no Tertiary sediments.

The generalized interpretation from this cross-section is that the fault clearly offsets Upper Cretaceous sediments on all lines, and may offset Lower Tertiary beds near the surface on lines 2, 3 and 24. On line 24, the low frequencies and small scale of the display preclude resolving offset near the surface (fig. 3). On lines 2 and 3, the analog data are obscured in the top 100 ms by the direct arrival (figs. 2 and 4), preventing resolution near the surface. The data in line 3 suggest that offset on the fault dies out near the surface; only a flexure is visible at 140 ms depth on the record. However, the offset on line 2 does not show the same decrease towards the surface, and the youngest reflector that is not obscured by the direct arrival is offset by about 40 ms. This suggests that considerable offset could continue shallower in the section and, therefore, offset Lower Tertiary rocks. Because of poor resolution in the shallow part of the seismic data and our lack of stratigraphic control, this conclusion must be considered tentative.

The evidence for motion of the fault in the Quaternary is based on a warped subbottom reflector on the 3.5-kHz profile collected simultaneously with the line 11 profile (fig. 10). The subbottom reflector comes within 7 ms of the water bottom, directly overlies the fault identified on the line 11 watergun profile (fig. 5), and is consistent with motion down to the west. Because the reflector disappears to the west, total warpage is unknown. The measured offset of 10 ms is therefore a minimum value.

The Uniboom record which crosses the fault at the same location as line 24 indicates that the glacial and post-glacial section is about 25 ms thick. This is the criteria by which we postulate that the warped subbottom reflector at 7 ms depth (fig. 10) is within the Quaternary section. Other studies suggest that the Quaternary secton is of variable thickness, ranging from 7 m (Rampino and Sanders, 1980) to 50-100 m (Hathaway and others, 1976, 1979).

The Uniboom record is of poor quality and shows no apparent offset in the Quaternary section. This is consistent with the line 3 profile (fig. 2) which suggests the fault dies out towards the surface at that location.

In summary, correlation of the seismic data with the cross-section of Perry and others (1975) indicates clear offset of Cretaceous beds and potential offset in the Tertiary beds. A warped subbottom reflector in the 3.5-kHz record suggests offset may have effected the Quaternary section. Our data are not well constrained, but fault motion as recent as the Quaternary cannot be unequivocally eliminated.

SEISMICITY

The New York Bight has a history of seismicity which extends from before the early 1900's to the present time (Smith, 1966: Yang and Aggarwal, 1981). Considerable effort has been devoted to studying the seismicity associated with the nearby Ramapo zone (Sbar and Sykes, 1973; Aggarwal and Sykes, 1978). The intensities and magnitudes for these events are generally low.

There are five instrumentally located epicenters in the Raritan Bay and New York Bight areas (fig. 8; table I). Except for the cluster of activity in the Ramapo zone, the earthquake activity appears to be diffuse.

Three events are located within 20 km of the New York Bight fault. Because a dense station network along the Long Island and New Jersey coastlines is lacking, these offshore epicenters are not well constrained, and the uncertainty in location probably exceeds 10 km (Yang and Aggarwal, 1981). Hence, the location errors for these three earthquakes probably allow parts of the fault to be located within the epicentral zone. This suggests active seismicity may be occurring very close to, if not actually on, the fault.

The north-northeast orientation of the New York Bight fault is completely consistent with north-northeast-striking nodal planes determined from 12 focal mechanism solutions for earthquakes from southeastern New York, northern New Jersey, and coastal New England (Yang and Aggarwal, 1981). The dominant sense of motion from these focal mechanisms is thrusting. Our seismic reflection data are not sufficient to determine the sense of dip on the fault or whether it is reverse or normal.

GRAVITY

The New York Bight is the one place on the east coast where the Piedmont gravity high, a major positive gravity anomaly associated with the trend of the Appalachian mountains, extends offshore (Woollard and Joesting, 1964; Grow and others, 1979a; Haworth and others, 1980). Preliminary processing of gravity data collected simultaneously with the seismic data in September, 1981, indicates that this Piedmont gravity high actually consists of three different positive anomalies: one major peak in Raritan Bay and two lesser peaks in the New York Bight (fig. 11). The fault occurs on the axis of the central peak.

A large negative gravity anomaly separates the Raritan Bay positive anomaly from the other 2 peaks (fig. 11). The large amplitude (40 mgal) and short wavelength (40 km) of this gravity anomaly are unique for any gravity anomaly along the east coast (for example, Grow and others, 1979a; Haworth and others, 1980) and suggest that the source is shallow. Since density contrasts in the Coastal Plain sediments cannot cause an anomaly of this size, we infer that its source arises from the Appalachian basement rocks which underlie the margin. The association of the fault with the positive anomaly at the edge of this low suggests that basement structure controls the location of the fault.

The new gravity data have not yet been mapped and contoured, so the shape of this negative and its associated positive anomalies is still uncertain. The fault does consistently fall on the axis of the central gravity high on each profile, suggesting the basement structure and lithology trends north-northeast. This is consistent with mapped trends of the Appalachian mountains onshore (Williams, 1978) and magnetic anomaly trends offshore (Klitgord and Behrendt, 1979).

SUMMARY AND DISCUSSION

The major results of this preliminary report on the New York Bight fault are:

1) The fault trends north-northeast over a minimum distance of 30 km.
2) It is a growth fault with displacement down to the west.
3) Maximum offset occurs on line 11 with offset apparently decreasing both northward and southward. On line 11 basement offset is 85 m; the shallowest identifiable offset in the Coastal Plain section is 45 m, and offset postulated to occur in the Quaternary section is greater than or equal to 10 m. The fault has no apparent expression on the water bottom.
4) The fault has offset Upper Cretaceous rocks, and may have offset Lower Tertiary and Quaternary deposits. Hence the fault is at least as young as the Upper Cretaceous and may be as young as the Quaternary.
5) Earthquakes have occurred in the New York Bight which could be related to the fault. The north-northeast orientation of the fault

is consistent with fault trends determined from focal mechanism solutions of onshore earthquakes.

6) A large gravity anomaly associated with the fault suggests basement structure has controlled its location and perhaps tectonic history.

It is important to emphasize that these results are preliminary. The magnitude of the fault offset may be slightly modified once the seismic data are processed. The shape and orientation of the gravity anomalies remain to be determined. Better estimates of the distance offset on the fault can be determined when the velocity functions of the multichannel data are analyzed. However, results from the processed data should not significantly alter our basic conclusion that a large fault exists in the New York Bight. No other fault its size or in proximity to a major metropolian area (i.e., New York City) has been identified on the east coast. Problems which warrant further documentation are:

1) the northward and southward extent of the fault;
2) the age of the youngest deposits offset by the fault;
3) better determination of the offset in distance;
4) the dip of the fault plane;
5) the nature of the basement structures and/or lithologies controlling the location of the fault;
6) the age or physical significance of traceable reflecting horizons;
7) the relation of offshore seismicity to the fault;
8) the potential for future movement of the fault;

ACKNOWLEDGEMENTS

We thank Mary Beth Hulit of Allegheny College for compiling many of these preliminary results, and Dick Wise for doing the preliminary processing of lines 11 and 13. Kim Klitgord, Pete Popenoe, and Elizabeth Winget reviewed the manuscript.

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FIGURE CAPTIONS

Figure 1: Location map of the New York Bight showing existing seismic-reflection profile grid. The fault is the heavy solid line. Down and up motion are indicated by D and U respectively.

Figure 2: Analog seismic-reflection profile of line 3 across the fault, filtered 8-60 Hz. Vertical scale is two-way travel time in seconds. Offset on the fault is shown to the right of the profile in milliseconds (ms).

Figure 3: Multicahnnel seismic-reflection profile of USGS line 24 across the fault, filtered at 15-45 Hz. Scales as described in figure 2.

Figure 4: Analog seismic-reflection profile of line 2 across the fault, filtered 8-60 Hz. Scales as described in figure 2.

Figure 5: Digital single-channel seismic-reflection profile of line 11 across the fault, filtered at 20-110 Hz. This profile shows the maximum observed offset on the fault.

Figure 6: Digital single-channel seismic-reflection profile of line 13 across the fault, filtered at 20-110 Hz.

Figure 7: Analog seismic-reflection profile of line 16 across the projected trace of the fault, filtered 8-60 Hz. The lack of apparent offset suggests the fault has terminated by this location.

Figure 8: Regional pre-Quaternary geology of the New York Bight showing the fault location, well locations, and instrumentally located epicenters. The geology is compiled from U.S. Geological Survey (1967), Fisher and others (1970), Weed and others (1974), and Williams (1978). The earthquake epicenters were compiled from the Lamont-Doherty Geological Observatory and Weston Observatory Bulletins for 1975-1980 (table I).

Figure 9: Cross section between the Island Beach and Fire Island wells with the locations of our seismic profiles projected into the cross section plane. After Perry and others (1975), with location coordinates and depths verified in Brown and others (1972).

Figure 10: Echo-sounding 3.5-kHz profile of line 11 showing the warped subbottom reflector at the location of the fault.

Figure 11: Gravity profile across the New York Bight showing the fault location. Free-air values are from preliminary processing of the R/V GYRE data. Bouguer values are taken from Haworth and others (1980).

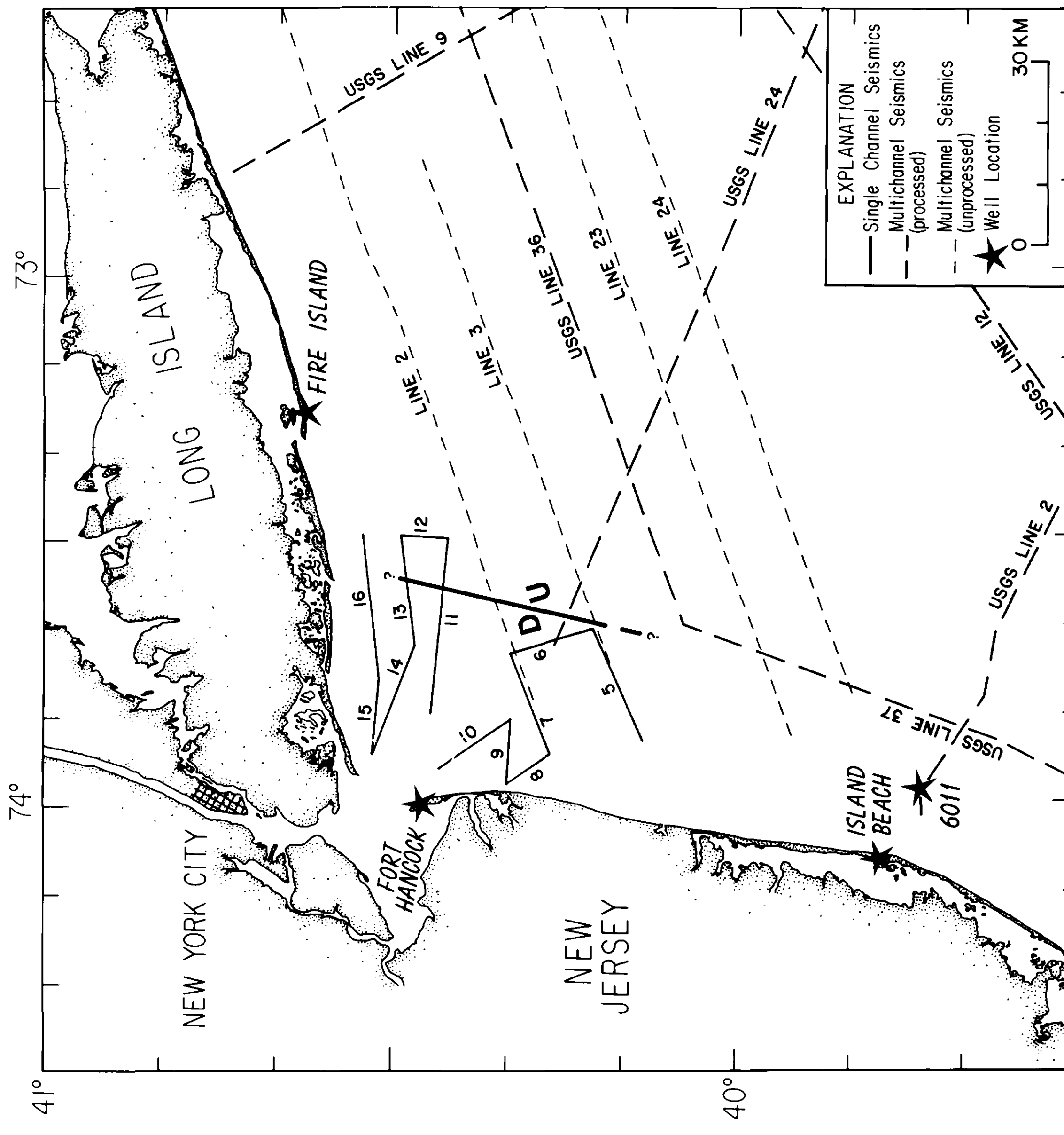
TABLE I: EARTHQUAKE EPICENTERS IN THE NEW YORK BIGHT AND VICINITY

DATE	TIME	LAT (N)	LONG (W)	DEPTH	MAGNITUDE[1]	LOCATION	REF
1981MAR19	0851:35.24	40°56.40´	73°21.60´	9.59	2.0 Mn	Boonton, N.J.	W
1980AUG20	1721:59.70	40°25.80´	74°09.00´	7.56	3.1 Mn	Keyport, N.J.	W
1980MAY07	0432:49.28	41°01.07´	73°52.32´	0.0	2.6 Mn	Ardsley, N.J.	L
1980APR05	1149:33.77	39°49.64´	74°02.97´	6.17	2.9 Mn	Seaside, N.J.	L
1979JAN30	1630:52.13	40°19.29´	74°15.81´	5.00	3.5 Mn	Cheesquake, N.J.	L
1979JAN17	1256:19.43	40°19.88´	73°43.41´	1.00	-	offshore, N.J.	L
1978SEP19	0411:46.62	40°59.49´	73°52.02´	4.62	1.8 Mn	Yonkers, N.J.	L
1978APR03	2357:58.0	40°31.80´	74°04.80´	-	2.0 Mn	offshore, N.J.	L
1978FEB15	0528:41.0	40°55.10´	74°25.83´	6.50	1.6 Mn	Bouton, N.J.	L
1977JAN21	2050:44.5	39°58.2´	74°19.20´	6.0	2.7 Mn	Lakehurst, N.J.	W
1976NOV22	0443:13.4	40°59.81´	73°51.48´	5.0	1.9 Mn	Yonkers, N.Y.	L
1976OCT28	0113:31.67	40°53.57´	74°29.24´	0.0	<1 Mn	Denville, N.J.	L
1976SEP22	0904:44.9	41°17.10´	73°57.08´	7.54	1.8 Mn	Indian Pt., N.Y.	L
1976MAY11	1318:14.42	40°29.07´	73°47.74´	1.17	2.8 Mn	offshore, N.J.	L
1976MAY11	0755:25.5	40°28.8´	73°48.0´	-	1.9 Mn	offshore, N.J.	L
1976APR13	1539:13.20	40°50.10´	74°02.85´	2.44	3.1 Mn	Ridgefield, N.J.	L
1976MAR12	1028:56.4	40°57.26´	74°21.41´	4.64	-	Riverdale, N.J.	L
1976MAR11	2107:20.25	40°57.12´	74°21.19´	0.0	2.4 Mn	Riverdale, N.J.	L

[1] Mn: Nuttli formula

[2] L: Regional Seismicity Bulletin of the Lamont-Doherty Geological Observatory (1975-1980)

W: Northeastern U.S. Seismic Network Bulletin of the Weston Observatory (Nos. 1-22)



41°
40°
74°
73°
NEW YORK CITY
LONG ISLAND
FIRE ISLAND
NEW JERSEY
FORT HANCOCK
ISLAND BEACH
6011
USGS LINE 9
LINE 2
LINE 3
USGS LINE 36
LINE 23
LINE 24
USGS LINE 24
USGS LINE 12
USGS LINE 2
USGS LINE 37
D U
EXPLANATION
Single Channel Seismics
Multichannel Seismics (processed)
Multichannel Seismics (unprocessed)
Well Location
0
30 KM

Fig. 1

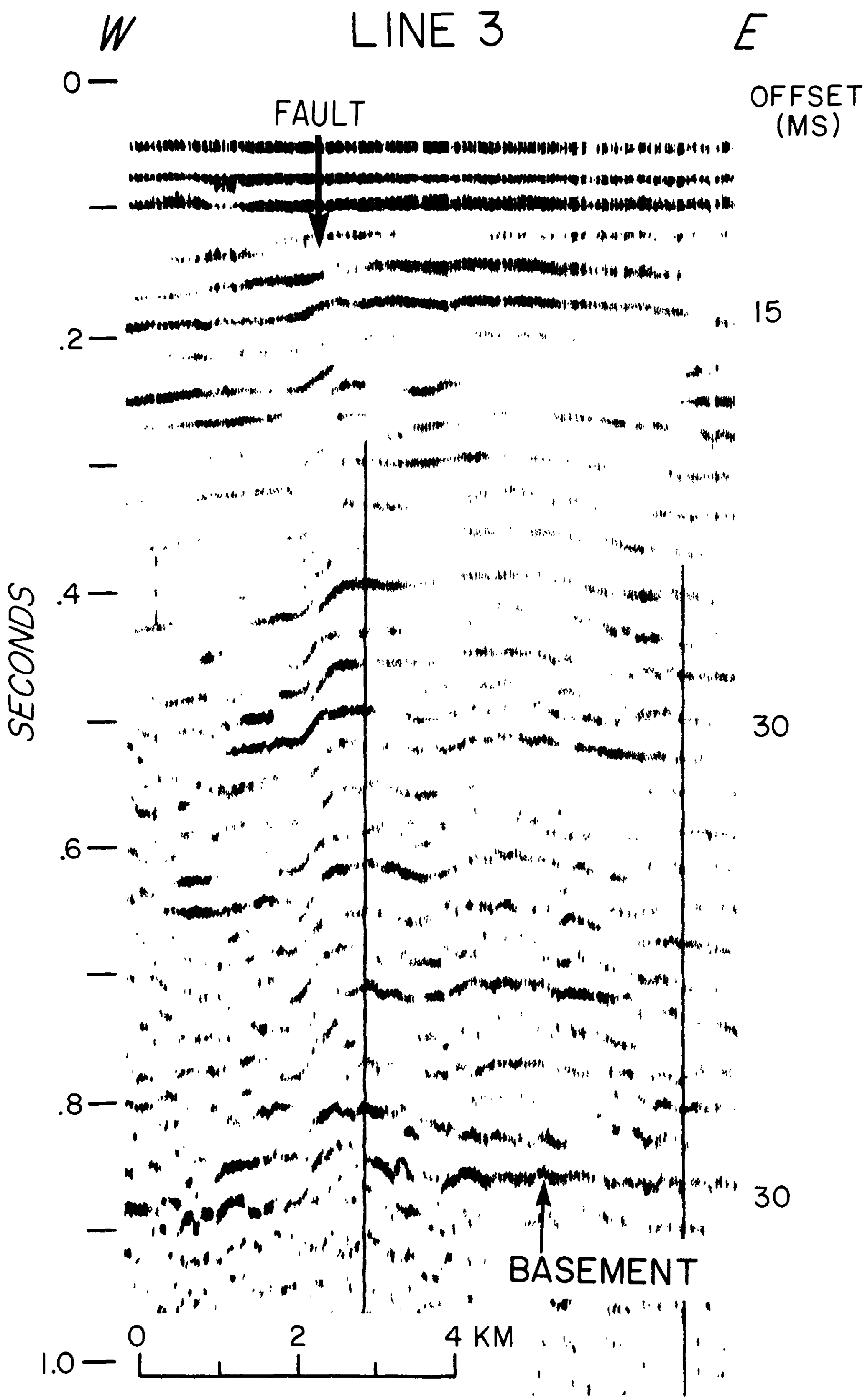

W
LINE 3
E
OFFSET (MS)
FAULT
15
30
30
SECONDS
0
.2
.4
.6
.8
1.0
BASEMENT
0
2
4 KM

Fig. 2

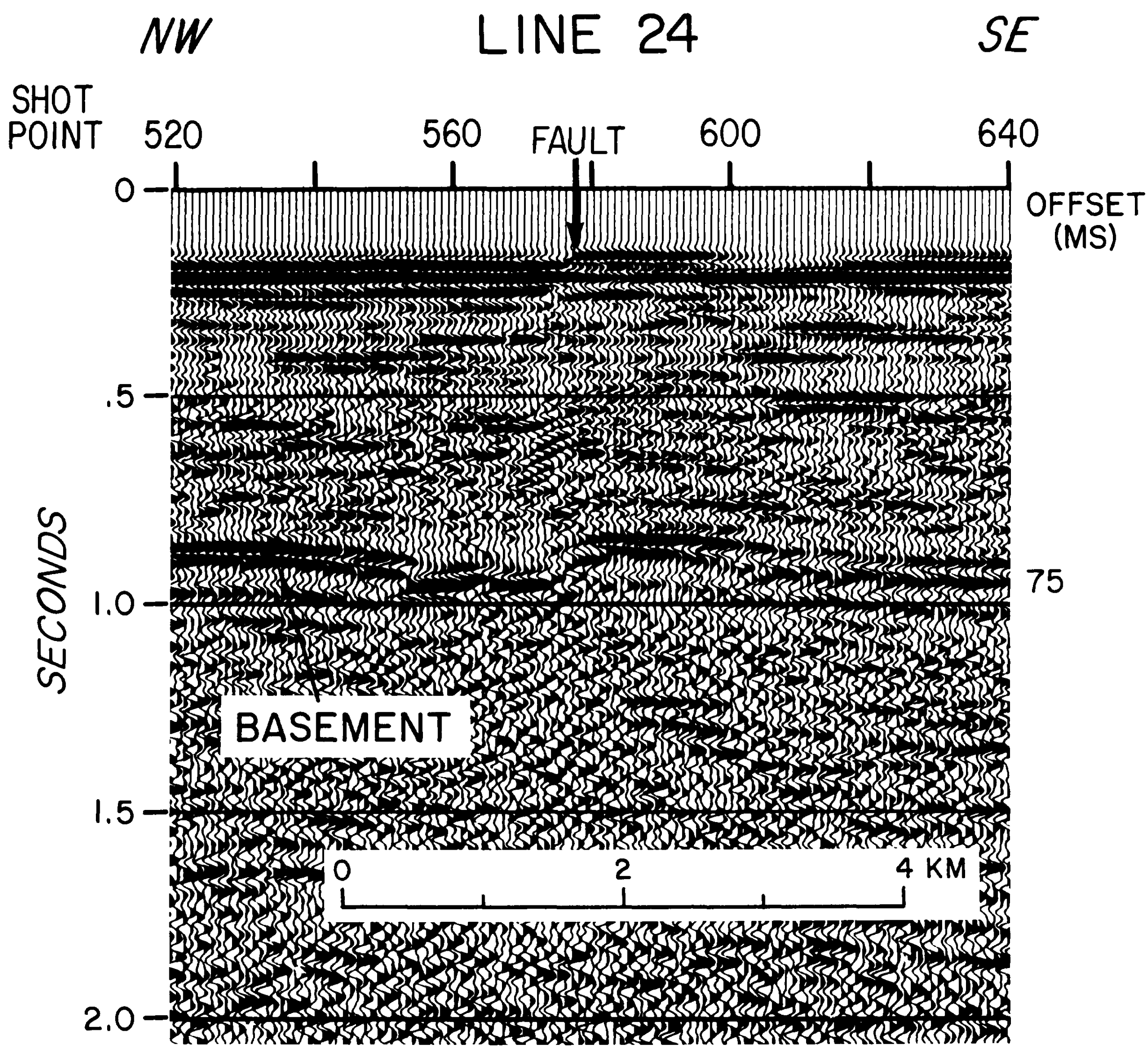

NW
LINE 24
SE
SHOT POINT
520
560
FAULT
600
640
0
.5
1.0
1.5
2.0
SECONDS
OFFSET (MS)
75
BASEMENT
0
2
4 KM

Fig. 3

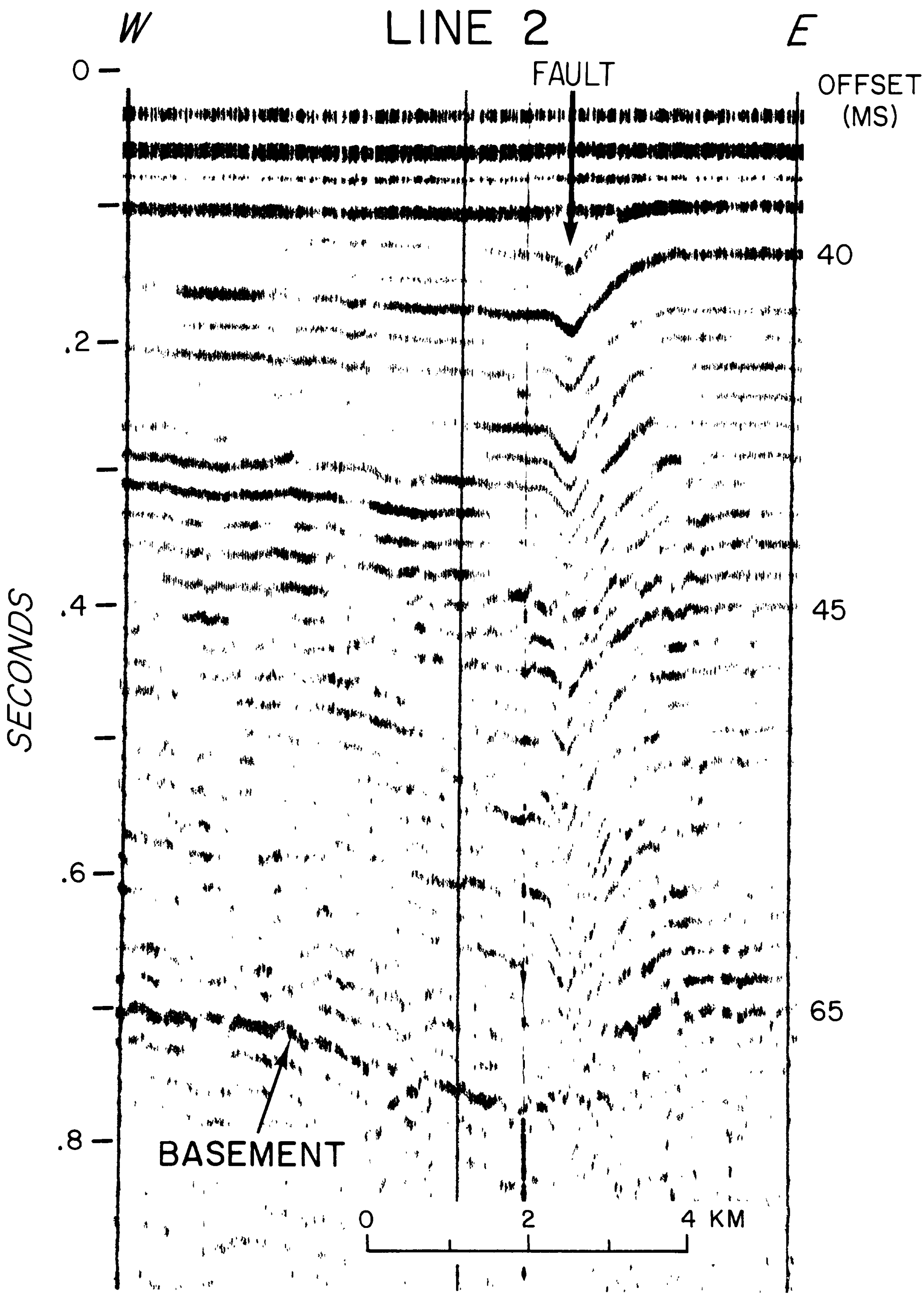

W
LINE 2
E
FAULT
OFFSET
(MS)
40
45
65
0
.2
.4
.6
.8
SECONDS
BASEMENT
0
2
4 KM

Fig. 4

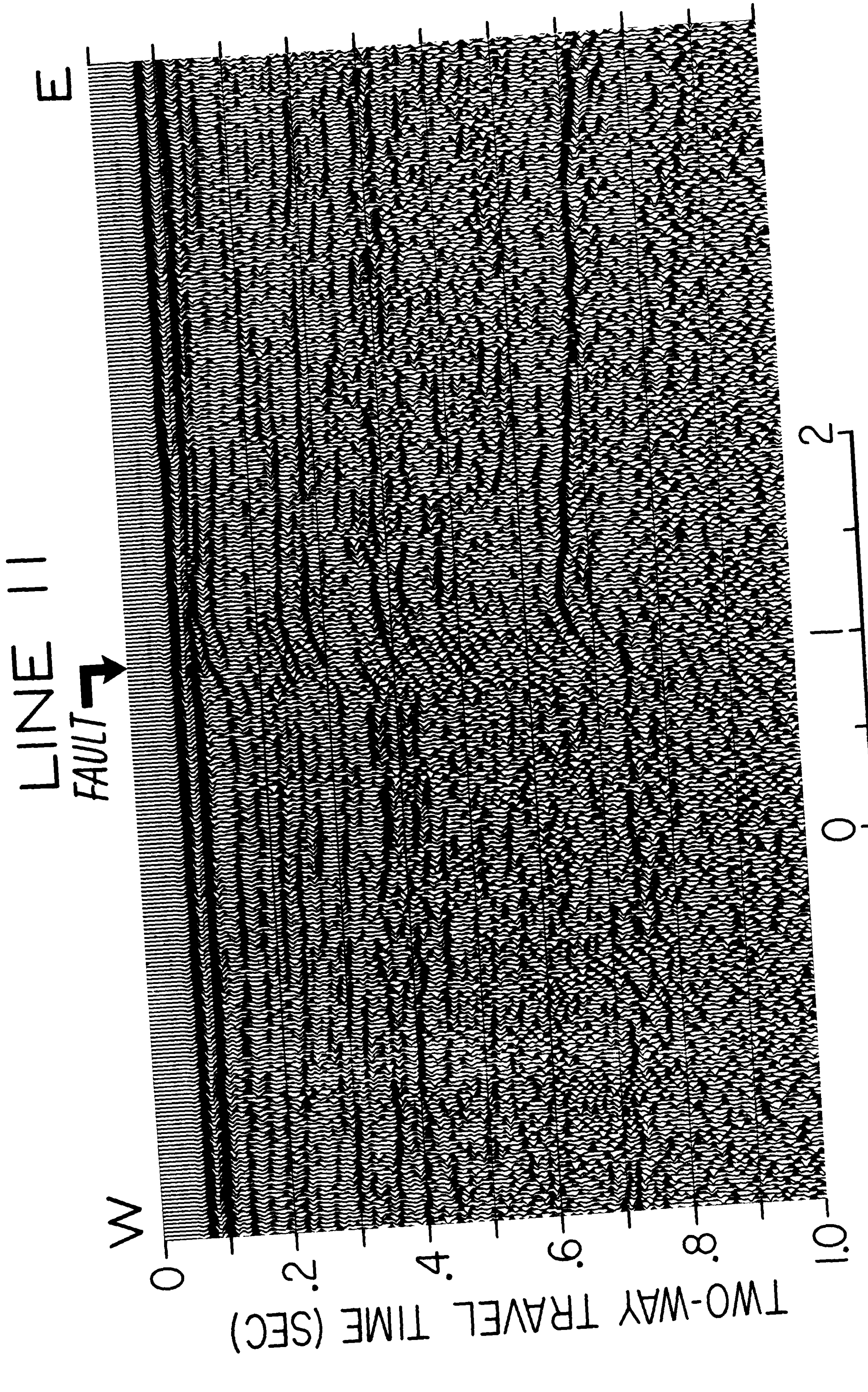


Fig. 5

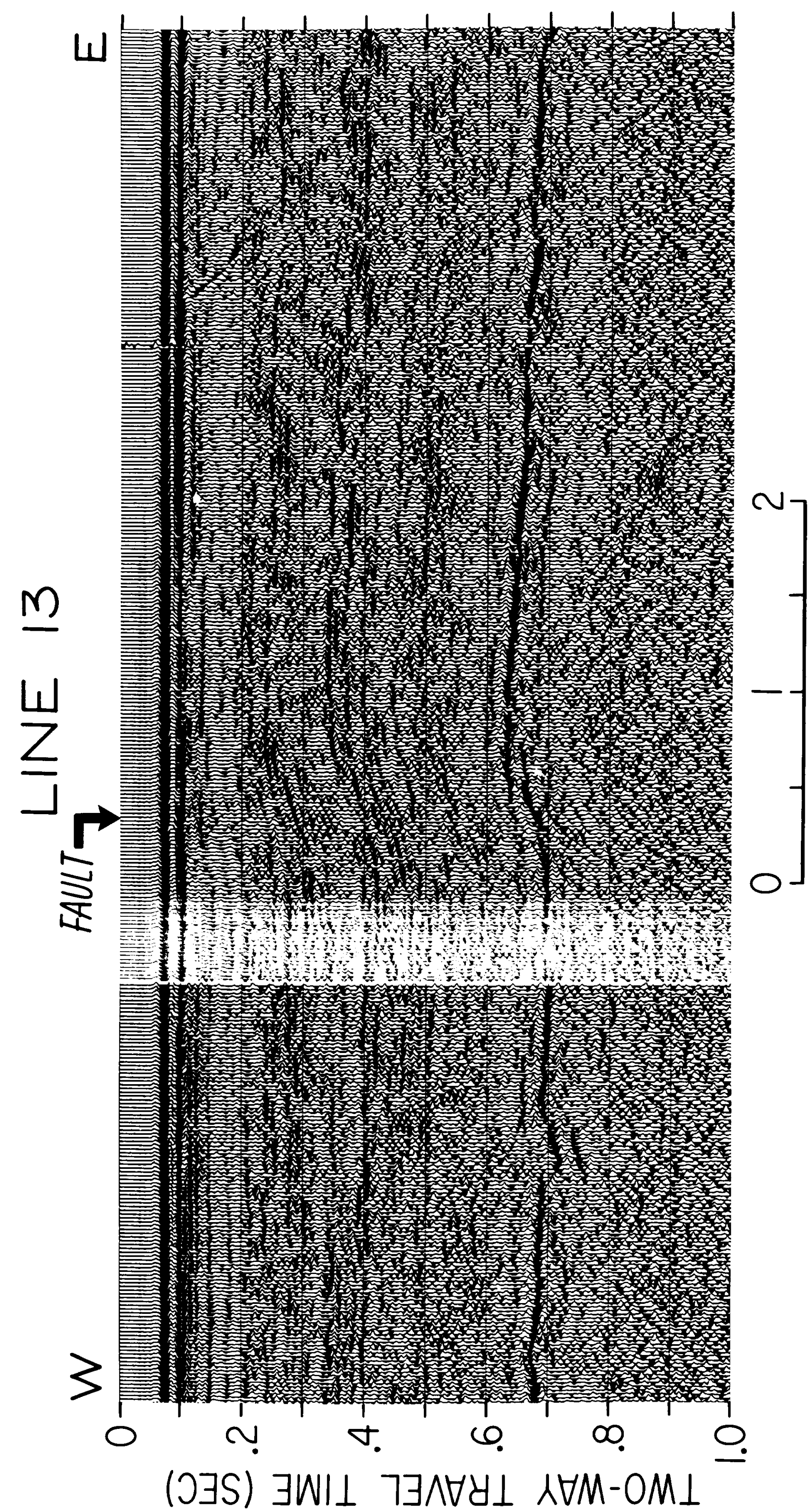


Fig. 6

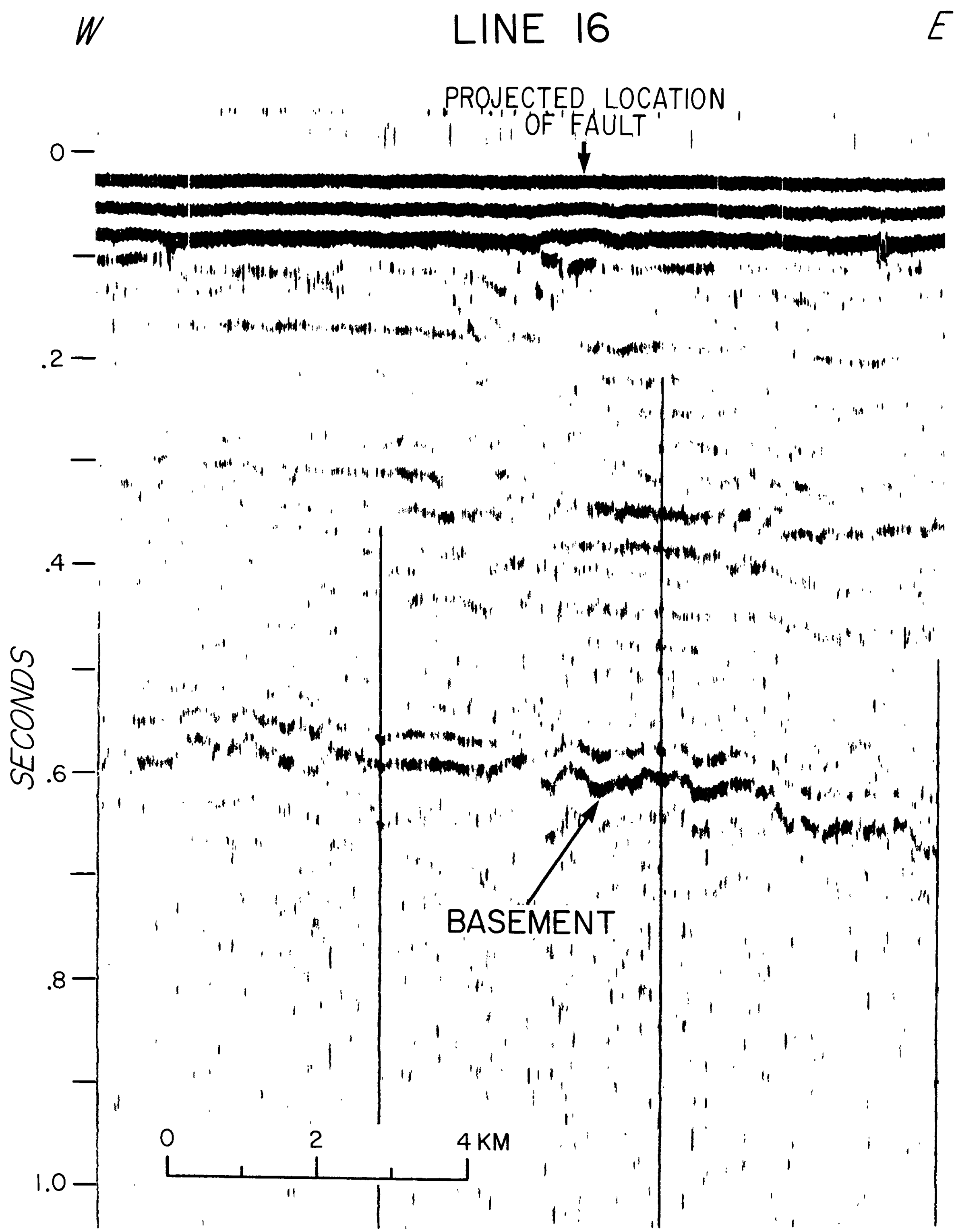
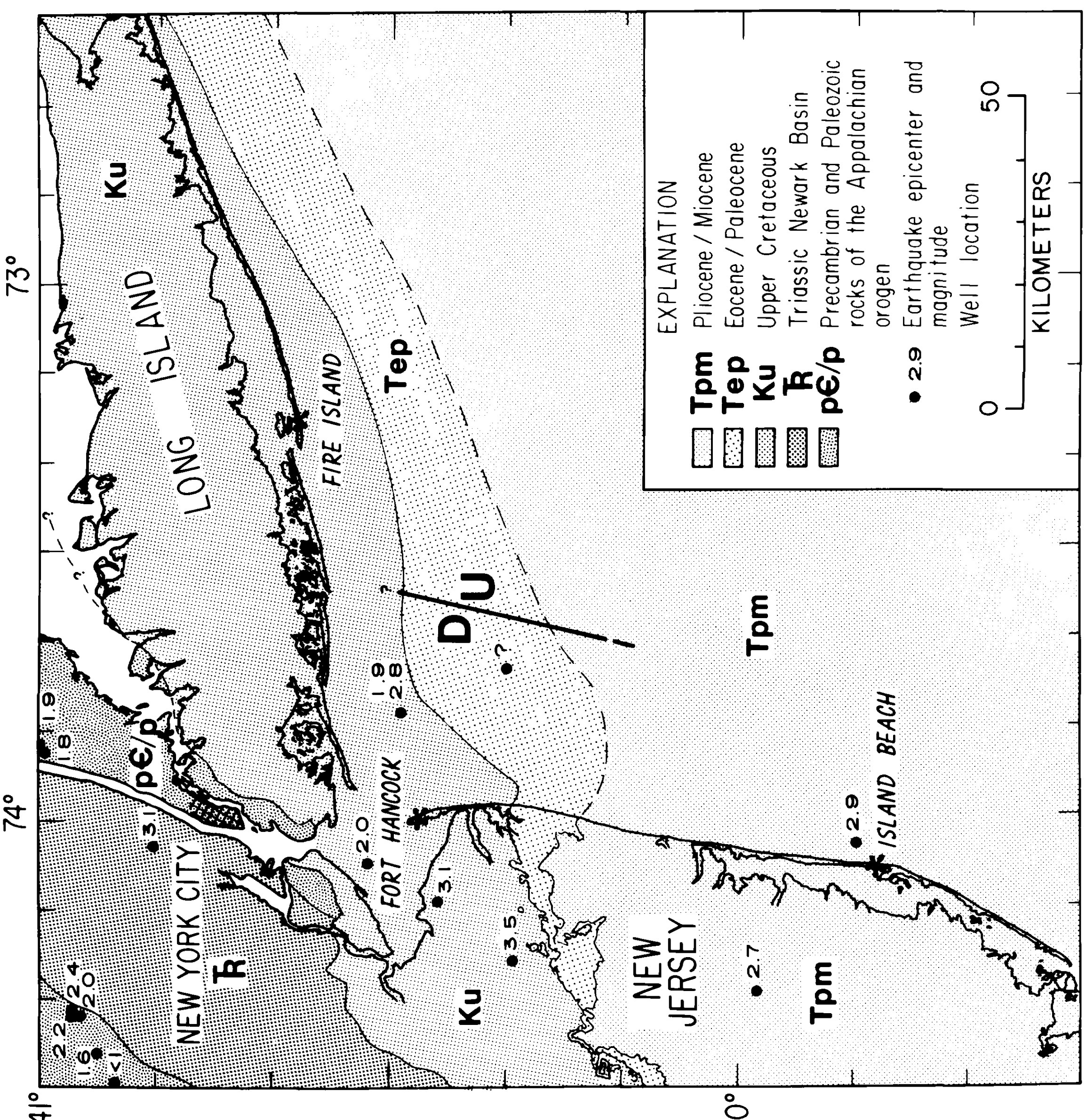
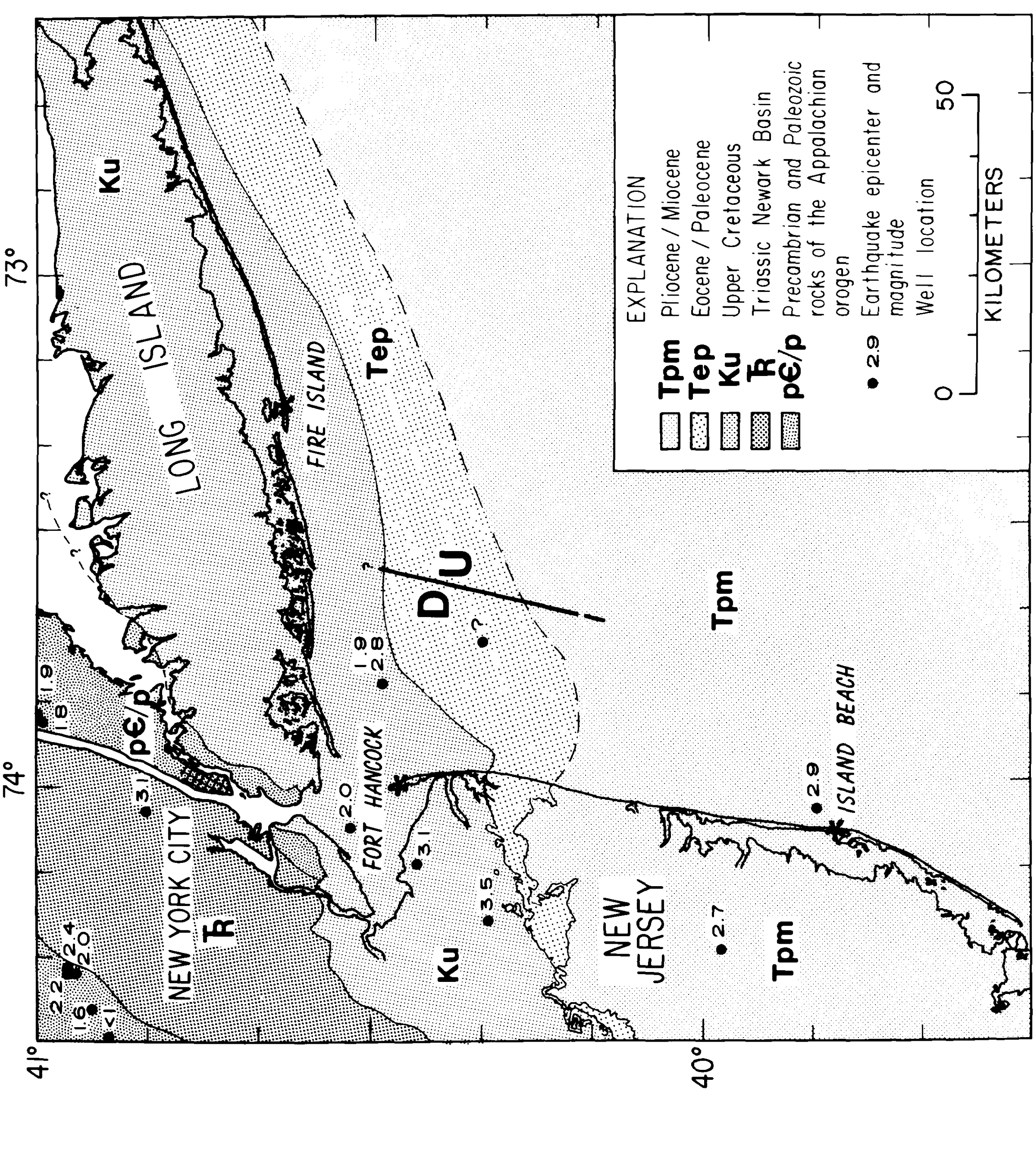

W
LINE 16
E
PROJECTED LOCATION
OF FAULT
0
.2
.4
.6
.8
1.0
SECONDS
BASEMENT
0
2
4 KM

Fig. 7



41°
40°
74°
73°
NEW YORK CITY
Ŧ̄R
pЄ/p
LONG ISLAND
FIRE ISLAND
FORT HANCOCK
ISLAND BEACH
NEW JERSEY
Ku
Tep
Tpm
D
U
EXPLANATION
Tpm Pliocene / Miocene
Tep Eocene / Paleocene
Ku Upper Cretaceous
Ŧ̄R Triassic Newark Basin
pЄ/p Precambrian and Paleozoic rocks of the Appalachian orogen
• 2.9 Earthquake epicenter and magnitude
Well location
0
50
KILOMETERS

Fig. 8



41°
40°
74°
73°
NEW YORK CITY
LONG ISLAND
FIRE ISLAND
FORT HANCOCK
ISLAND BEACH
NEW JERSEY
Ku
Tep
Tpm
pЄ/p
D
U
EXPLANATION
Tpm Pliocene / Miocene
Tep Eocene / Paleocene
Ku Upper Cretaceous
Triassic Newark Basin
pЄ/p Precambrian and Paleozoic rocks of the Appalachian orogen
2.9 Earthquake epicenter and magnitude
Well location
0
50
KILOMETERS

Fig. 9

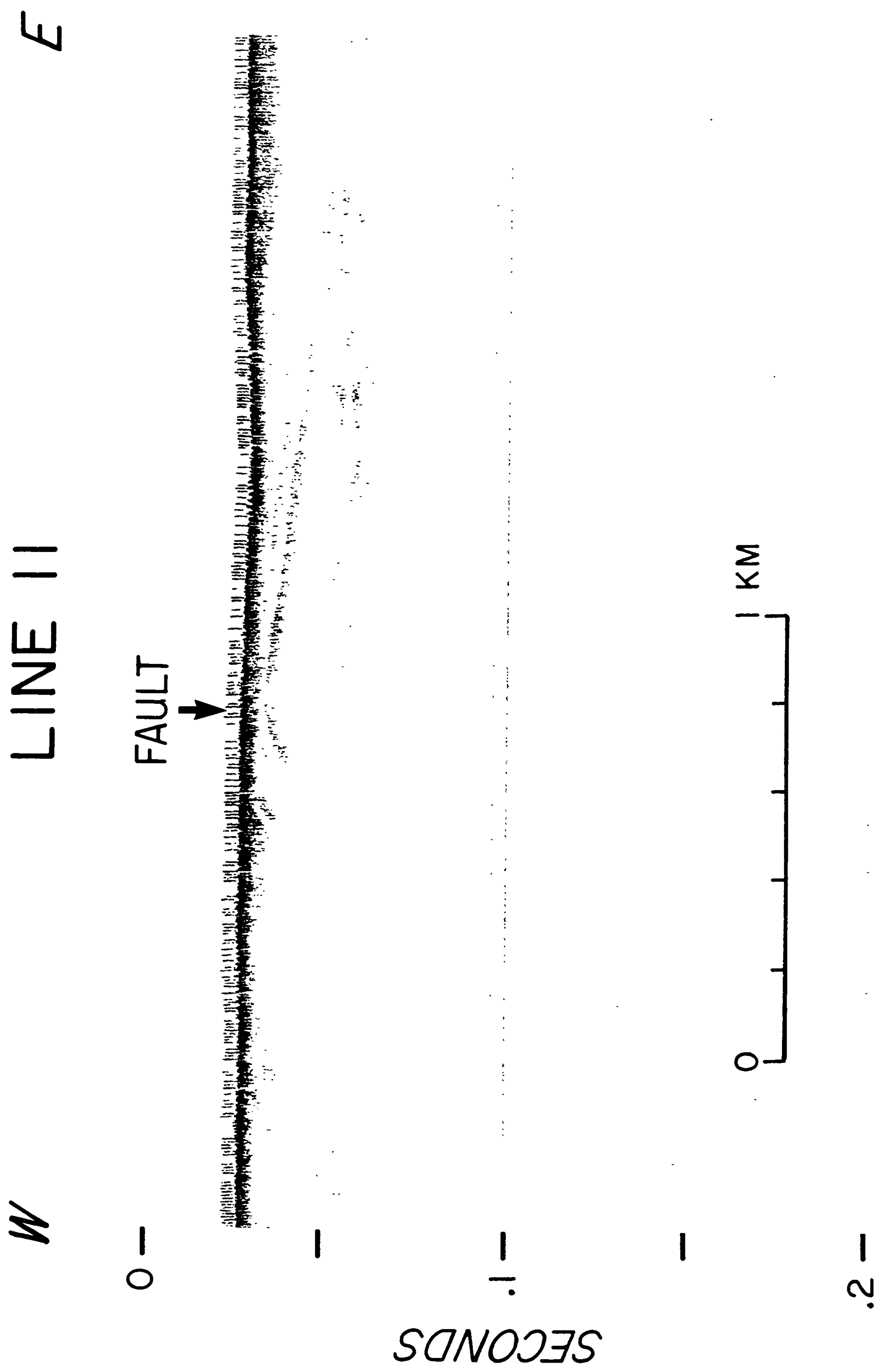


Fig. 10

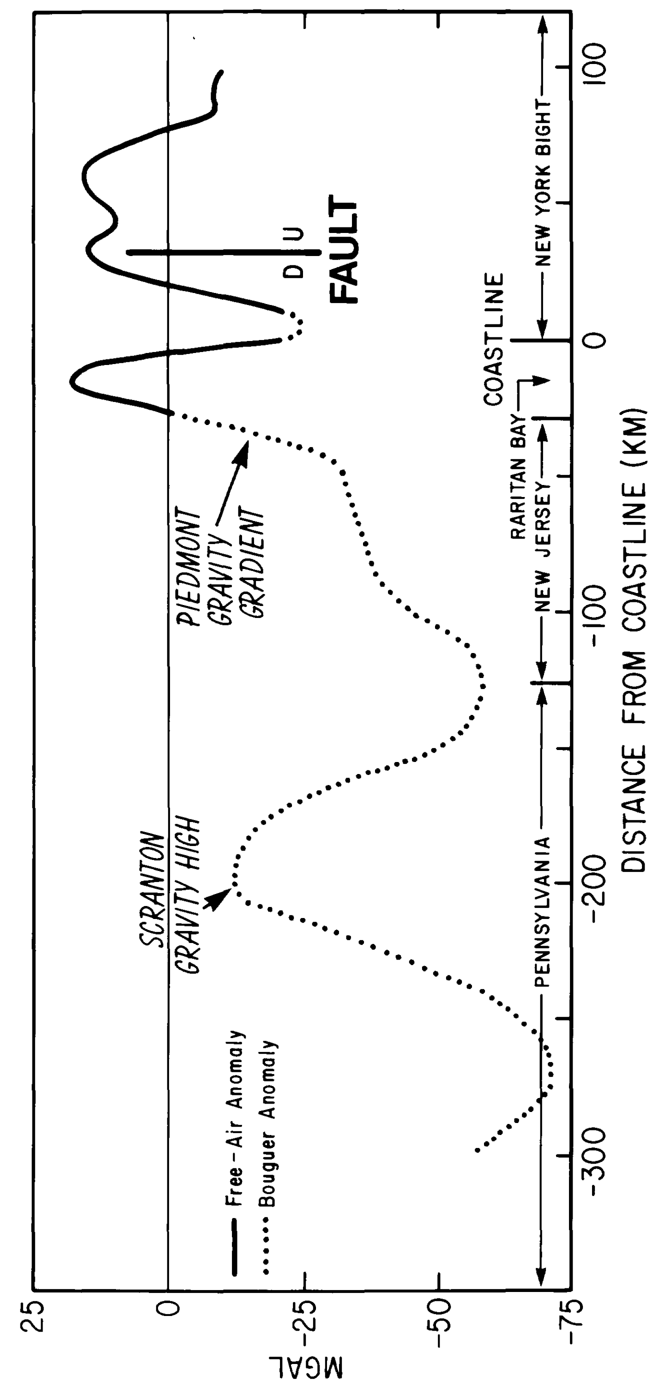

MGAL
25
0
-25
-50
-75
DISTANCE FROM COASTLINE (KM)
-300
-200
-100
0
100
Free - Air Anomaly
Bouguer Anomaly
SCRANTON GRAVITY HIGH
PIEDMONT GRAVITY GRADIENT
D
U
FAULT
PENNSYLVANIA
NEW JERSEY
RARITAN BAY
COASTLINE
NEW YORK BIGHT

Fig. 11