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GEOLOGIC STRUCTURE OF THE FOREARC REGION OFF THE WEST COAST OF COSTA RICA IN THE VICINITY OF THE NICOYA PENINSULA— RESULTS OF A MULTIFOLD SEISMIC REFLECTION SURVEY

by

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INTRODUCTION

During 1977 and again in 1978 the University of Texas Institute for Geophysics (formerly Geophysics Laboratory, Marine Science Institute) collected multifold seismic reflection data off the west coast of Costa Rica. The purpose of this report is to 1) present the seismic data, 2) describe briefly the main structural and geologic features observed on the lines, and 3) discuss briefly how these observations fit into the overall geologic and tectonic setting and evolution of the Costa Rica-Middle America Trench forearc area.

PHYSIOGRAPHIC SETTING

The study area is located off the west coast of Costa Rica in the vicinity of the Nicoya Peninsula (Figs. 1 and 2). The seismic data collected extend from the shelf down across the slope and Middle America Trench (MAT) and into the deep ocean basin (Figs. 1 and 2).

The Middle America Trench is a prominent topographic and geologic feature that extends the entire length of central America from southern Mexico to Panama. Across the study area it shallows from about 5000 m in the northwest to about 2000 m in the southeast (Fig. 1). Just south of the Nicoya Peninsula the trench makes a prominent bend or offset to the northeast.

The deep ocean basin in the northwestern part of the study area contains numerous seamounts called the Guardian Seamounts. They probably are of volcanic origin (Fig. 1). The sea floor in the southeastern part of the area is also very irregular and contains numerous seamounts and extensive elevated areas. This is the northwestern part of the Cocos Ridge,


TRENCH
Lago de Nicaragua
Golfo de Papagayo
Guardian Seamount
PENINSULA DE NICOYA
COSTA RICA
San José
Bluefields
OCEA
D158 323 Miocene
150 KILOMETERS
MILES

FIG. 1

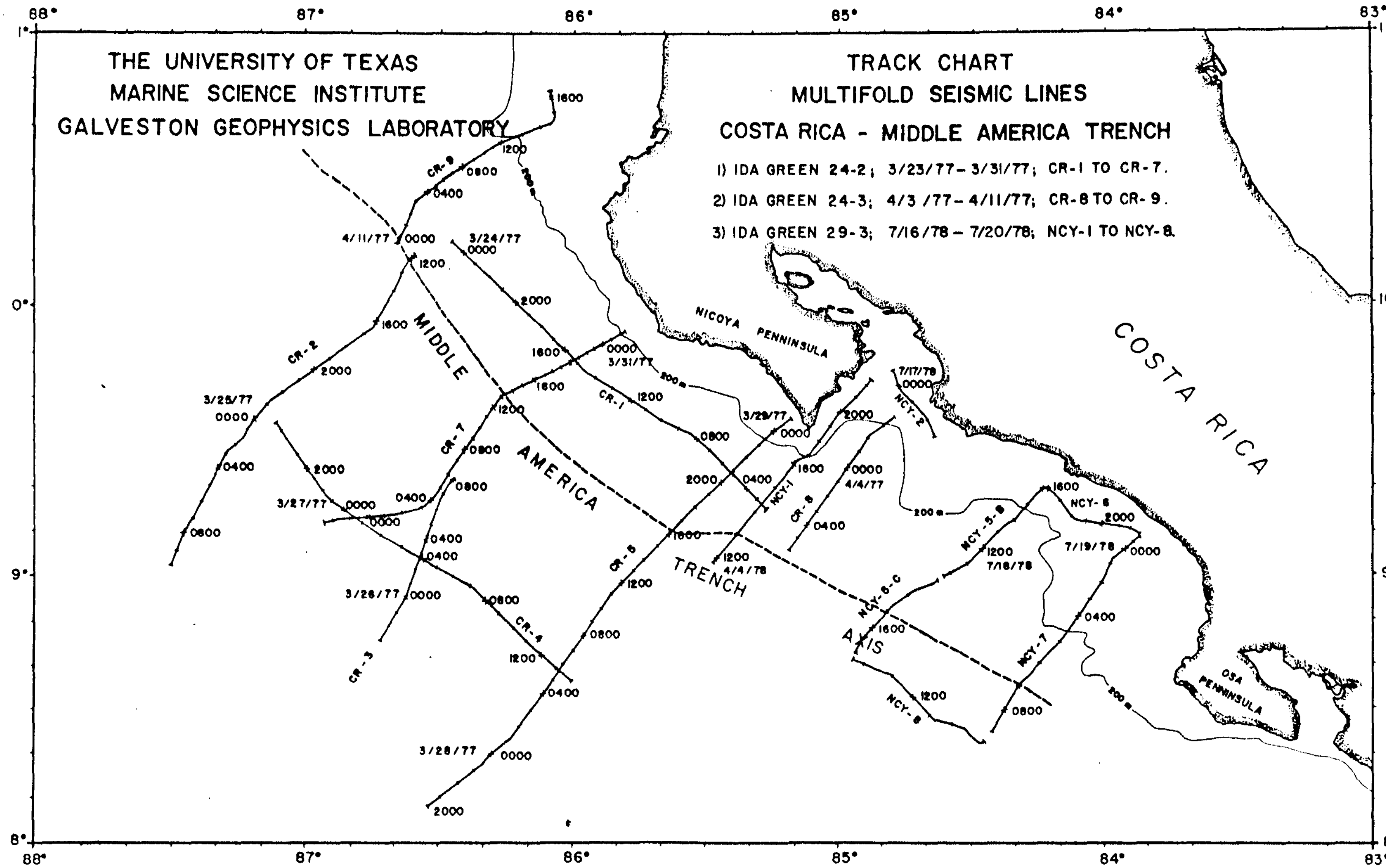
THE UNIVERSITY OF TEXAS
MARINE SCIENCE INSTITUTE
GALVESTON GEOPHYSICS LABORATORY
TRACK CHART
MULTIFOLD SEISMIC LINES
COSTA RICA - MIDDLE AMERICA TRENCH
1) IDA GREEN 24-2; 3/23/77 - 3/31/77; CR-1 TO CR-7.
2) IDA GREEN 24-3; 4/3/77 - 4/11/77; CR-8 TO CR-9.
3) IDA GREEN 29-3; 7/16/78 - 7/20/78; NCY-1 TO NCY-8.
NICOYA PENINSULA
COSTA RICA
OSA PENINSULA
MIDDLE AMERICA TRENCH AXIS
88°
87°
86°
85°
84°
83°
11°
10°
9°
8°

FIG. 2

an extensive oceanic plateau that extends southwest to the Galapagos Islands (Fig. 3).

The continental slope along the northwestern part of the region is relatively smooth. To the southeast it becomes very irregular in the vicinity of the intersection with the Cocos Ridge (Fig. 1). The shelf is relatively broad and is dominated by the Nicoya and Osa peninsulas, although it narrows considerably in the area between the two peninsulas.

GEOLOGIC SETTING

Studies of plate motions suggest that the Cocos Plate is being consumed beneath Costa Rica at about 9 cm/yr along an azimuth of N29°E (Minster and Jordan, 1978) (Fig. 3). Oceanic crust in the area is probably late Oligocene-early Miocene in age based on analyses of sea-floor magnetic anomalies (e.g., Hey, 1977a and b) and DSDP drilling off Guatemala (von Huene et al, 1980). The crust is overlain by up to 500 m of oceanic sediments as observed on the seismic data. These oceanic sediments were drilled during DSDP Leg 67 off Guatemala to the north (von Huene et al, 1980). The Guardian Seamounts are probably of volcanic origin. They occur near the trace of the triple junction within the Cocos Plate marked by a change in relative spreading direction (Hey, 1977a and b) (Fig. 3) and may be related to this feature. The Cocos Ridge is a large oceanic plateau area that extends from the Galapagos Islands to the Central America margin (Fig. 3). It is generally thought to represent the trace of a mantle hot-spot now located at the Galapagos Islands (e.g., Hey, 1977a and b), although other origins have been suggested.

The onland part of the forearc area of Costa Rica landward of the trench has been the subject of various studies. Dengo (1962) presented

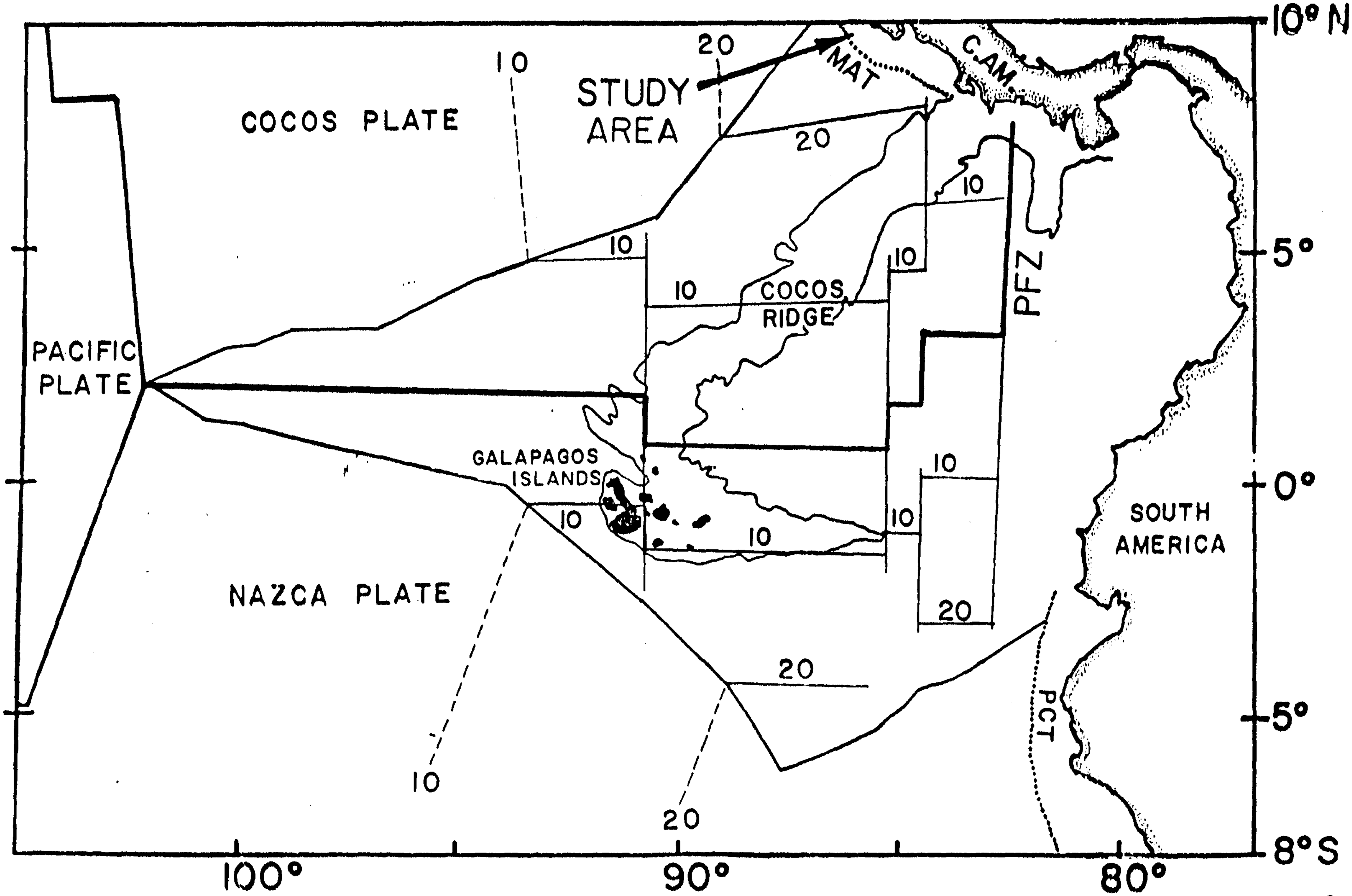
COCOS PLATE
STUDY AREA
MAT
C.AM.
PFZ
COCOS RIDGE
PACIFIC PLATE
GALAPAGOS ISLANDS
NAZCA PLATE
SOUTH AMERICA
PCT
10
20
10° N
5°
0°
-5°
8°S
100°
90°
80°

FIG. 3

the first good overview of the geology of Costa Rica. A generalized geologic map of Costa Rica was published in 1968 (ICAITI, 1968) and is still the most recent known map of the entire country. Some of the more recent papers on the geology of Costa Rica, particularly the Nicoya Peninsula area, include de Boer (1979), Galli-Olivier (1979), Kuijpers (1980), and Schmidt-Effing et al (1981). All of these papers contain good reference lists of earlier works. A recent book on the geology of Central America presents a good summary of Costa Rica (Weyl, 1980), while the recent geologic-tectonic map of the Caribbean area shows the regional structural setting (Case and Holcombe, 1980). A comprehensive study of the rocks along the southeastern end of the Nicoya Peninsula is currently being completed by Mr. Neil Lundberg, a Ph.D. student at the University of California, Santa Cruz. Some results of this study are in press (Lundberg, a and b). A brief description of the geology of the area based on all of these references follows.

The basement of the entire southwestern margin of Costa Rica consists mainly of an igneous complex known collectively as the "Nicoya Complex." It includes gabbros, basalts, pillow basalts, volcanic sediments, and oceanic sediments. In places it can be subdivided into two major sequences (upper and lower) (Schmidt-Effing et al, 1981). It is generally agreed that the igneous rocks were formed in an oceanic environment as ocean crust, either at an ocean ridge or as an oceanic plateau. Its age is generally thought to be late Jurassic through Late Cretaceous (Galli-Olivier, 1979), although volcanic rocks as young as Paleocene-Eocene have been associated with the complex (Schmidt-Effing et al, 1981).

Overlying the "Nicoya Complex" in the Nicoya Peninsula area is a sedimentary sequence that ranges in age from Late Cretaceous to Recent. The Late Cretaceous to Eocene rocks consist mainly of volcanic turbidites and mudstones deposited in a relatively deep-water slope environment. The presence of scattered Late Cretaceous shallow-water limestones, however, suggests a very complex and irregular slope environment with local shallow-water areas. The Eocene and younger rocks were deposited mainly in relatively shallow-water environments. The rocks all have a large volcanic component, indicating the presence of a nearby volcanic arc and subduction zone in the area since at least Late Cretaceous.

The Costa Rica margin appears segmented with major boundaries possibly along the north and south ends of the Nicoya Peninsula and along the north side of the Osa Peninsula (Carr and Stoiber, 1977). A boundary along the south side of the Nicoya is supported by the offset of the trench (Fig. 1). Another major boundary may extend across the central Nicoya Peninsula (Liaw, 1981).

Not much is known about the offshore part of the Costa Rica forearc region. Prior to the surveys discussed in this report, there have been no nonproprietary multifold seismic data collected offshore. One of the lines of this survey (CR-7) was used in a recent paper discussing different tectonic processes and styles along the Middle America Trench (Shipley et al, in press). Another line (CR-8) was used in a recent paper that discussed the occurrence of gas hydrates from various margins (Shipley et al, 1979). It is the purpose of this report, therefore, to present the complete set of seismic data collected by the University of Texas off Costa Rica, to describe the main structural and geologic features observed on the data, and to discuss briefly how these observations fit into the geologic and tectonic setting of the margin.

SEISMIC DATA

The University of Texas Institute for Geophysics (formerly part of the Marine Science Institute) collected over 1500 km of multifold seismic reflection data off the western coast of Costa Rica during two cruises in 1977 and 1978, respectively. Figure 2 is a track chart showing the location of the lines collected. Figure 2 also shows cruise names, dates, and lines collected. The 1977 cruise was sponsored by the National Science Foundation as part of a larger study of the entire Middle America Trench between Costa Rica and southern Mexico (lines CR-1 to CR-9). Collection of the second set of lines (NCY-1 to NCY-8) during 1978 was sponsored by the Instituto Centroamericano de Investigacion y Tecnologia Industrial (ICAITI) and the Costa Rican government.

Line CR-7 was shot using *Maxipulse** charges as a sound source, while all the rest of the lines were shot using either 3 or 4 1500-cubic inch Bolt air guns with 400 to 500 psi air. All lines are nominally 24-fold. Several sonobuoys were deployed along line CR-7. Data were recorded on a Texas Instruments DFS 10,000 (Cruise *Ida Green* 24) and DFS III (Cruise *Ida Green* 29) using a 24-channel streamer. The lines were processed at the University of Texas facilities at Galveston using a Petty-Ray *Tempus* system. Preliminary velocity data along a few of the lines were obtained by sonobuoys and Ocean Bottom Seismographs (OBS) (CR 7) as well as common-depth-point (CDP) velocity analyses (CR-5 and CR-8). The discussion of the seismic data that follows is divided into two sections: the ocean crust area seaward of the Middle America Trench and the inner trench slope area landward of the trench.

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*Western Geophysical trademark.

OCEAN CRUST

There are six regional lines that extend for some distances over the area of ocean crust seaward of the trench axis (CR-2, CR-3, CR-7, and CR-5 perpendicular to the slope, and CR-4 and NCY-8 parallel to the trench) (Figs. 1 and 2). These lines are discussed briefly in this section (Figs. 4 through 11). Two other slope lines extend for short distances across across the trench onto the ocean area (NCY -5C and NCY-7) (Fig. 1).

All of the crust lines show similar geology, i.e., a relatively thin section of layered ocean sediments up to 500-m thick overlying acoustic basement (Figs. 4 through 11). Acoustic basement is inferred to represent the top of the ocean crust. This surface is relatively smooth over most of the area, although there is minor faulting and offsets along some of the lines. Major offsets of the crust or faults occur in places near the trench axis, probably due to the downbending of the subducting Cocos Plate (e.g., CR-2, Fig. 5).

There is one major offset of the ocean crust and overlying sediments seen on the seismic data. The offset is abrupt along line CR-4 (Fig. 10, 1700 Z) but gradual along line CR-5 (Fig. 8, 1000 Z to 1100 Z) indicating a major fault oriented in a NE-SW direction. The offset is down to the west and involves the entire sedimentary column, suggesting fairly recent activity.

The fault is roughly on line with the inferred segment boundary along the southeast end of the Nicoya Peninsula (Fig. 2). This boundary is marked by an abrupt change in bathymetry and an offset of the Middle America Trench (Figs. 1 and 2). There is another major offset of the crust seen on line NCY-8 (Fig. 11, 1000 Z), which is not observed on the

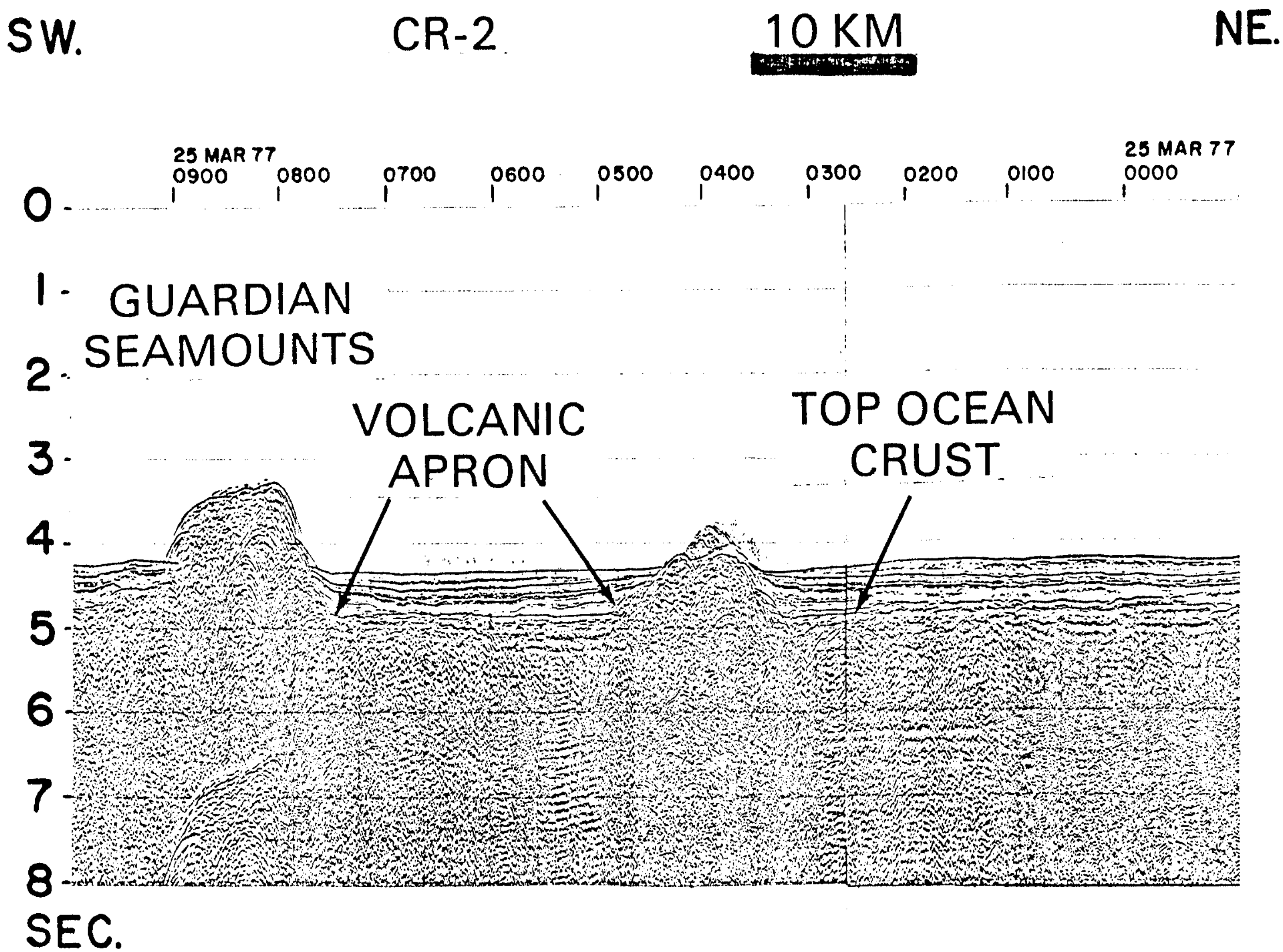

SW.
CR-2
10 KM
NE.
25 MAR 77
0900
0800
0700
0600
0500
0400
0300
0200
0100
25 MAR 77
0000
0
1
2
3
4
5
6
7
8
SEC.
GUARDIAN SEAMOUNTS
VOLCANIC APRON
TOP OCEAN CRUST

FIG. 4

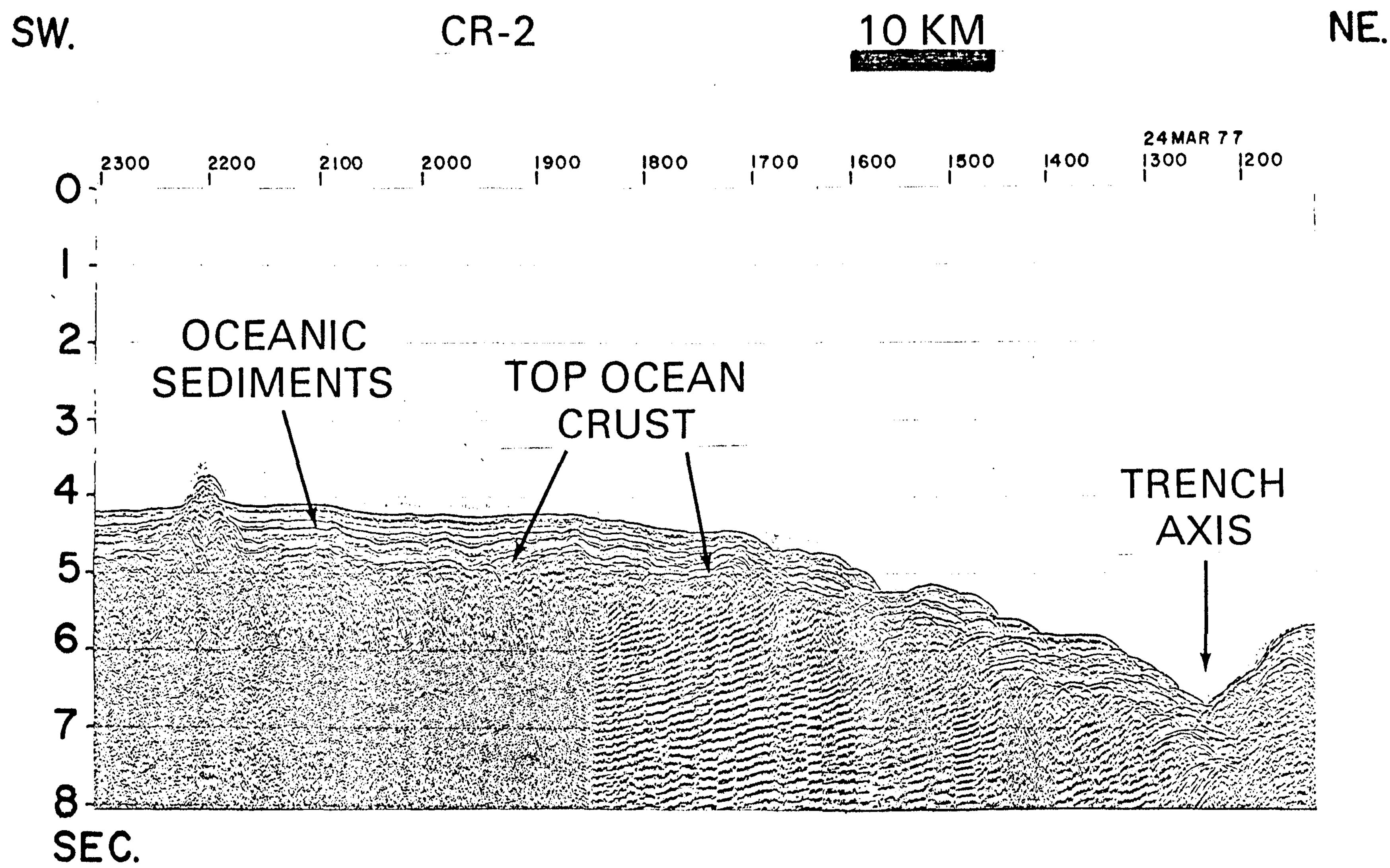
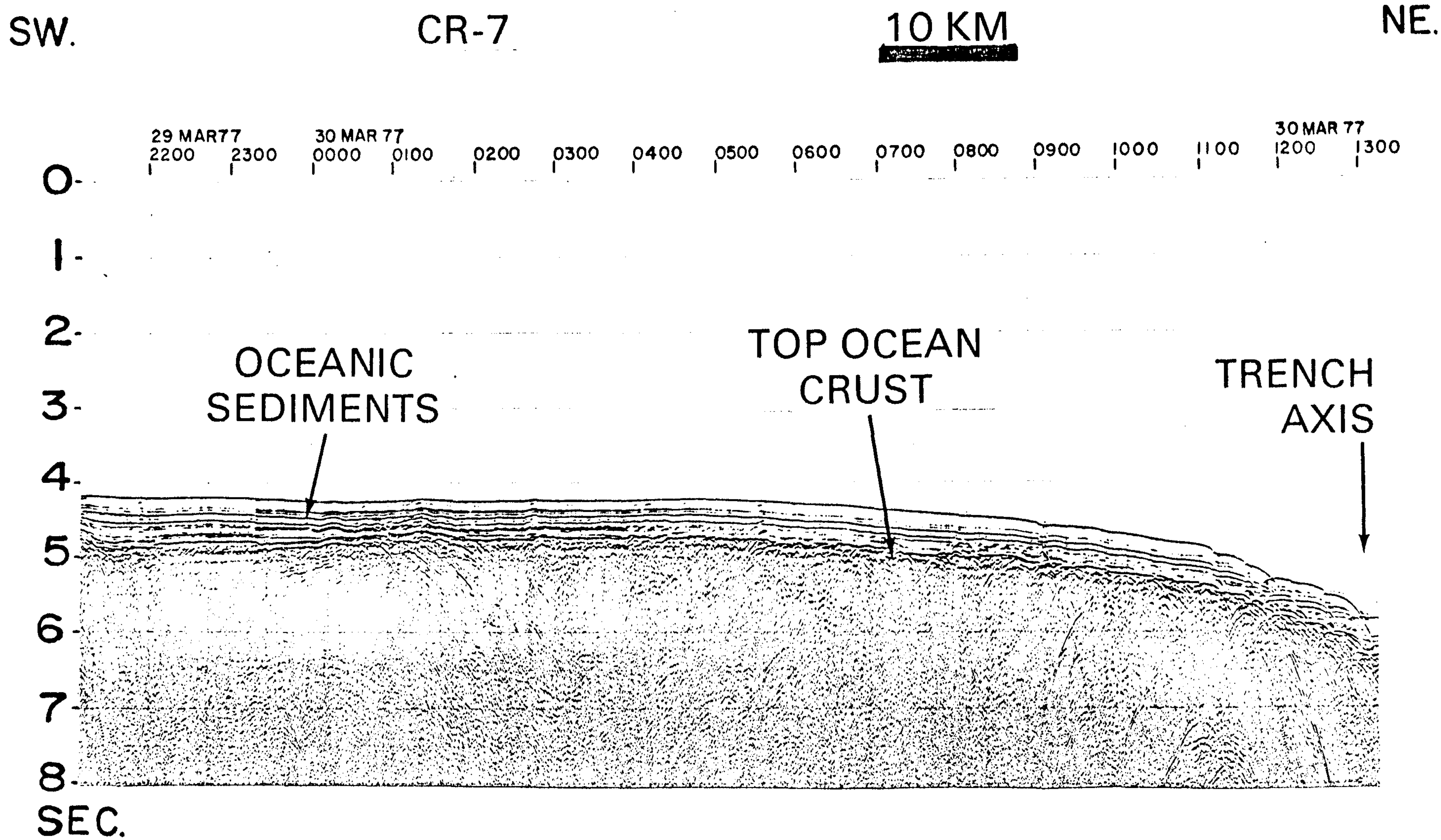

SW.
CR-2
10 KM
NE.
24MAR77
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
0
1
2
3
4
5
6
7
8
SEC.
OCEANIC SEDIMENTS
TOP OCEAN CRUST
TRENCH AXIS

FIG. 5



SW.
CR-7
10 KM
NE.
29 MAR77
30 MAR 77
30 MAR 77
2200
2300
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
0
1
2
3
4
5
6
7
8
SEC.
OCEANIC SEDIMENTS
TOP OCEAN CRUST
TRENCH AXIS

FIG. 6

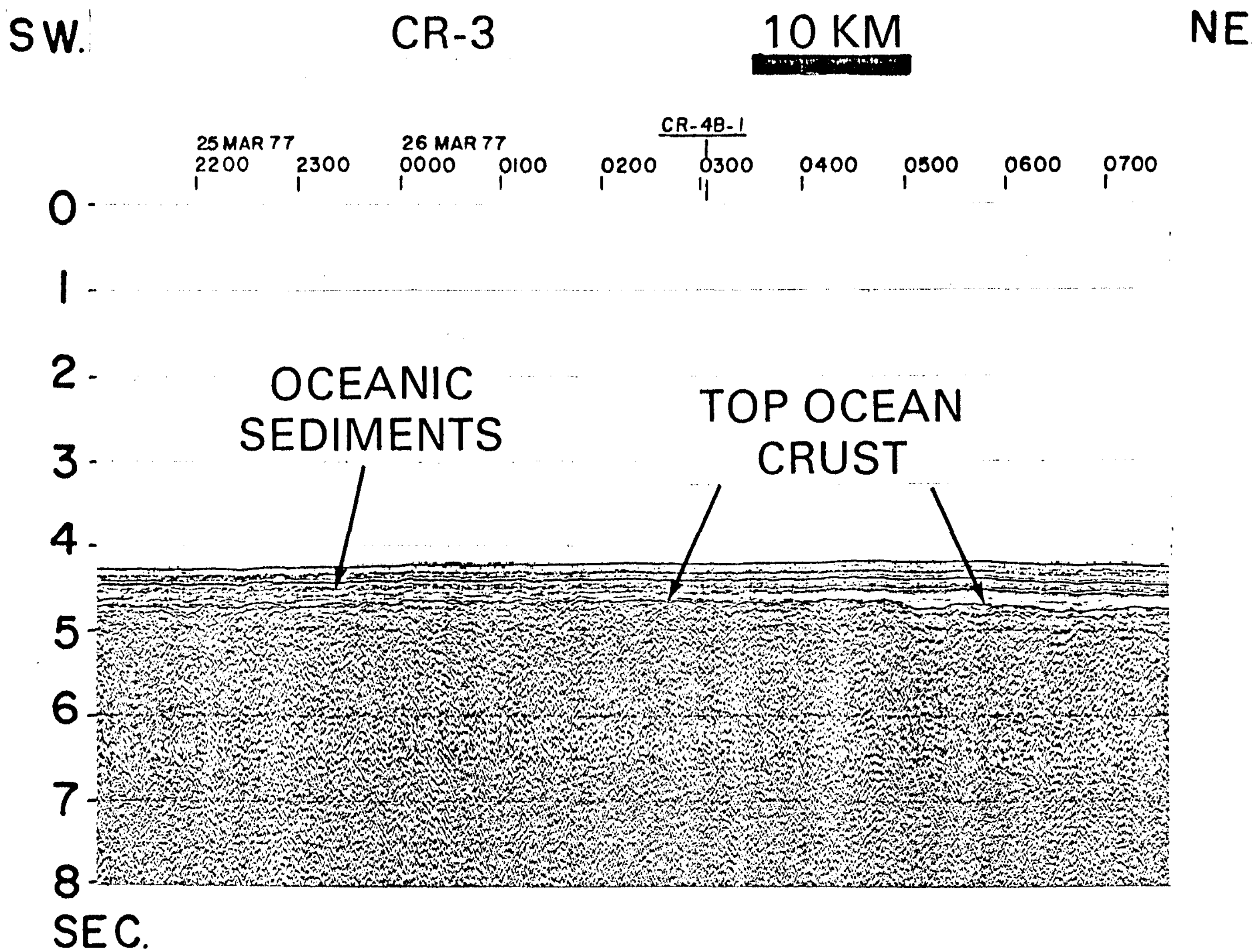

SW.
CR-3
10 KM
NE.
CR-4B-1
25 MAR 77
26 MAR 77
2200
2300
0000
0100
0200
0300
0400
0500
0600
0700
0
1
2
3
4
5
6
7
8
SEC.
OCEANIC SEDIMENTS
TOP OCEAN CRUST

FIG. 7

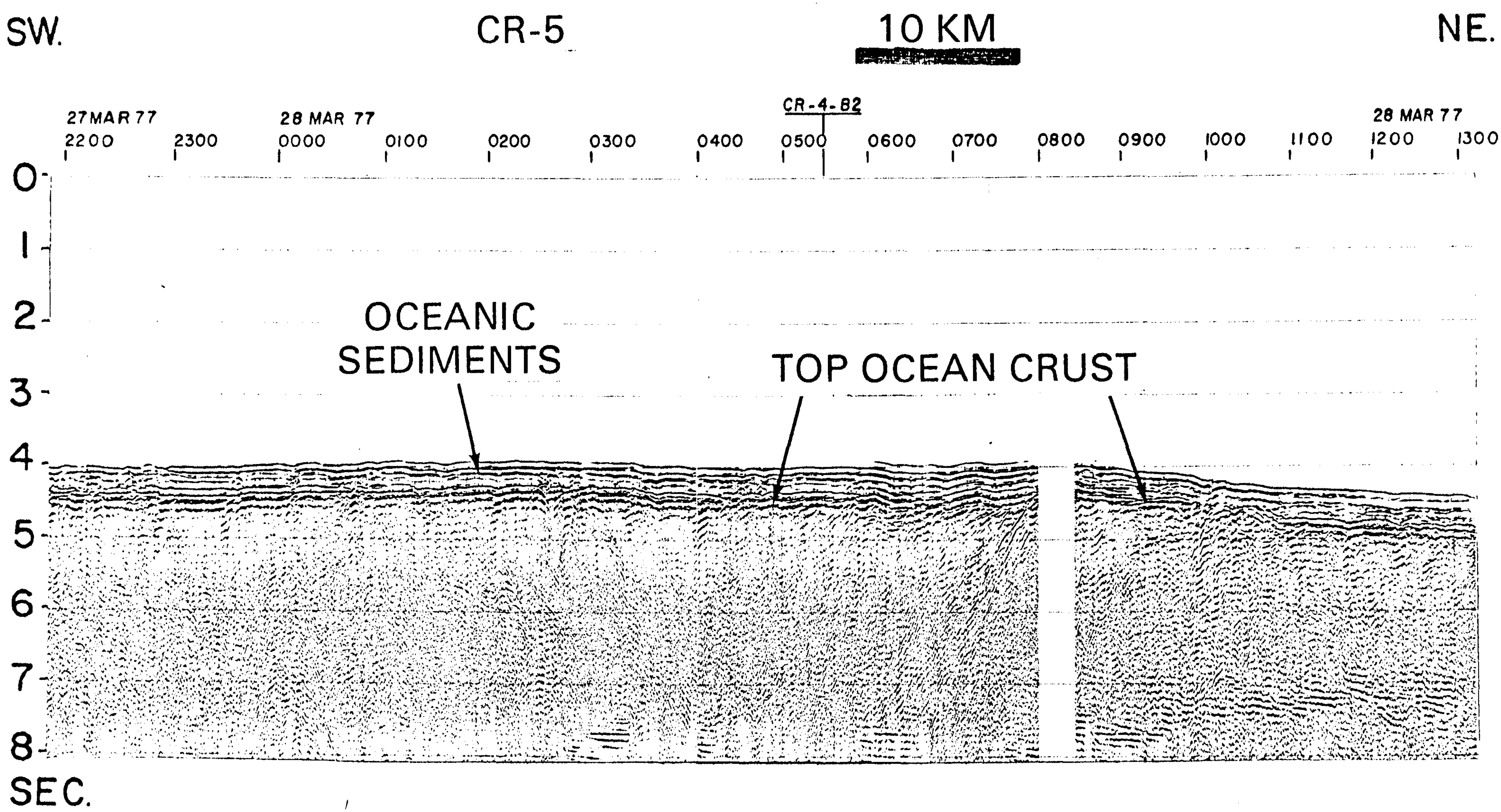

SW.
CR-5
10 KM
NE.
27 MAR 77
28 MAR 77
CR-4-82
28 MAR 77
2200
2300
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
0
1
2
3
4
5
6
7
8
SEC.
OCEANIC SEDIMENTS
TOP OCEAN CRUST

FIG. 8

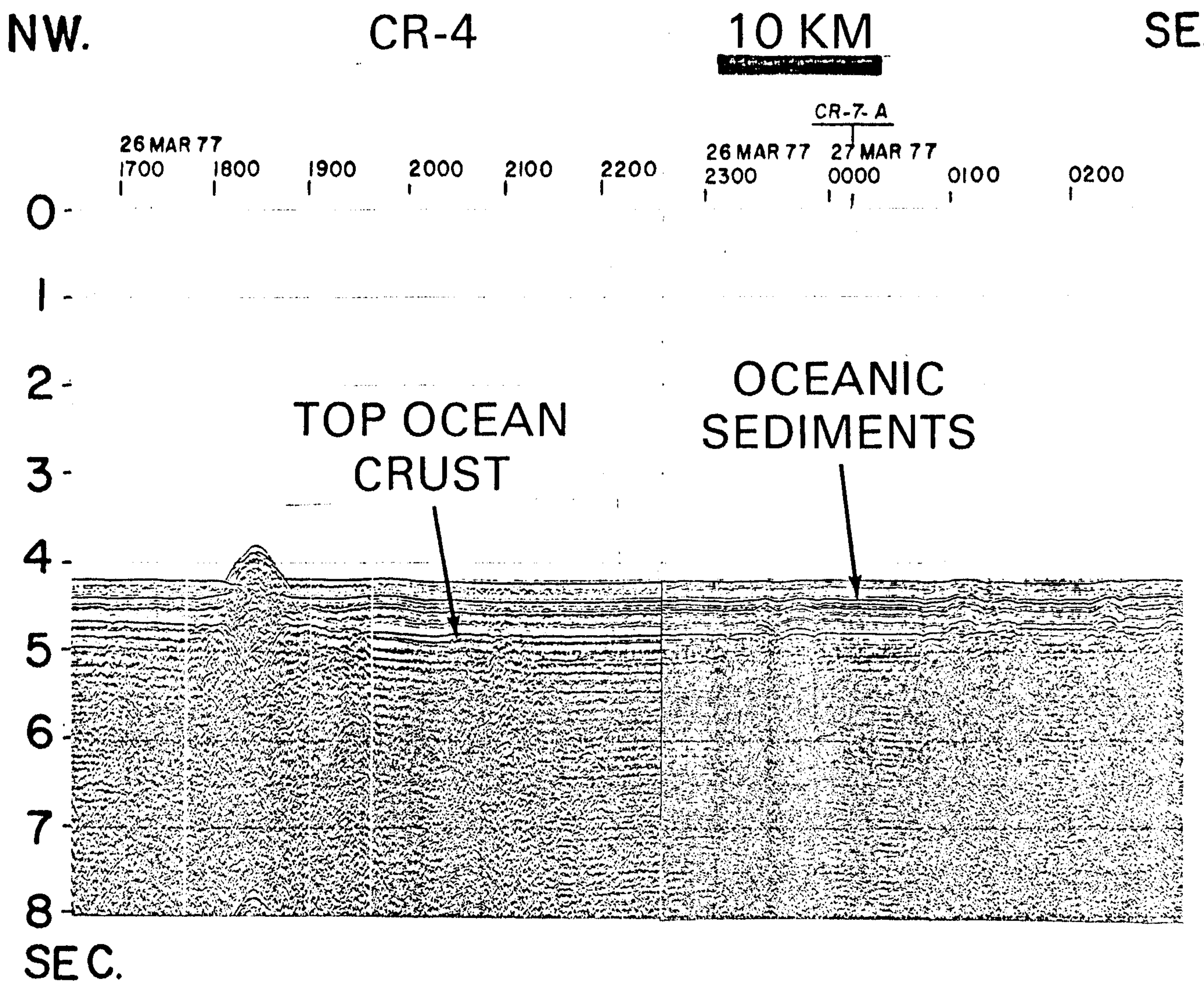

NW.
CR-4
10 KM
SE.
CR-7-A
26 MAR 77
1700
1800
1900
2000
2100
2200
26 MAR 77
2300
27 MAR 77
0000
0100
0200
0
1
2
3
4
5
6
7
8
SEC.
TOP OCEAN CRUST
OCEANIC SEDIMENTS

FIG. 9

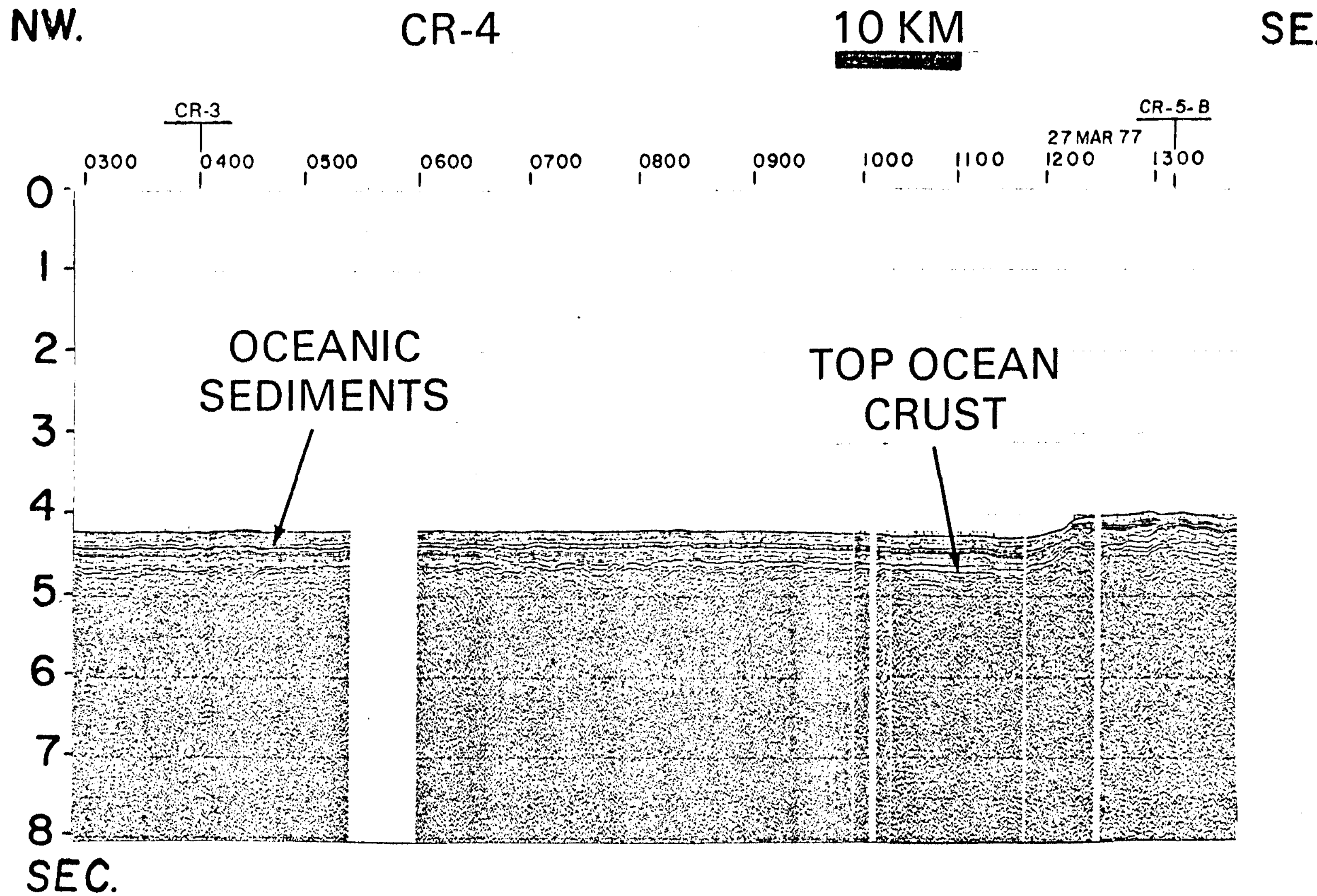

NW.
CR-4
10 KM
SE.
CR-3
CR-5-B
27 MAR 77
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
0
1
2
3
4
5
6
7
8
SEC.
OCEANIC SEDIMENTS
TOP OCEAN CRUST

FIG. 10

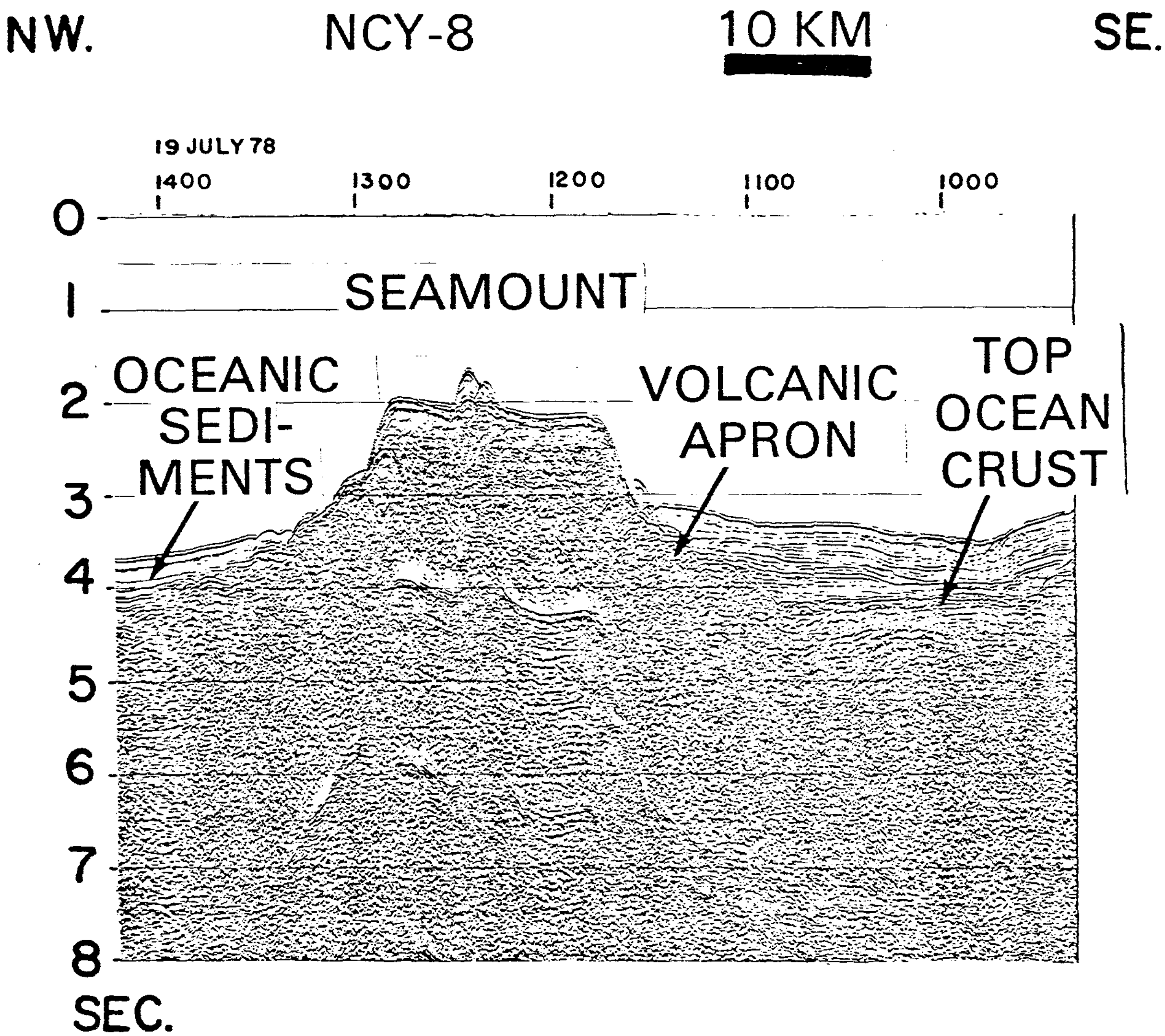

NW.
NCY-8
10 KM
SE.
19 JULY 78
1400
1300
1200
1100
1000
0
1
2
3
4
5
6
7
8
SEC.
SEAMOUNT
OCEANIC SEDI- MENTS
VOLCANIC APRON
TOP OCEAN CRUST

FIG. 11

adjacent perpendicular line NCY-7, again suggesting a NE-SW trend. It also corresponds to a major topographic break in the shelf/slope (Figs. 1 and 2) and possibly represents another segment boundary. These inferred correlations between segment boundaries and faults in the ocean crust suggest that there is some coupling of structures between the forearc region landward of the trench and the ocean crust seaward of the trench.

The oceanic sedimentary section off Costa Rica is about 500-m thick and probably consists of pelagic sediments overlain by hemipelagic sediments, similar to that drilled offshore Guatemala to the north (von Huene et al, 1980). Several distinct seismic sequences and facies are discernible on the seismic lines (e.g., CR-2, Figs. 4 and 5), indicating several major depositional episodes. A seismic stratigraphic analysis of these rocks is the subject of an ongoing study, and no attempt is made to develop it further in this report.

Several of the lines intersect seamounts on the ocean floor. Line CR-2 (Figs. 4 and 5) and line CR-4 (Fig. 9) cross several seamounts of the Guardian chain, while line NCY-8 (Fig. 11) crosses a broad, flat-topped seamount which is probably part of the Cocos Ridge. All of the features are presumed to have originated by volcanic processes. Wedge-shaped sedimentary sequences along the base of the seamounts are interpreted to be aprons of volcanic material deposited while the volcanoes were erupting on the sea floor (Figs. 4 and 11). The aprons seem to correspond to the oldest sedimentary unit, making them probably late Oligocene-early Miocene in age, the inferred age of the ocean crust.

INNER TRENCH SLOPE

There are 7 dip lines (CR-9, CR-7, CR-5, NCY-1, CR-8, NCY-5, and NCY-7) and 3 strike lines (CR-1, NCY-2, and NCY-6) crossing the inner trench slope landward of the Middle America Trench (Figs. 12 to 34). Discussed below are several general observations about the geology of the slope based mainly on these seismic data.

The ocean crust appears to extend beneath the inner trench slope for distances up to 50 km from the trench axis. It is observed on the seismic data as a strong, discontinuous, high-amplitude reflector. The best example is along line CR-7 (Figs. 14 and 15) where the crust extends up to 50 km to a point just seaward of the Nicoya Peninsula. The crust actually dips approximately 5° to 10°, as can be seen on the seismic section which has been converted to depth (km) (Fig. 16) using the approximate velocities shown on Fig. 15. These observations tend to support the model of a subducting oceanic plate.

Well-defined layered oceanic sediments extend below the lower inner trench slope on many lines for up to 10 to 15 km. The best example is again along line CR-7 (Figs. 14 and 15). This suggests that most of the normal oceanic sedimentary section is not presently being scraped off at the trench or lower slope, but it is being subducted for at least some distance.

The ocean crust bends down at the trench. Along some lines the crust and overlying sediments are broken by normal faults (e.g., lines CR-2 and NCY-5C; Figs. 5, 29, and 30), while some lines show little or no deformation at all (e.g., CR-5, Figs. 17 and 18). There is no apparent reason why some areas are faulted and others not. An inferred uplifted block within the slope just landward of the trench on line NCY-5C could be partly

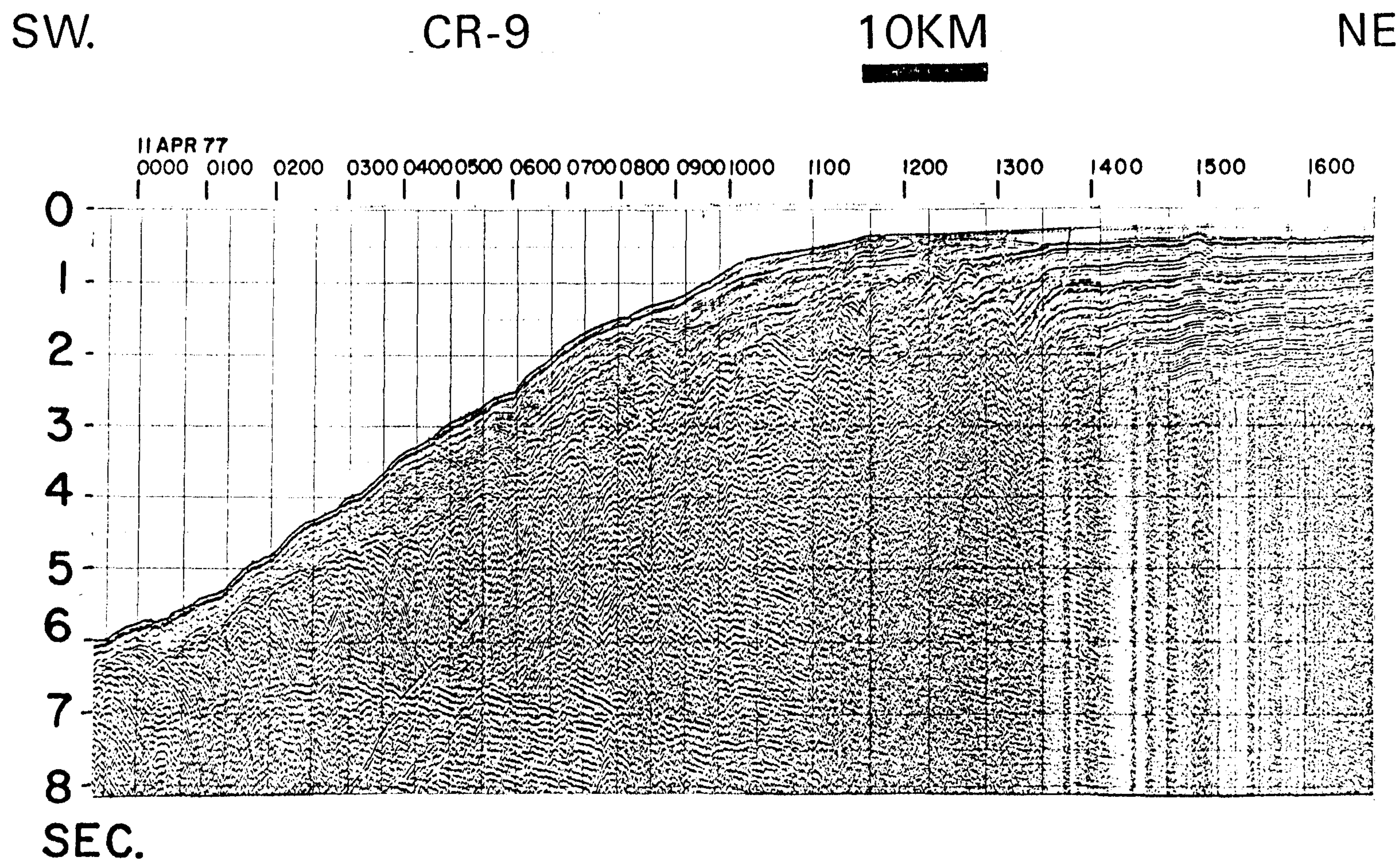

SW.
CR-9
10KM
NE.
11 APR 77
0000 0100 0200 0300 0400 0500 0600 0700 0800 0900 1000 1100 1200 1300 1400 1500 1600
0
1
2
3
4
5
6
7
8
SEC.

FIG. 12

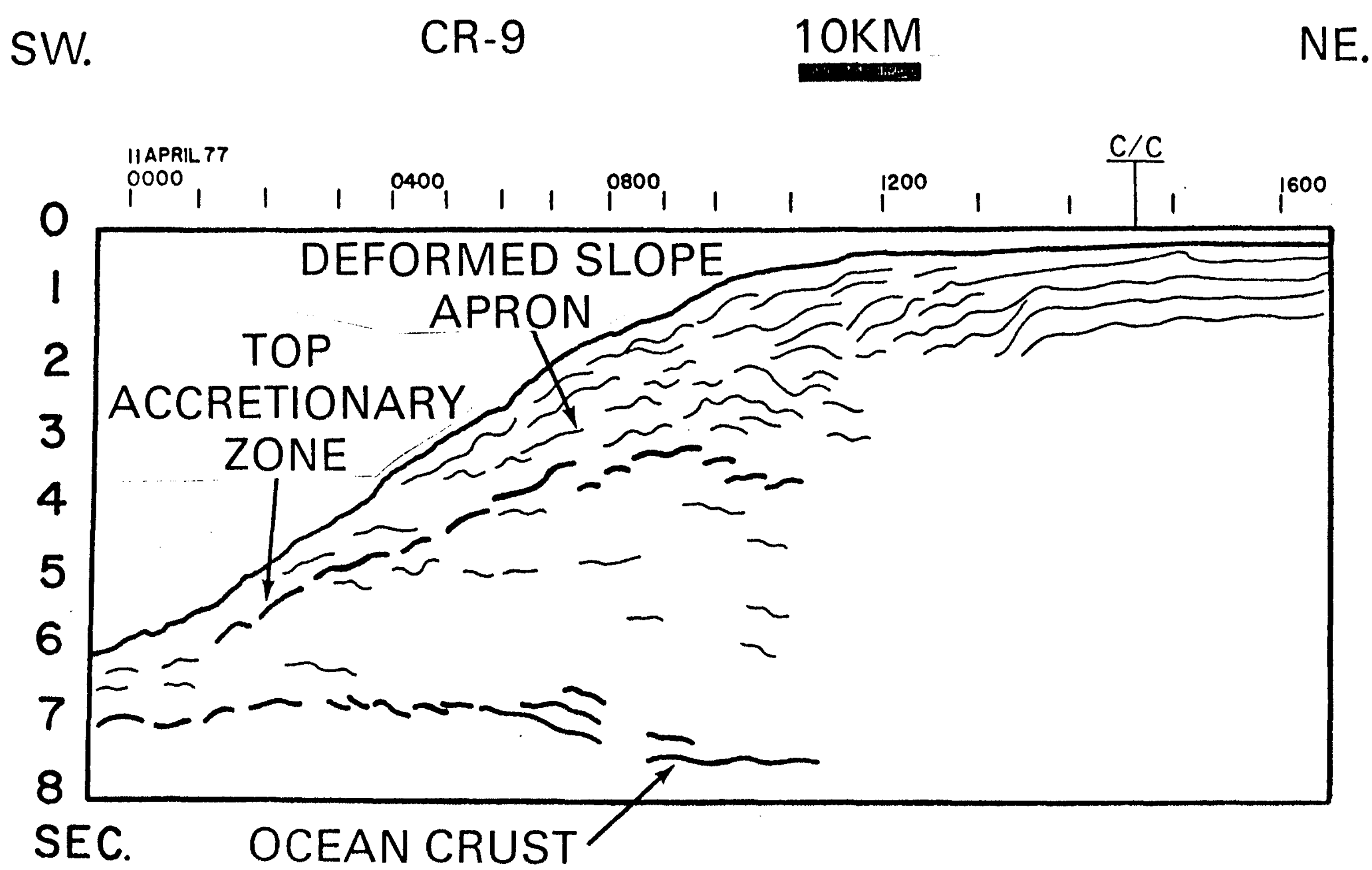

SW.
CR-9
10KM
NE.
11 APRIL 77
0000
0400
0800
1200
C/C
1600
0
1
2
3
4
5
6
7
8
SEC.
DEFORMED SLOPE
APRON
TOP
ACCRETIONARY
ZONE
OCEAN CRUST

FIG. 13

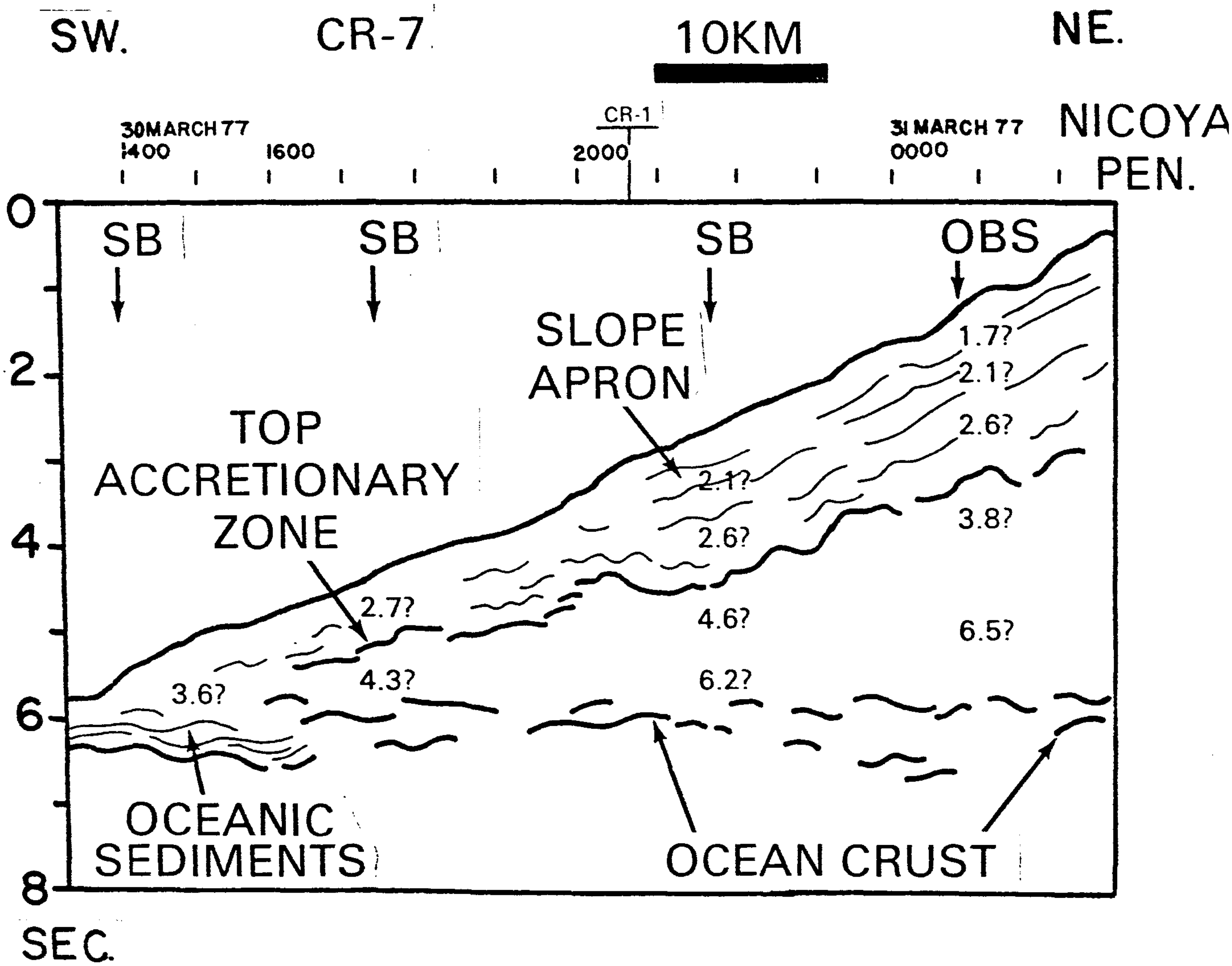

SW.
CR-7
10KM
NE.
30MARCH 77
1400
1600
CR-1
2000
31 MARCH 77
0000
NICOYA
PEN.
0
2
4
6
8
SEC.
SB
SB
SB
OBS
SLOPE
APRON
TOP
ACCRETIONARY
ZONE
1.7?
2.1?
2.6?
2.1?
2.6?
3.8?
2.7?
4.6?
6.5?
4.3?
6.2?
3.6?
OCEANIC
SEDIMENTS
OCEAN CRUST

FIG. 15

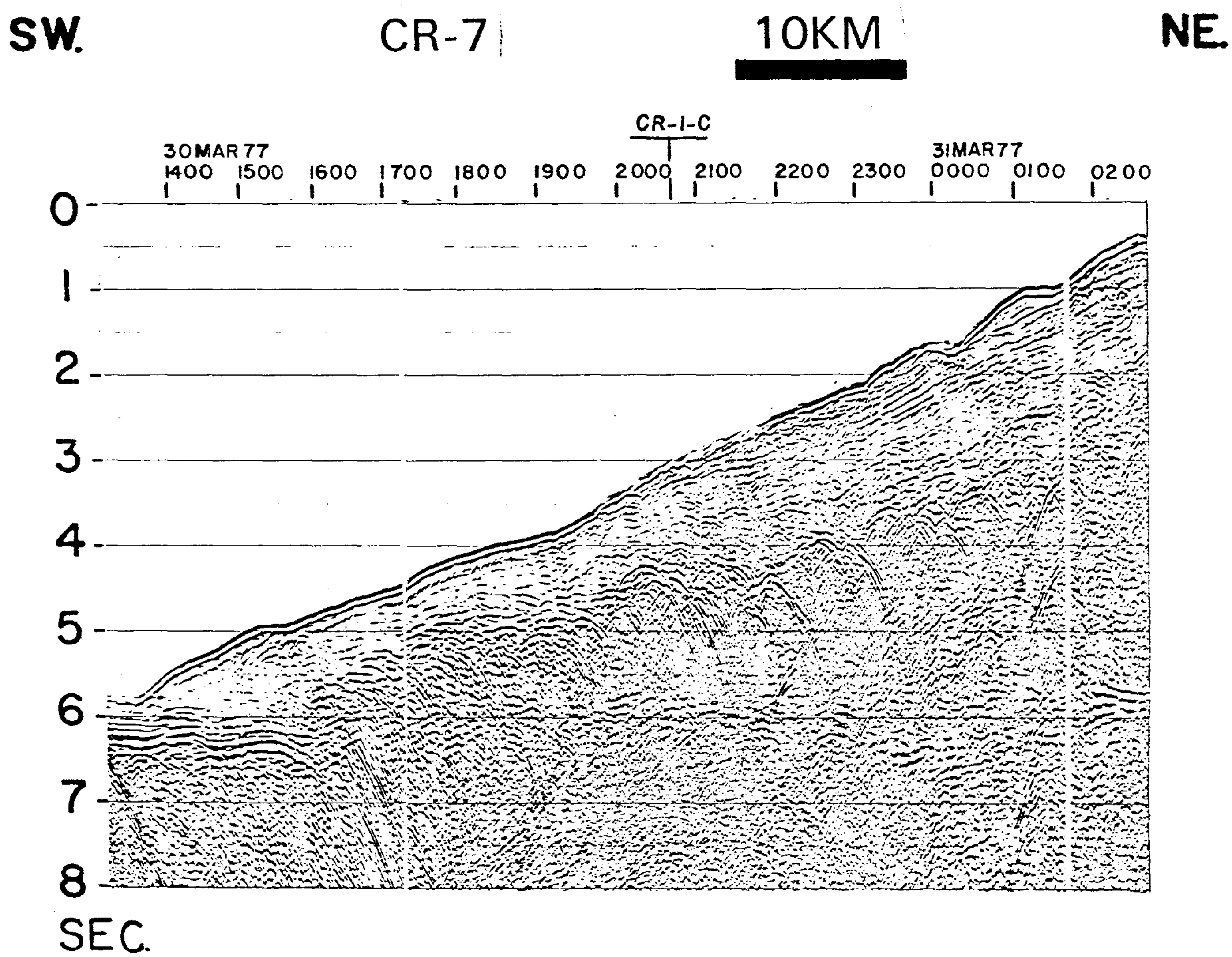

SW.
CR-7
10KM
NE.
CR-1-C
30MAR77
1400 1500 1600 1700 1800 1900 2000 2100 2200 2300
31MAR77
0000 0100 0200
0
1
2
3
4
5
6
7
8
SEC.

FIG. 14

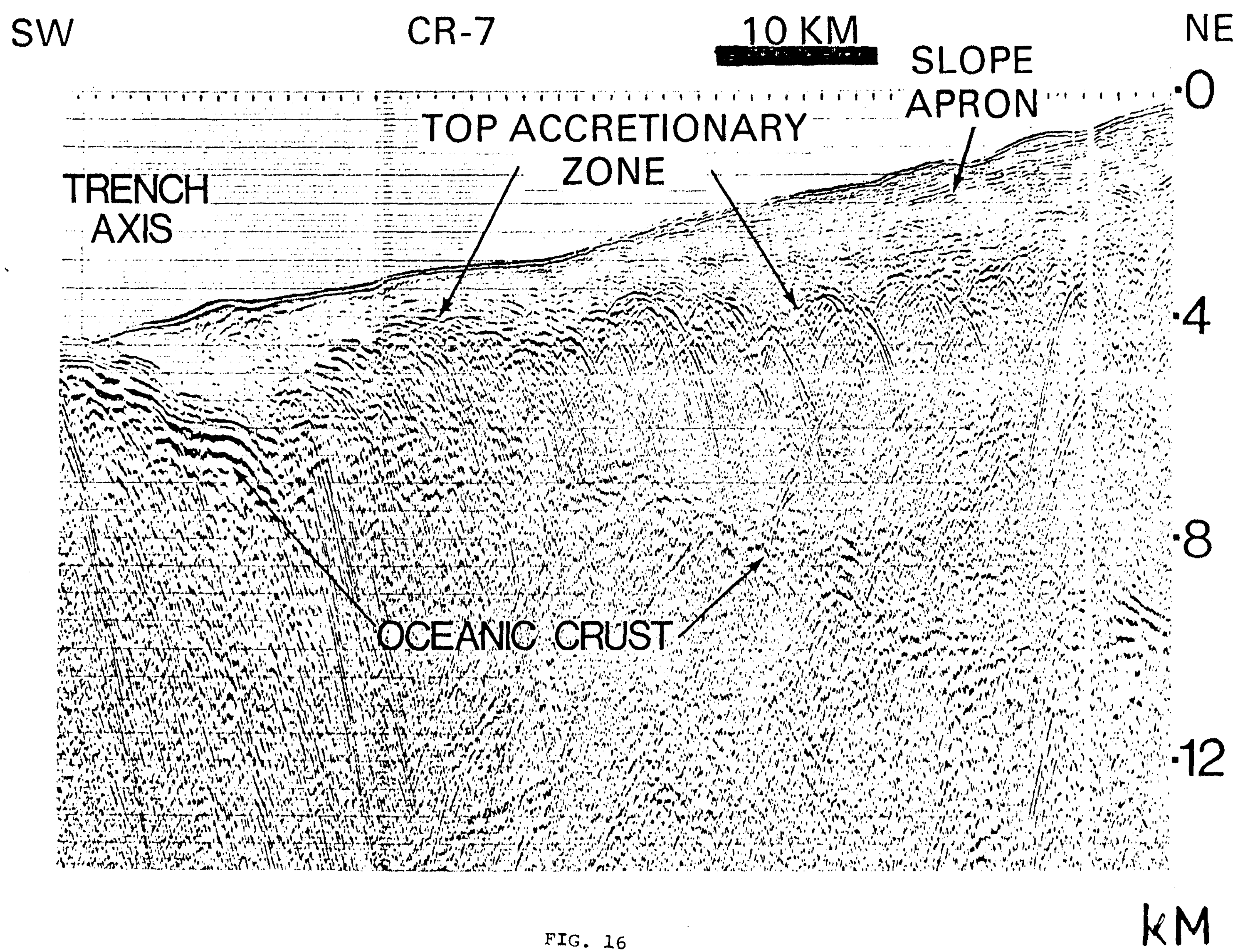

SW
CR-7
10 KM
NE
SLOPE APRON
TOP ACCRETIONARY ZONE
TRENCH AXIS
OCEANIC CRUST
0
4
8
12
kM

FIG. 16

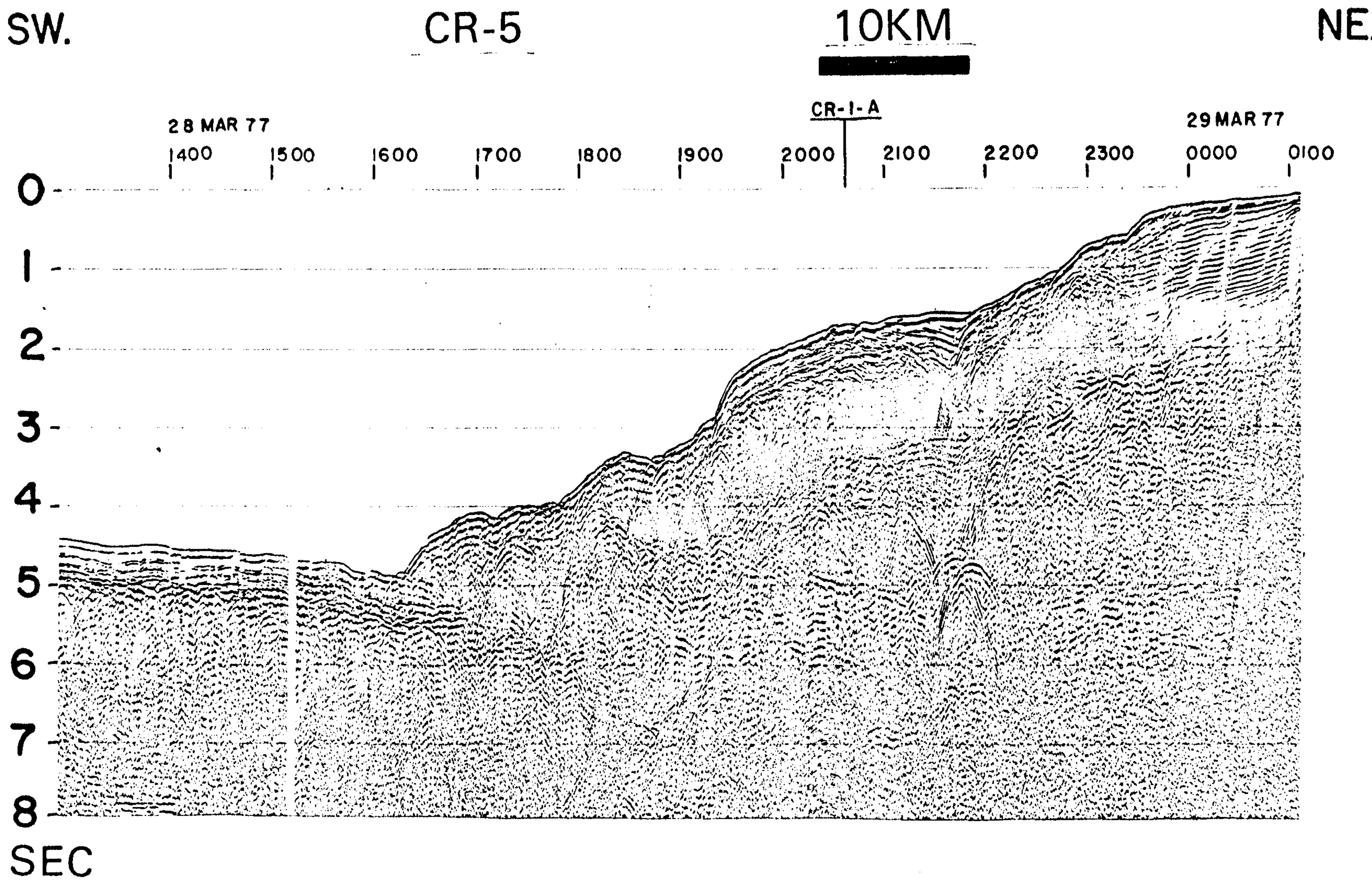

SW.
CR-5
10KM
NE.
CR-1-A
28 MAR 77
29 MAR 77
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
0000
0100
0
1
2
3
4
5
6
7
8
SEC

FIG. 17

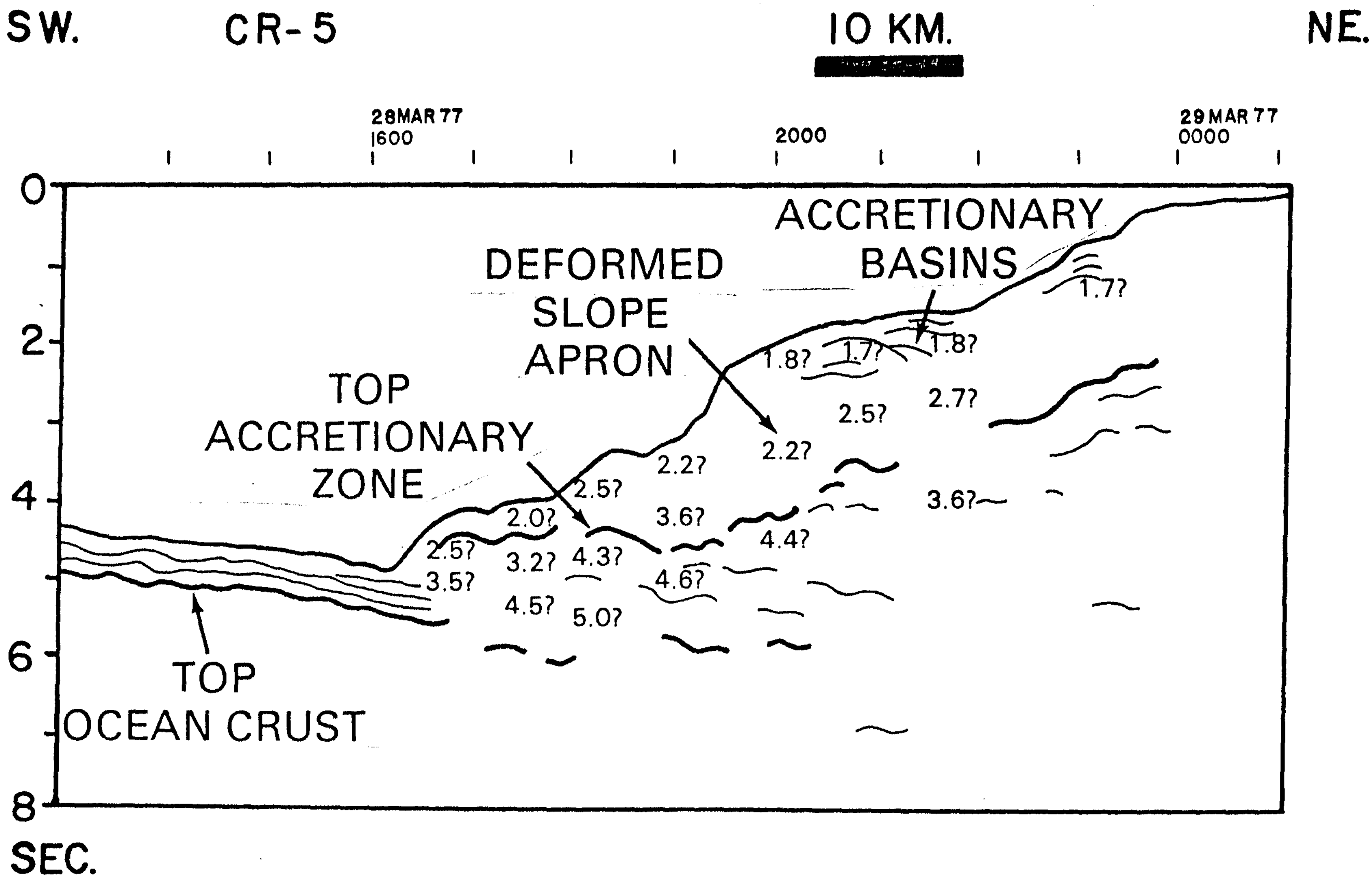

SW.
CR-5
10 KM.
NE.
28MAR 77
1600
2000
29 MAR 77
0000
0
2
4
6
8
SEC.
ACCRETIONARY
BASINS
DEFORMED
SLOPE
APRON
TOP
ACCRETIONARY
ZONE
TOP
OCEAN CRUST
1.7?
1.8?
1.7?
1.8?
2.7?
2.5?
2.2?
2.2?
2.5?
3.6?
3.6?
2.0?
4.4?
2.5?
3.2?
4.3?
3.5?
4.6?
4.5?
5.0?

FIG. 18

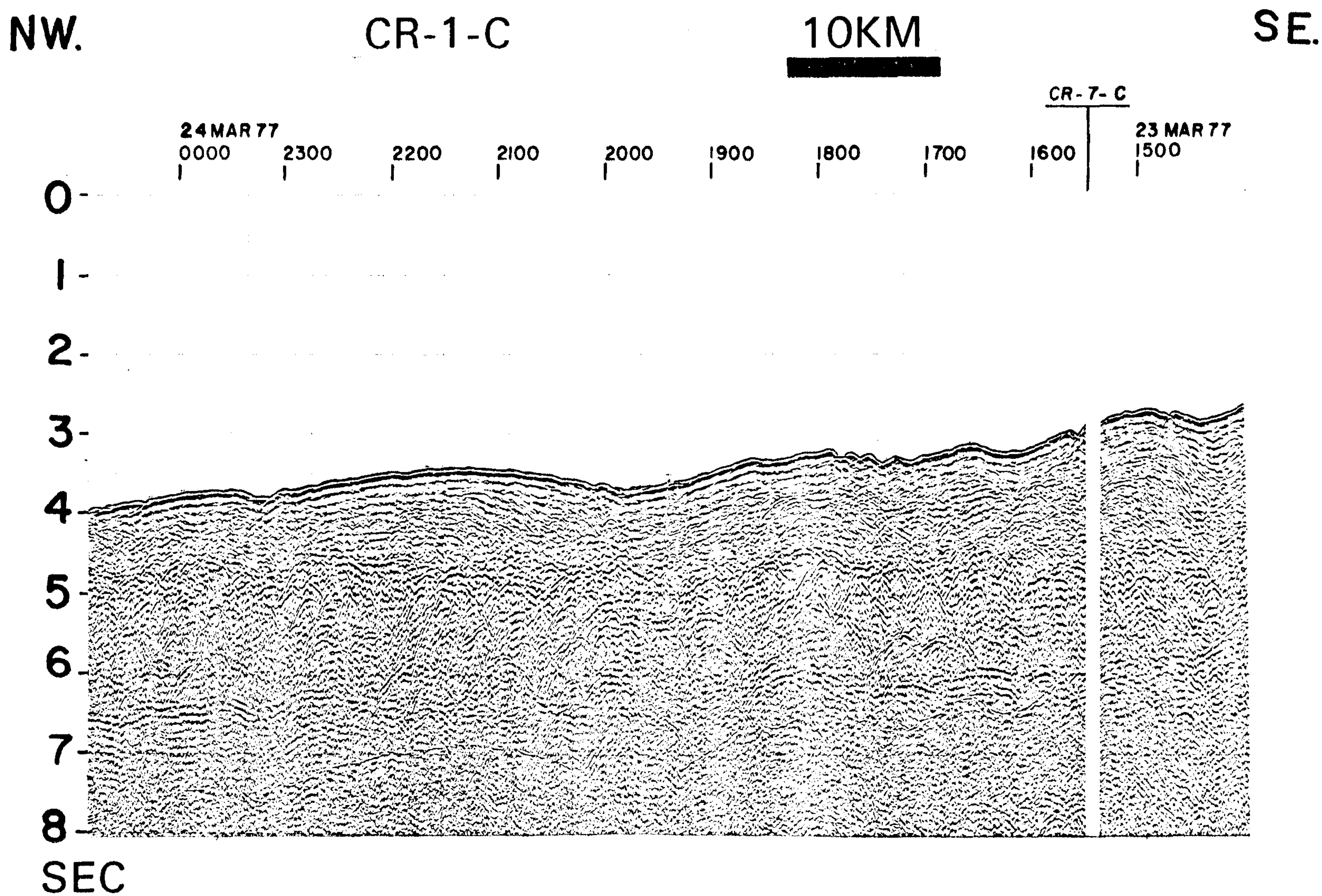

NW.
CR-1-C
10KM
SE.
CR-7-C
24 MAR 77
0000
2300
2200
2100
2000
1900
1800
1700
1600
23 MAR 77
1500
0
1
2
3
4
5
6
7
8
SEC

FIG. 19

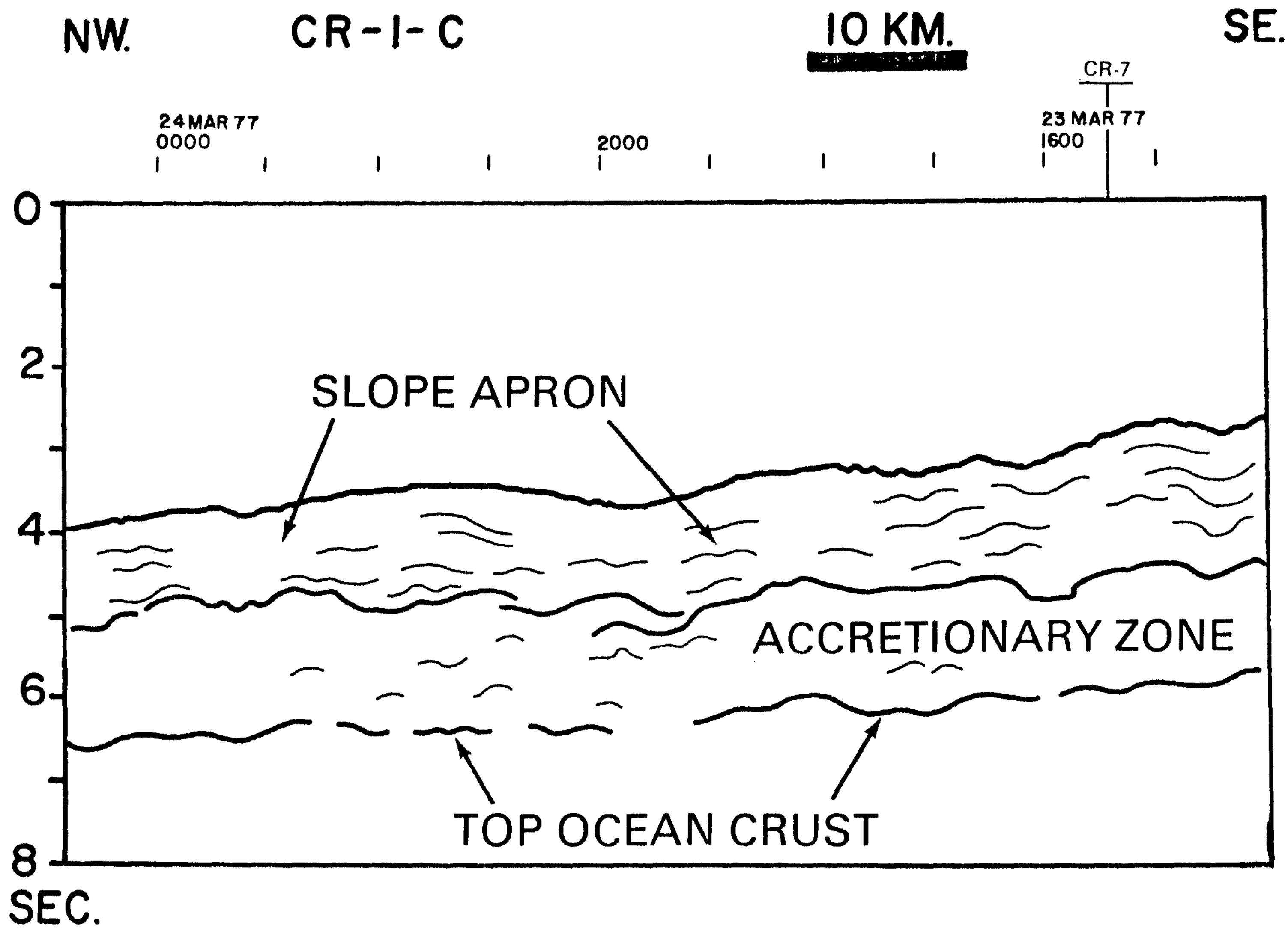

NW.
CR-1-C
10 KM.
SE.
CR-7
24 MAR 77
0000
2000
23 MAR 77
1600
0
2
4
6
8
SEC.
SLOPE APRON
ACCRETIONARY ZONE
TOP OCEAN CRUST

FIG. 20

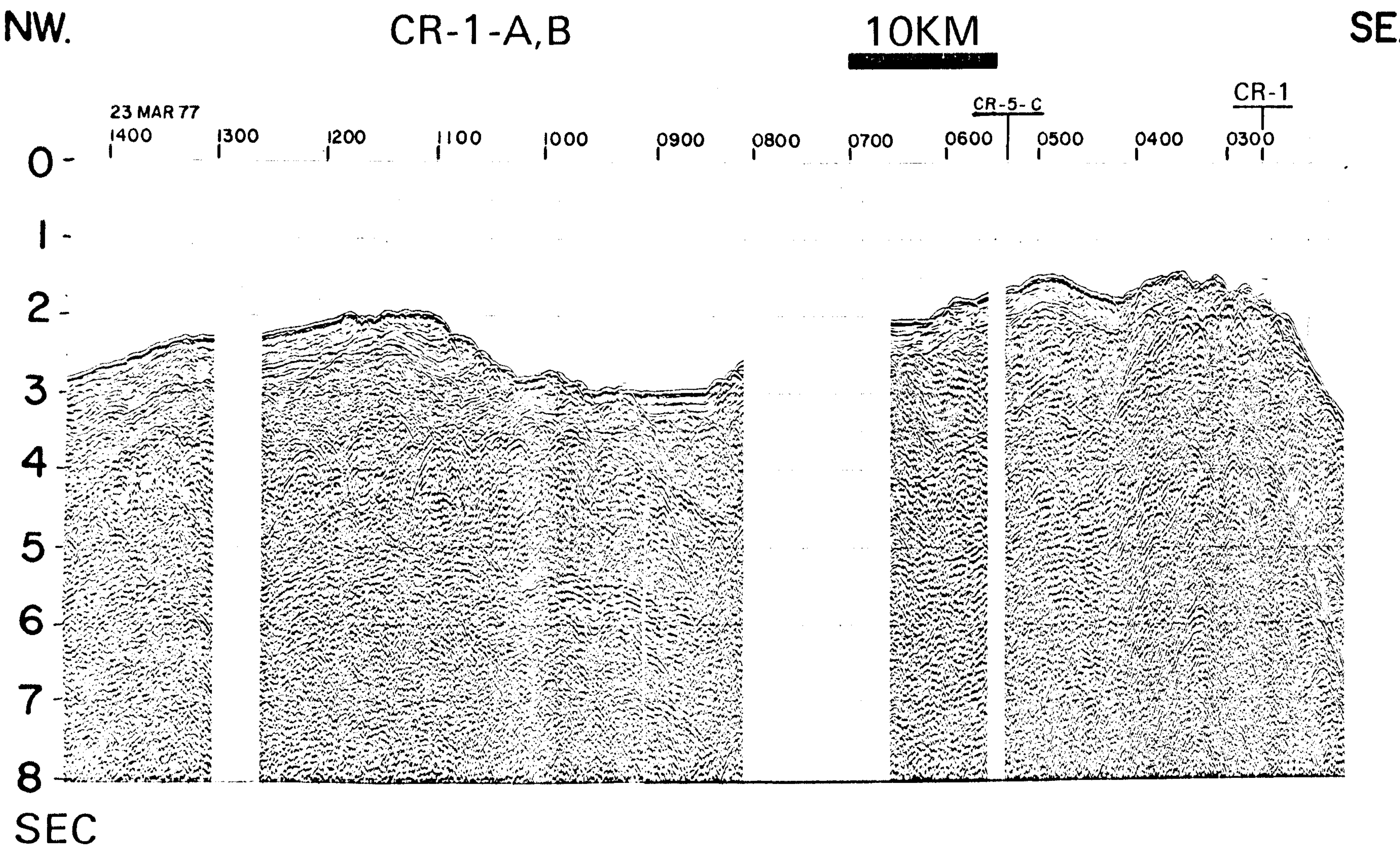
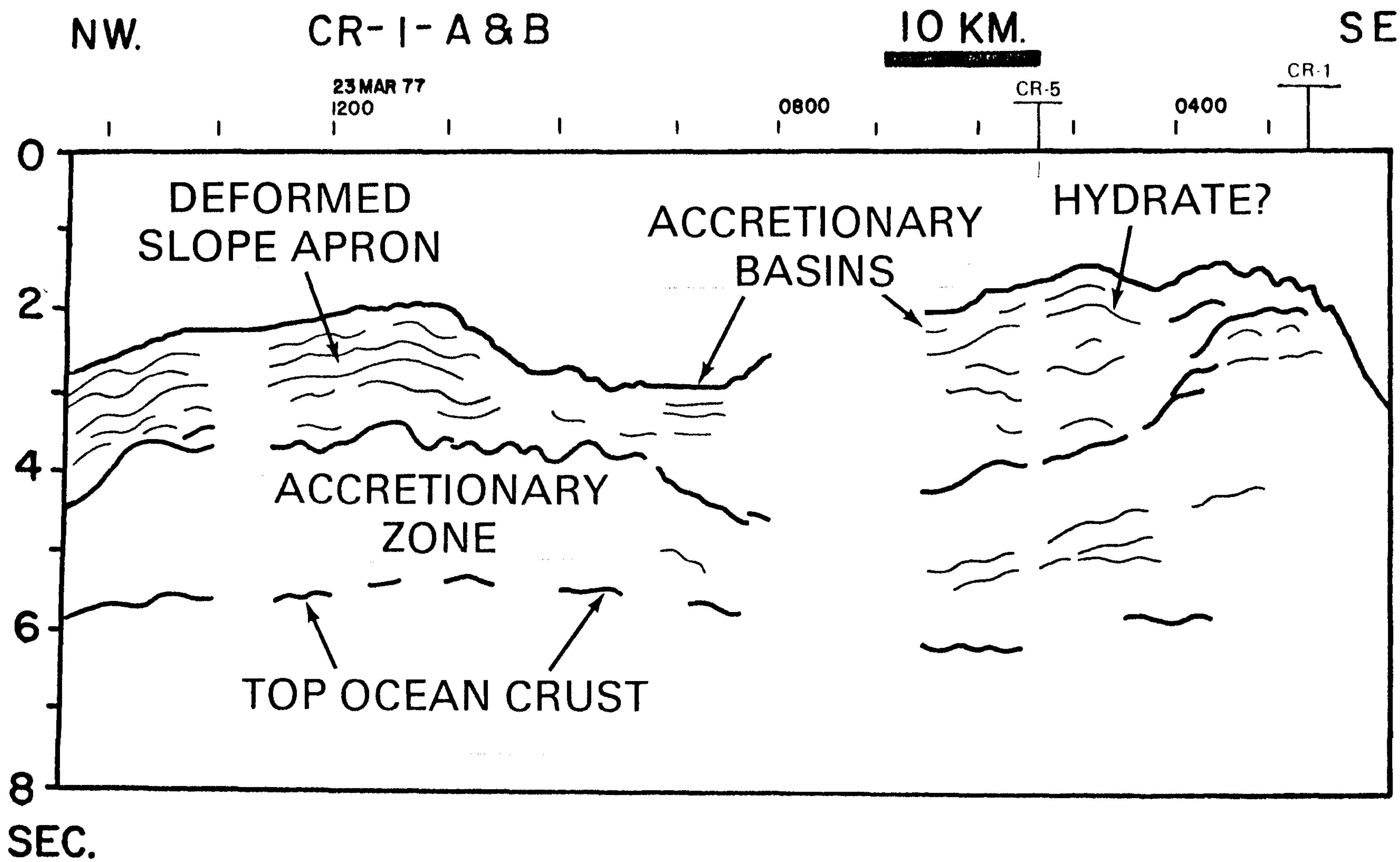

NW.
CR-1-A,B
10KM
SE.
CR-5-C
CR-1
23 MAR 77
1400
1300
1200
1100
1000
0900
0800
0700
0600
0500
0400
0300
0
1
2
3
4
5
6
7
8
SEC

FIG. 21



NW.
CR-1-A & B
10 KM.
SE.
23 MAR 77
1200
0800
CR-5
0400
CR-1
0
2
4
6
8
SEC.
DEFORMED
SLOPE APRON
ACCRETIONARY
BASINS
HYDRATE?
ACCRETIONARY
ZONE
TOP OCEAN CRUST

FIG. 22

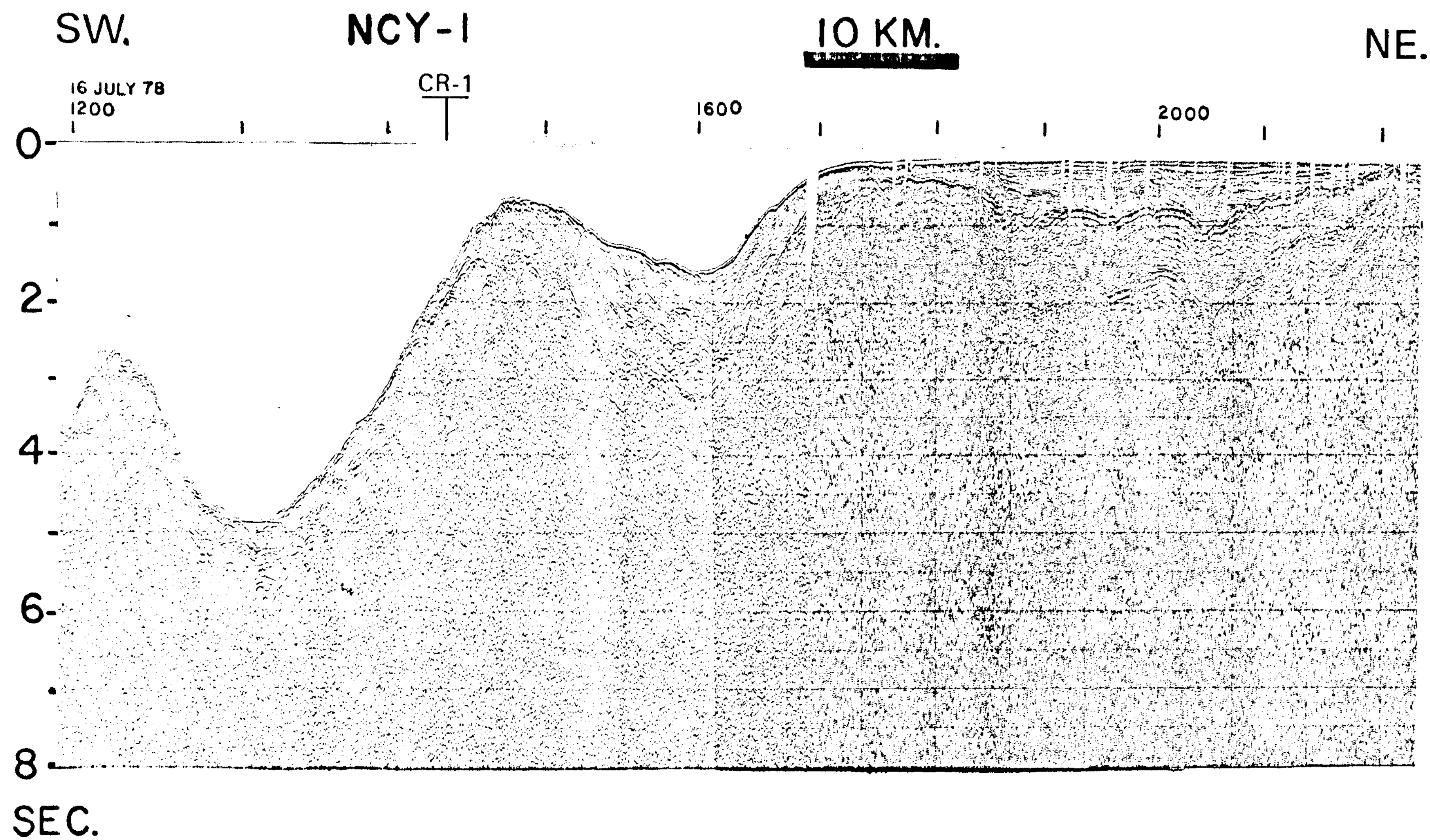


FIG. 23

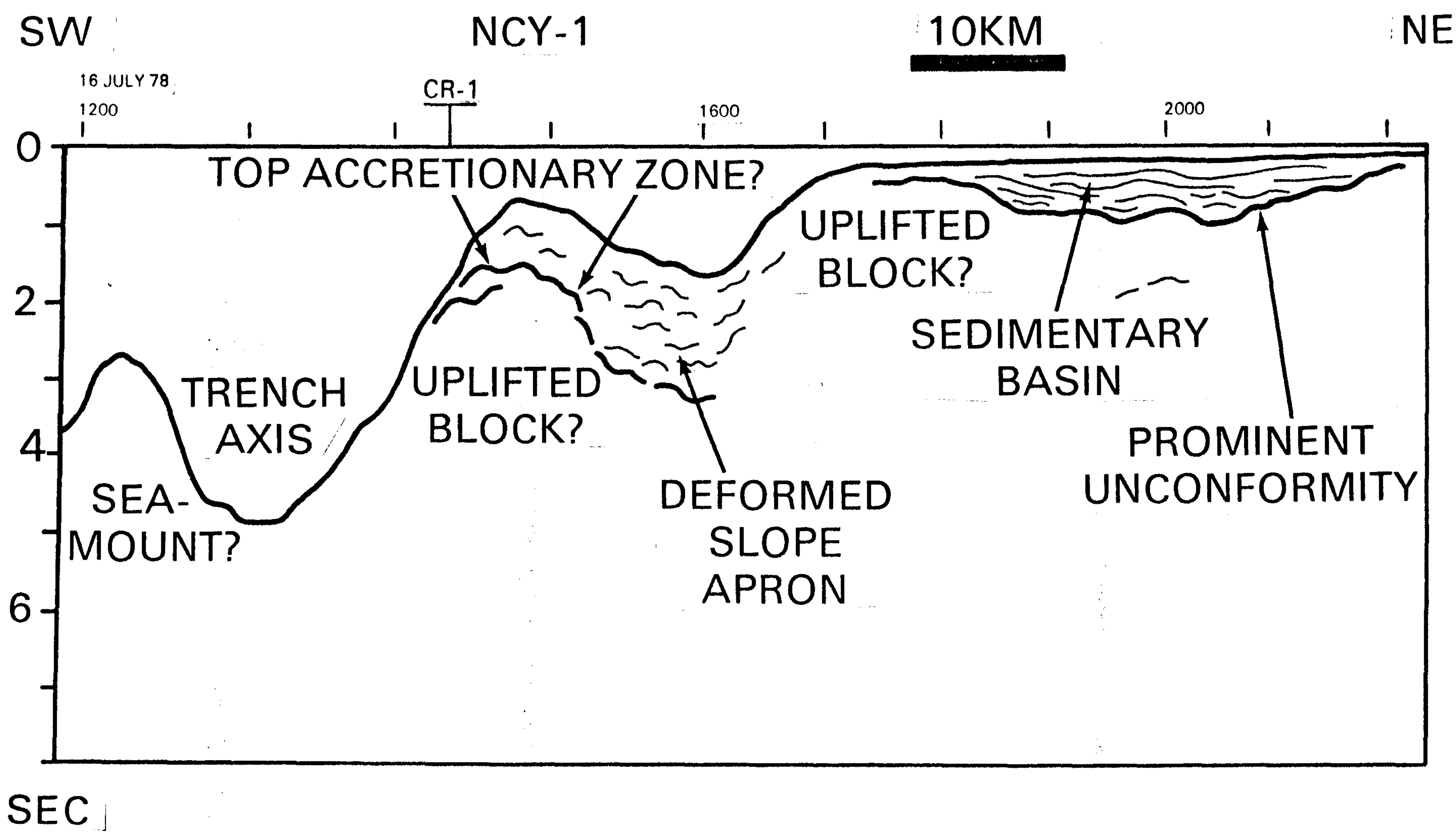

SW
NCY-1
10KM
NE
16 JULY 78
CR-1
1200
1600
2000
0
2
4
6
SEC
TOP ACCRETIONARY ZONE?
UPLIFTED BLOCK?
SEDIMENTARY BASIN
TRENCH AXIS
UPLIFTED BLOCK?
SEA-MOUNT?
DEFORMED SLOPE APRON
PROMINENT UNCONFORMITY

FIG. 24

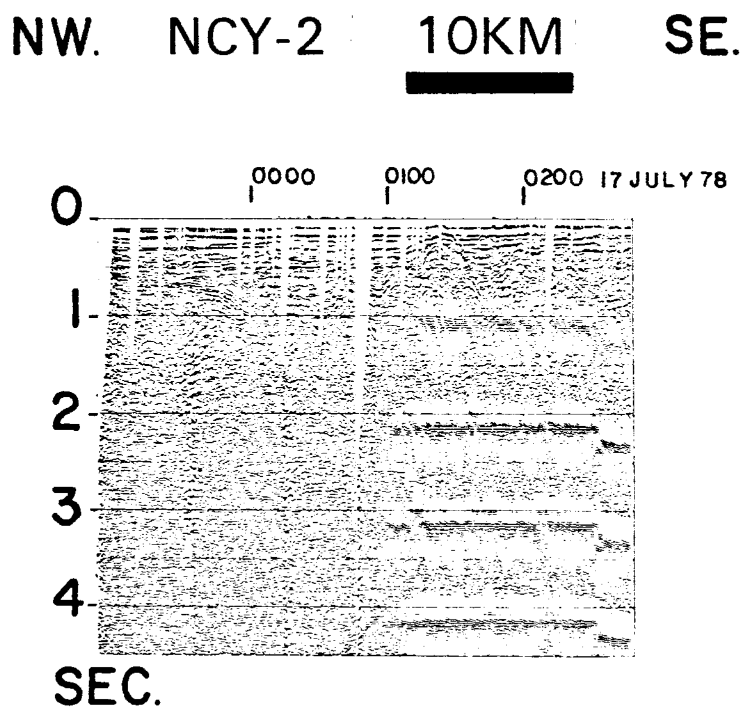


FIG. 25

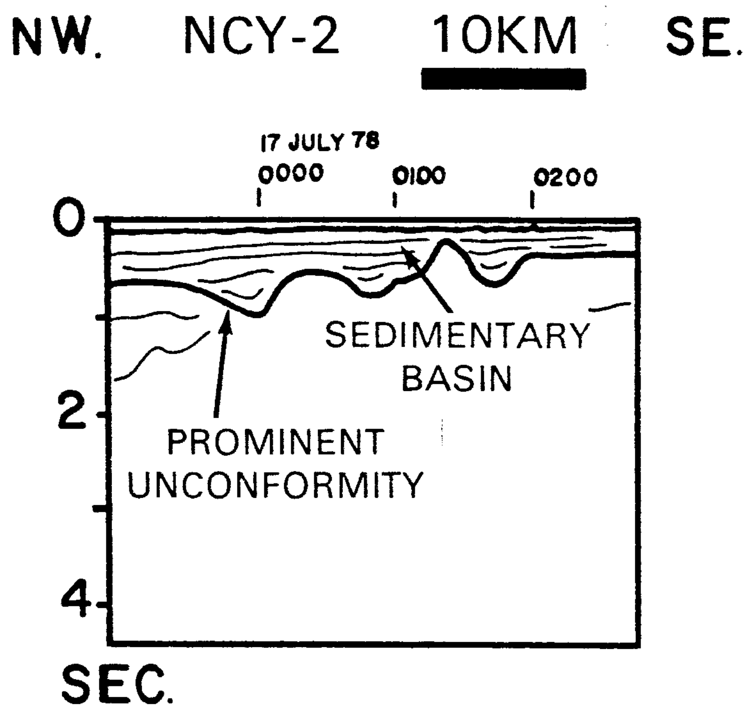

NW.
NCY-2
10KM
SE.
17 JULY 78
0000
0100
0200
0
2
4
SEC.
SEDIMENTARY BASIN
PROMINENT UNCONFORMITY

FIG. 26

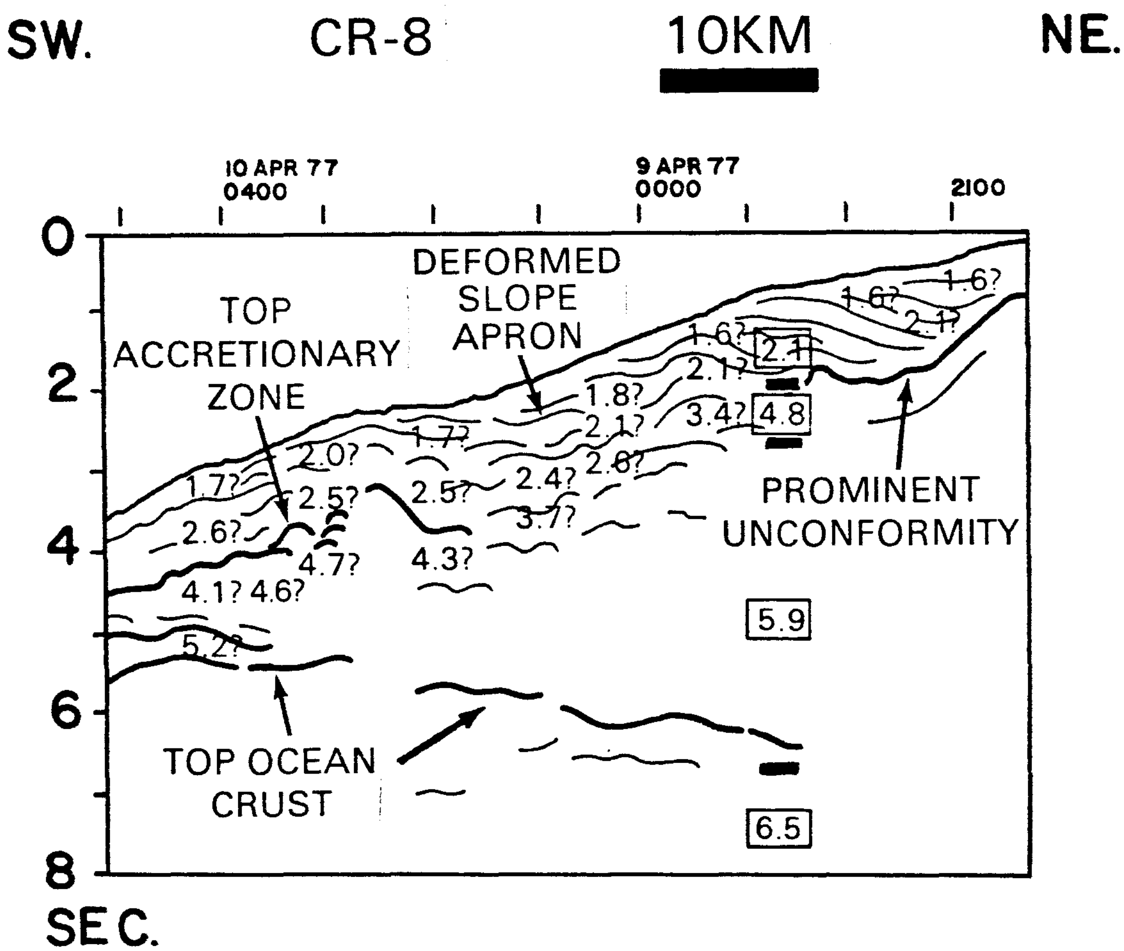

SW.
CR-8
10KM
NE.
10 APR 77
0400
9 APR 77
0000
2100
0
2
4
6
8
SEC.
TOP
ACCRETIONARY
ZONE
DEFORMED
SLOPE
APRON
PROMINENT
UNCONFORMITY
TOP OCEAN
CRUST
1.6?
2.1?
1.8?
3.4?
2.1
4.8
2.0?
1.7?
2.5?
2.4?
2.6?
3.7?
4.7?
4.3?
4.1?
4.6?
5.2?
5.9
6.5

FIG. 28

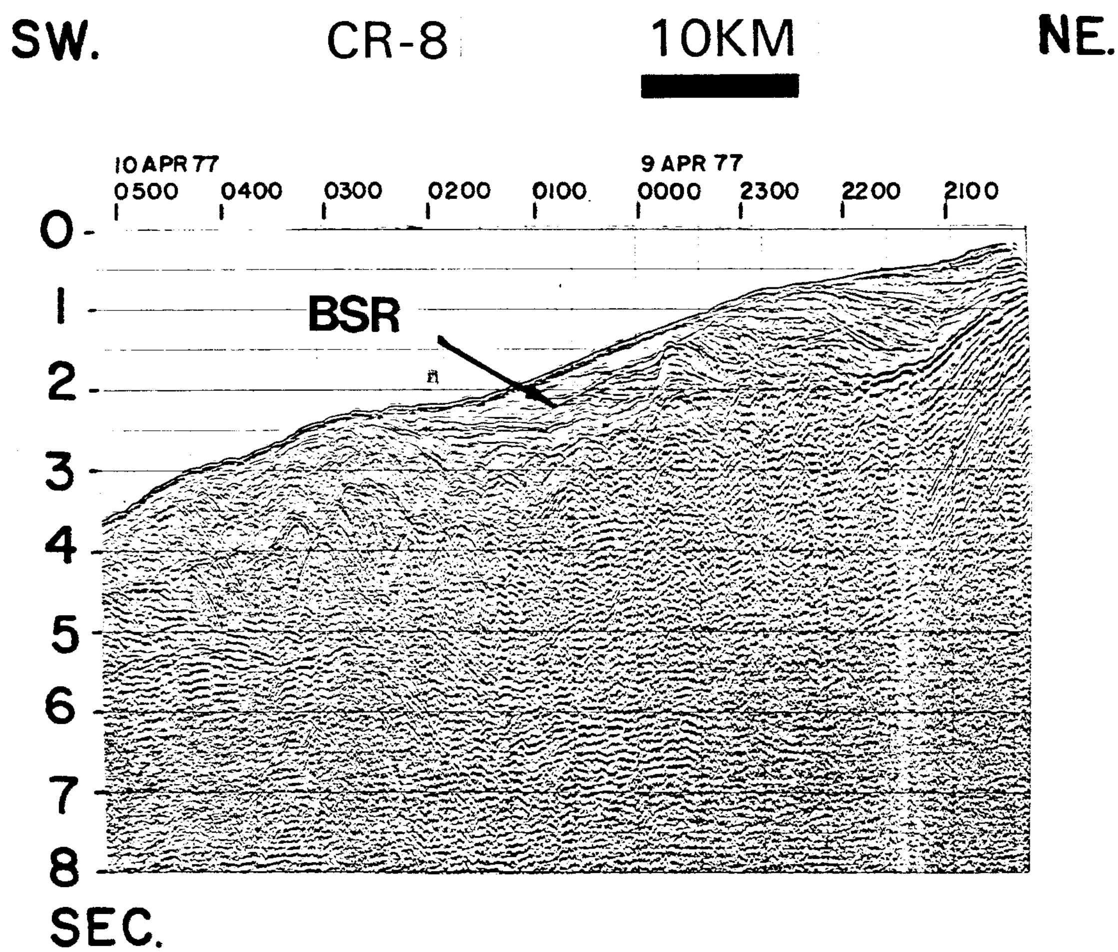

SW.
CR-8
10KM
NE.
10 APR 77
9 APR 77
0500
0400
0300
0200
0100
0000
2300
2200
2100
BSR
0
1
2
3
4
5
6
7
8
SEC.

FIG. 27

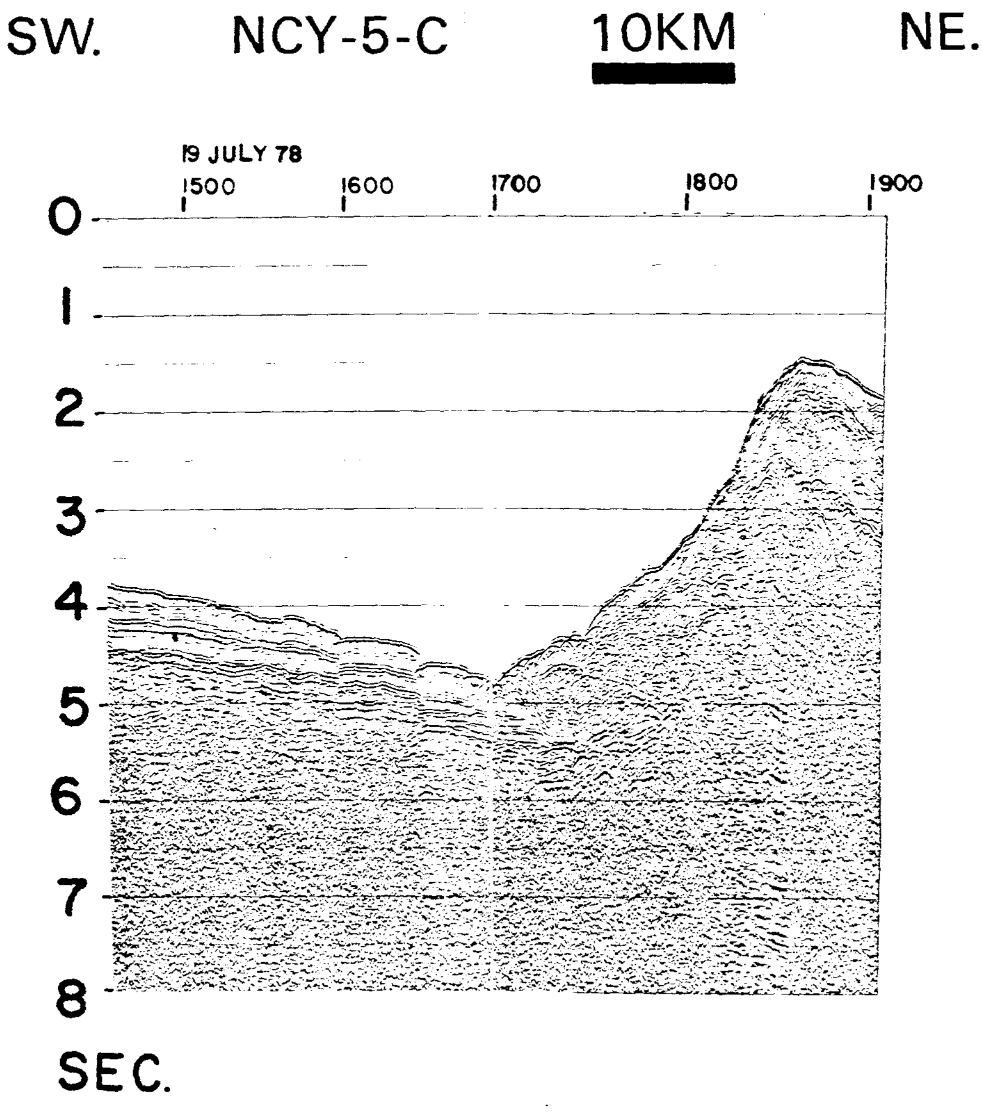

SW.
NCY-5-C
10KM
NE.
19 JULY 78
1500
1600
1700
1800
1900
0
1
2
3
4
5
6
7
8
SEC.

FIG. 29

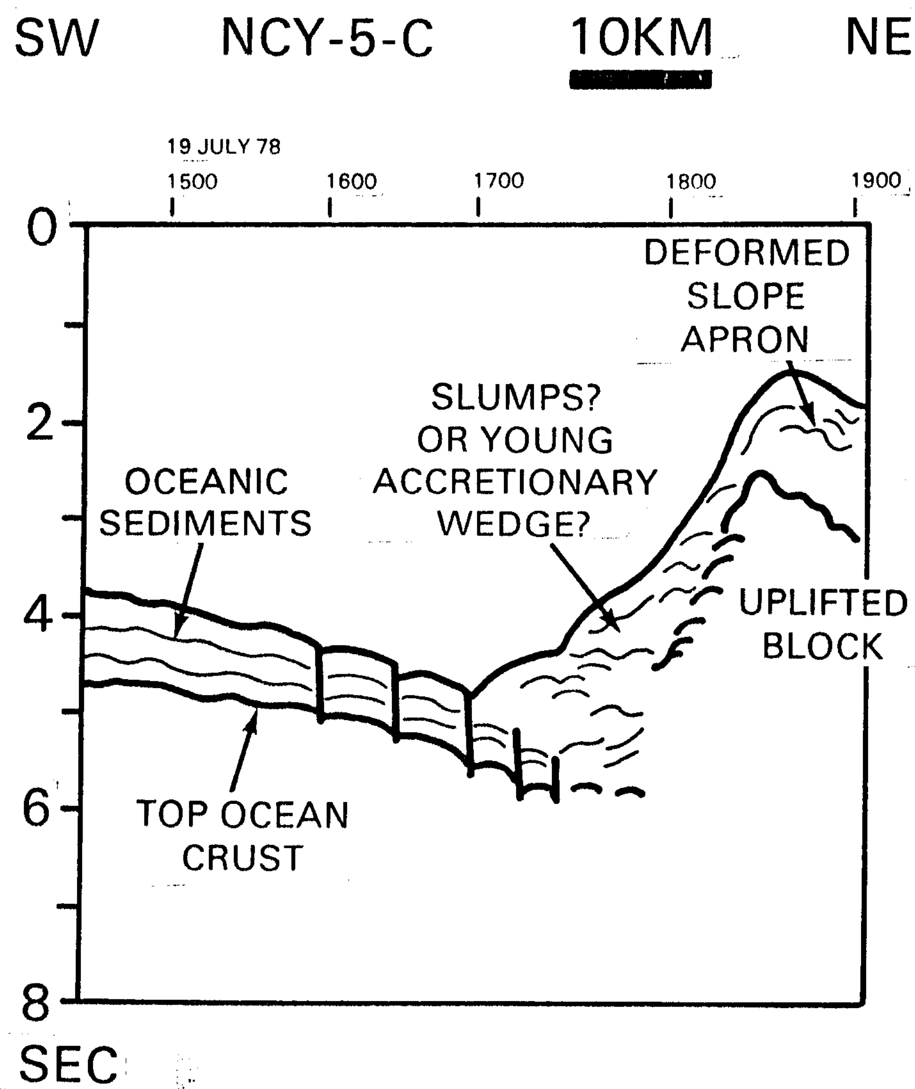

SW
NCY-5-C
10KM
NE
19 JULY 78
1500
1600
1700
1800
1900
0
2
4
6
8
SEC
DEFORMED SLOPE APRON
SLUMPS? OR YOUNG ACCRETIONARY WEDGE?
OCEANIC SEDIMENTS
UPLIFTED BLOCK
TOP OCEAN CRUST

FIG. 30

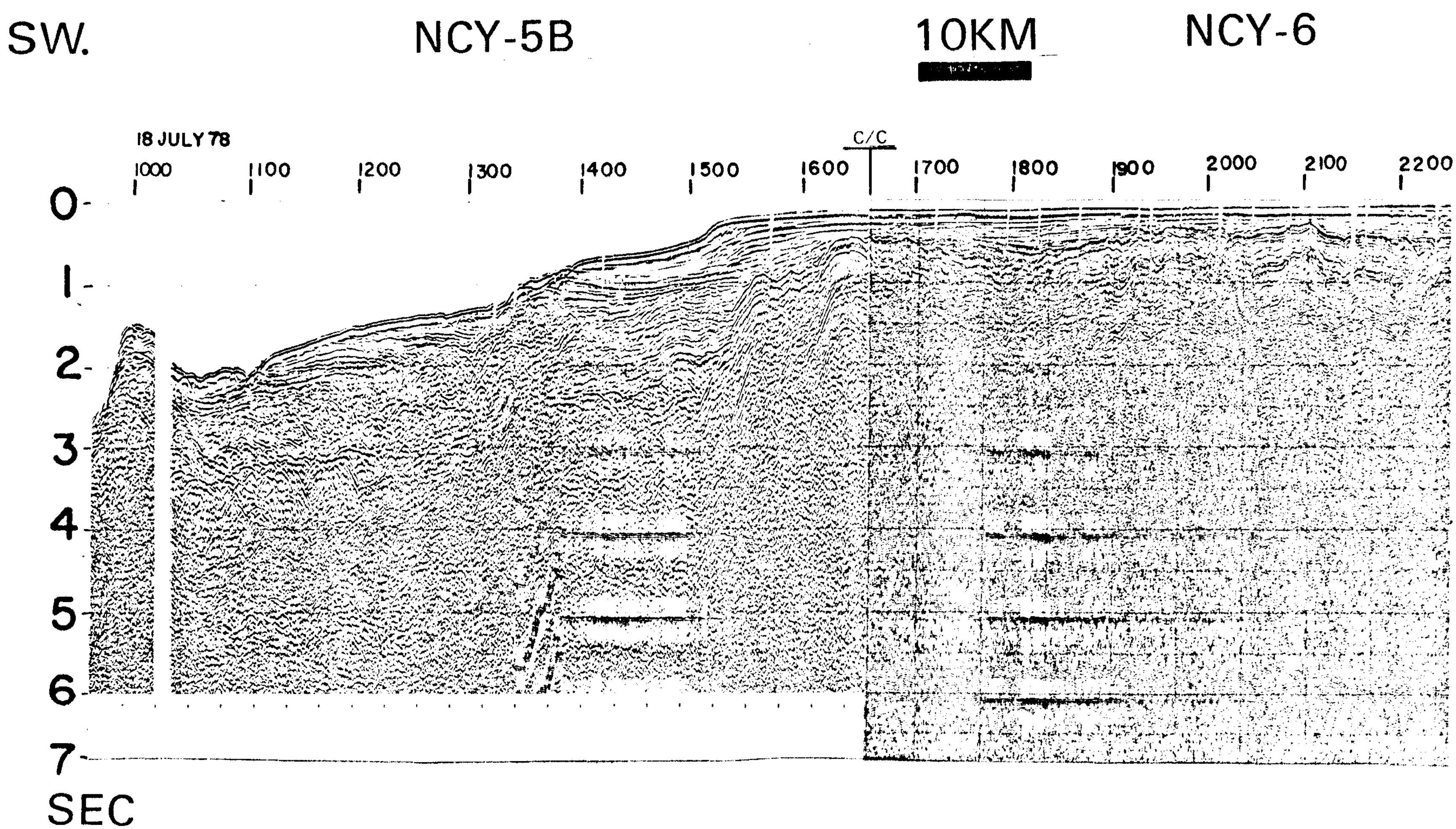

SW.
NCY-5B
10KM
NCY-6
NE.
18 JULY 78
C/C
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
0
1
2
3
4
5
6
7
SEC

FIG. 31

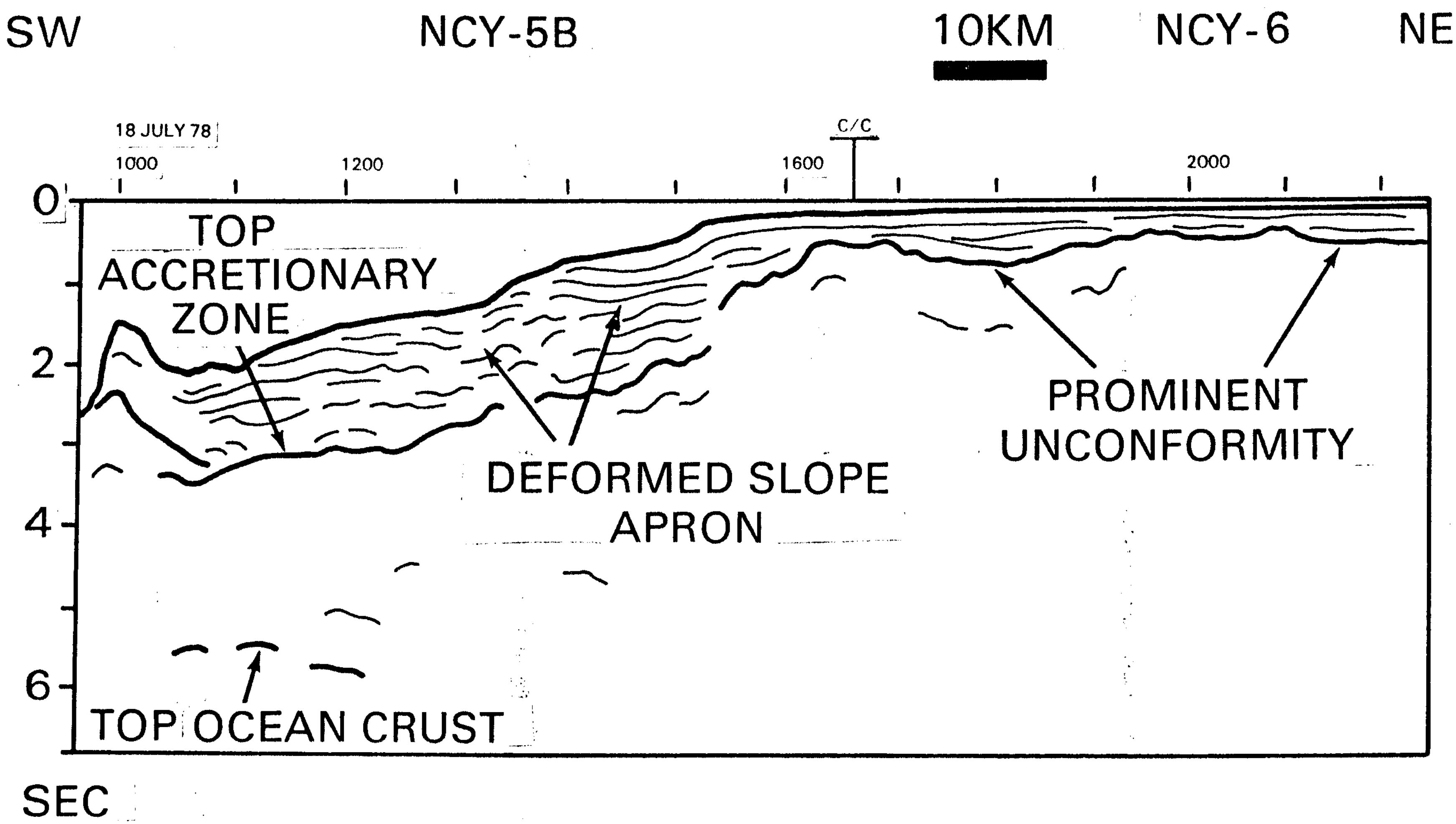

SW
NCY-5B
10KM
NCY-6
NE
18 JULY 78
C/C
1000
1200
1600
2000
0
2
4
6
SEC
TOP
ACCRETIONARY
ZONE
DEFORMED SLOPE
APRON
PROMINENT
UNCONFORMITY
TOP OCEAN CRUST

FIG. 32

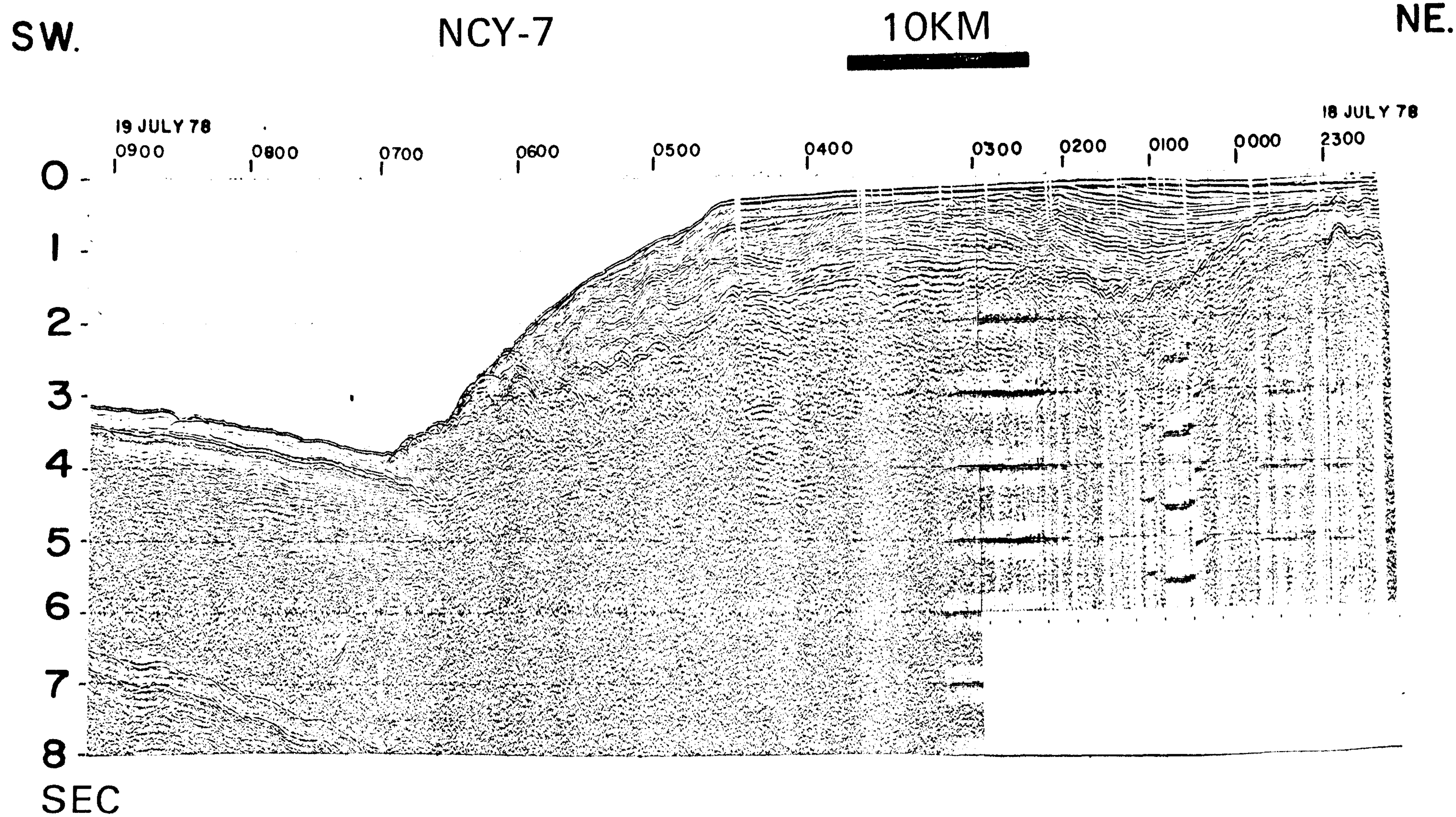

SW.
NCY-7
10KM
NE.
19 JULY 78
18 JULY 78
0900
0800
0700
0600
0500
0400
0300
0200
0100
0000
2300
0
1
2
3
4
5
6
7
8
SEC

FIG. 33

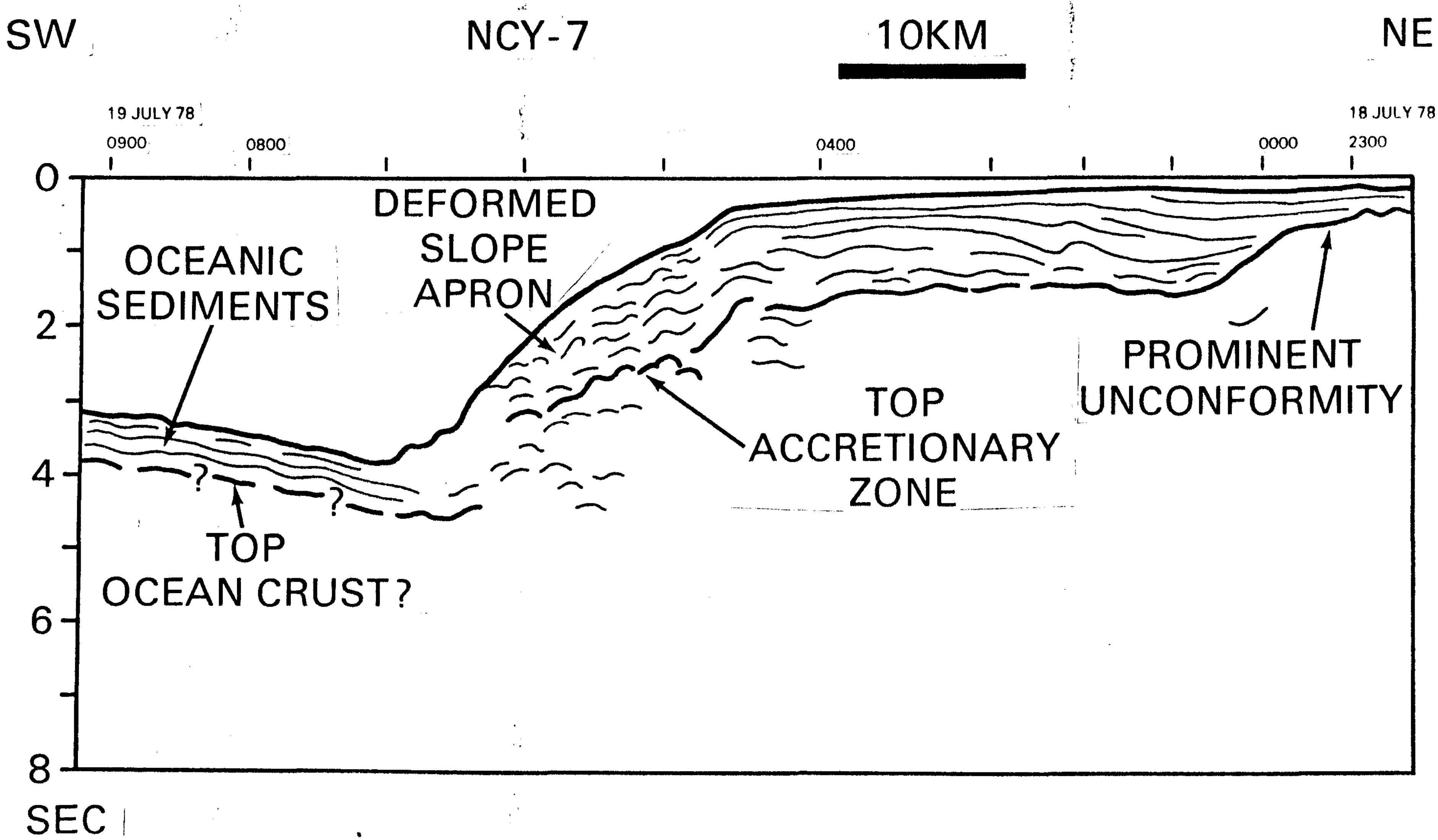

SW
NCY-7
10KM
NE
19 JULY 78
18 JULY 78
0900
0800
0400
0000
2300
0
2
4
6
8
SEC
DEFORMED SLOPE APRON
OCEANIC SEDIMENTS
TOP ACCRETIONARY ZONE
PROMINENT UNCONFORMITY
TOP OCEAN CRUST?
?
?

FIG. 34

responsible for the prominent faults (Figs. 29 and 30), but no such block is evident along CR-2 and CR-9 (Figs. 5, 12, and 13).

There is no horizontally-layered trench fill in this area. Apparently the trench has no access to canyons or abundant supplies of terrigenous material. At the very base of the slope along most lines, however, there is a slight bulge or flattening of the slope that appears to be some type of accumulation of material. Alternatives for the origin of such a feature include: (a) sedimentary material accumulated at the base of the slope by slumping or downslope processes; (b) sedimentary material deposited by contour currents flowing parallel to the trench; (c) a young accretionary prism consisting of some material being scraped off the downgoing ocean slab; and (d) a slab of older material thrust up along the lower slope. The relatively high velocities in part of this section on several lines (CR-7, and CR-5; Figs. 15 and 17) support the latter two alternatives, at least in part.

There is a thick, wedge-shaped zone of material lying beneath the slope that is designated the *accretionary zone*. The term is somewhat misleading, as the nature and origin of this zone is still one of the major problems in convergent margin studies. The zone is characterized by either no reflections or in places poorly-defined, high-amplitude, discontinuous reflections. Where present these reflections generally dip in a landward direction. Good examples of the dipping reflections occur on line CR-5 (Figs. 17 and 18). The lower boundary of this zone is the descending ocean crust, while the upper boundary is a strong, irregular reflector often characterized by diffraction hyperbola. Very preliminary velocity data from sonobuoys, OBS data, long refraction profiles, and multifold seismic data all suggest layers of relatively high velocity in this zone (3.6 to 5.0 km/sec). These velocities could represent both indurated sediments or layered volcanic sequences.

Overlying the accretionary zone is a thick, layered section inferred to be sedimentary rocks. It is designated the *slope apron*. There are several major seismic sequences within the apron, indicating several major depositional episodes. Where relatively undeformed, the slope apron appears to thin downslope and also downlap onto the underlying accretionary zone (e.g., CR-9 and CR-7; Figs. 12 and 15). It has thicknesses up to 1.5 sec. Using an average velocity of 2.5 km/sec for the sequence, this converts to maximum thickness of about 1900 m. In many cases the sequence appears to become more folded and deformed in a downslope direction (CR-9 and NCY-7; Figs. 12, 13, 33, and 34). This could be due either to slumping and downslope movements or tectonic movements related to subduction processes. The sequence also appears to become more deformed deeper stratigraphically in the section (e.g., NCY-5B; Figs. 31 and 32).

The younger part of the slope apron onlaps and fills in against a prominent unconformity (strong reflector) along the landward ends of the NCY lines. This reflector appears to be acoustic basement in the area. It could correspond to the top of the Nicoya complex which outcrops just onshore, or it could represent a major unconformity separating highly-deformed and thus reflectionless rocks below from a younger sedimentary sequence above. Lundberg (in press, a) mentions such a structural change in the Eocene between older, highly-deformed, deep-water deposits and younger, relatively-undeformed, shallow-water deposits. In places the prominent unconformity can be traced seaward under the shelf and slope and appears to be almost continuous with the top of the accretionary zone (lines NCY-5B and NCY-7; Figs. 31 to 34).

In some places the inner trench slope is relatively smooth and undisturbed, while in other places the slope is irregular and disrupted. For example, off the coast of the Nicoya Peninsula the northwestern part of the slope is smooth (CR-9 and CR-7; Figs. 12 to 16), while the southeastern part is more irregular and contains small accretionary basins (CR-5, Figs. 17 and 18). Line CR-1 shows this change along the strike (Figs. 19 to 22). In still other places the lower slope appears to be underlain by large blocks that apparently have uplifted and deformed the slope apron (NCY-1 and NCY-5C and B; Figs. 23, 24, 29, 30, 31, and 32). Also on line NCY-1 (Figs. 23 and 24) as well as NCY-8 (Fig. 11) there are large seamounts just seaward of the trench. Perhaps the large blocks in the lower slope are seamounts of the Cocos Ridge that have collided with and have been incorporated into the lower slope. Alternatively, the blocks could be large pieces of older rocks thrust into the lower slope by accretionary processes.

REGIONAL STRUCTURE

A cross section at no vertical exaggeration shows the general regional structure of the forearc area off Costa Rica (Fig. 35). The section reflects only observed seismic data and is not intended to be interpretive. The velocity data are from unpublished earthquake and refraction studies of Dr. Toshimatsu Matsumoto and his students of the Institute for Geophysics (Matsumoto et al, 1976; Matsumoto and Latham, 1977, and Liaw, 1981). The ocean crust and slope data are from the seismic reflection data discussed in this report. Earthquake hypocenters projected onto the line of section were furnished by Dr. Matsumoto. They are from 1974 to 1979 and include only the most reliable data.

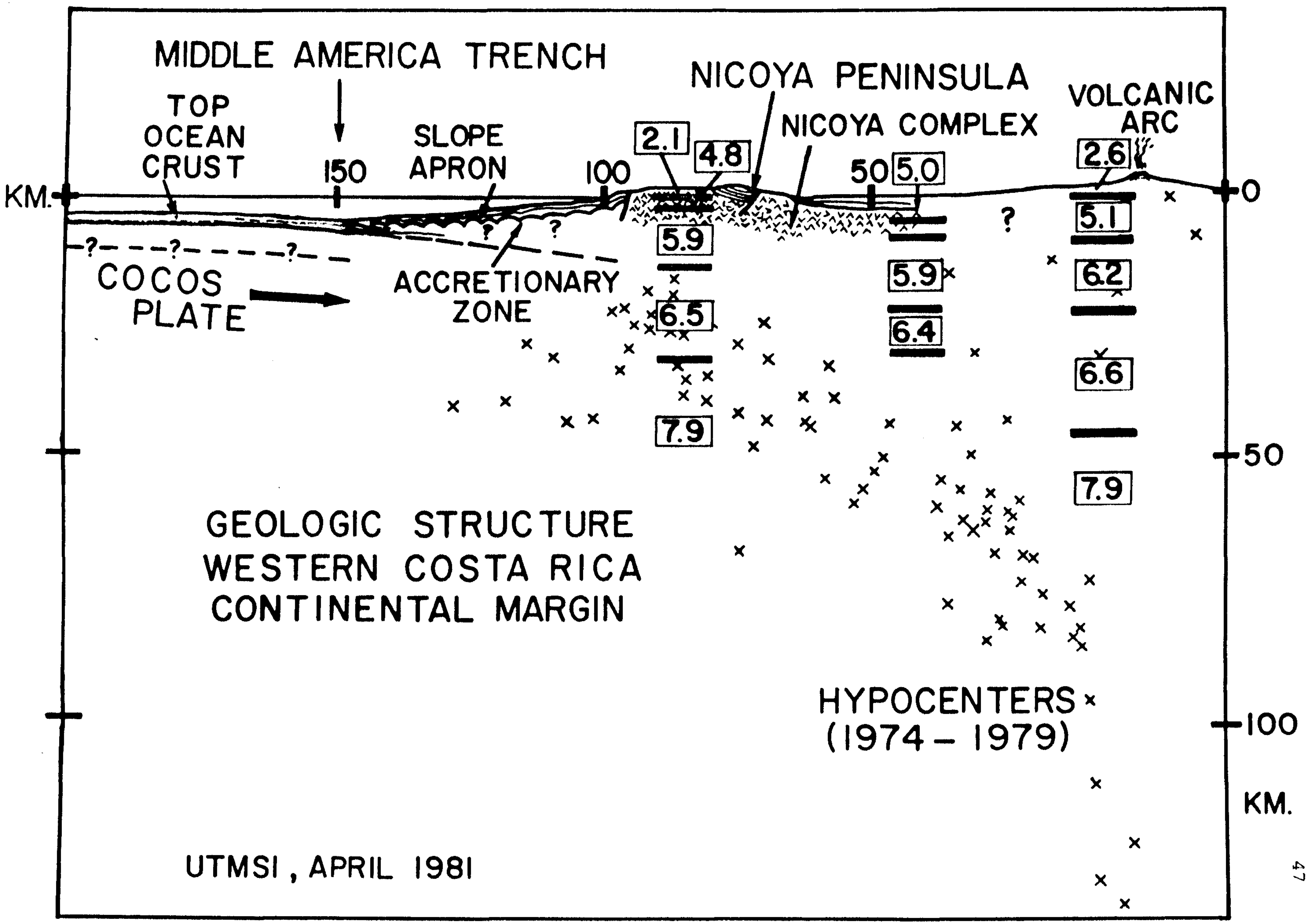

MIDDLE AMERICA TRENCH
NICOYA PENINSULA
VOLCANIC ARC
TOP OCEAN CRUST
SLOPE APRON
NICOYA COMPLEX
150
100
50
0
KM.
2.1
4.8
5.0
2.6
5.9
5.1
5.9
6.2
6.5
6.4
6.6
7.9
7.9
COCOS PLATE
ACCRETIONARY ZONE
50
100
KM.
GEOLOGIC STRUCTURE
WESTERN COSTA RICA
CONTINENTAL MARGIN
HYPOCENTERS (1974 – 1979)
UTMSI, APRIL 1981

FIG. 35

The earthquakes define nicely the Benioff Zone along the top of the downgoing Cocos plate. The top of the 6.5 km/sec layer beneath the Nicoya Peninsula appears to correspond to the top of the subducting ocean crust, while the same velocity layer further east appears to be another high-velocity layer within a thickened crust beneath the arc.

The velocity data show crustal thicknesses beneath the arc corresponding to continental thicknesses. The presence of oceanic rocks (Nicoya complex) beneath most of western Costa Rica and Panama, however, suggest that southern Central America is not an original continental block but consists of a thickened ocean crust. This thickening could have taken place by a combination of several mechanisms, such as a) accretion of ocean slabs by imbricate thrusting and underplating; b) buildup of crust by magmatic arc processes, e.g., intrusion and extrusion of igneous material; and c) collision with the arc of a thick oceanic plateau such as the Cocos Ridge.

GAS OCCURRENCES

Strong bottom-simulating reflections (BSR) are obvious along a few of the lines. They are recognized by their crosscutting relationship to sedimentary layers (e.g., CR-1,Figs. 21 and 22, and CR-8, Fig. 27). An example of CR-8 was included in a recent paper by Shipley et al (1979). These BSR are interpreted to represent the contact between a zone containing gas hydrate above and nonhydrated sediments below. Gas hydrates were encountered in drilling on both DSDP Legs 66 and 67 to the north off southern Mexico and Guatemala.

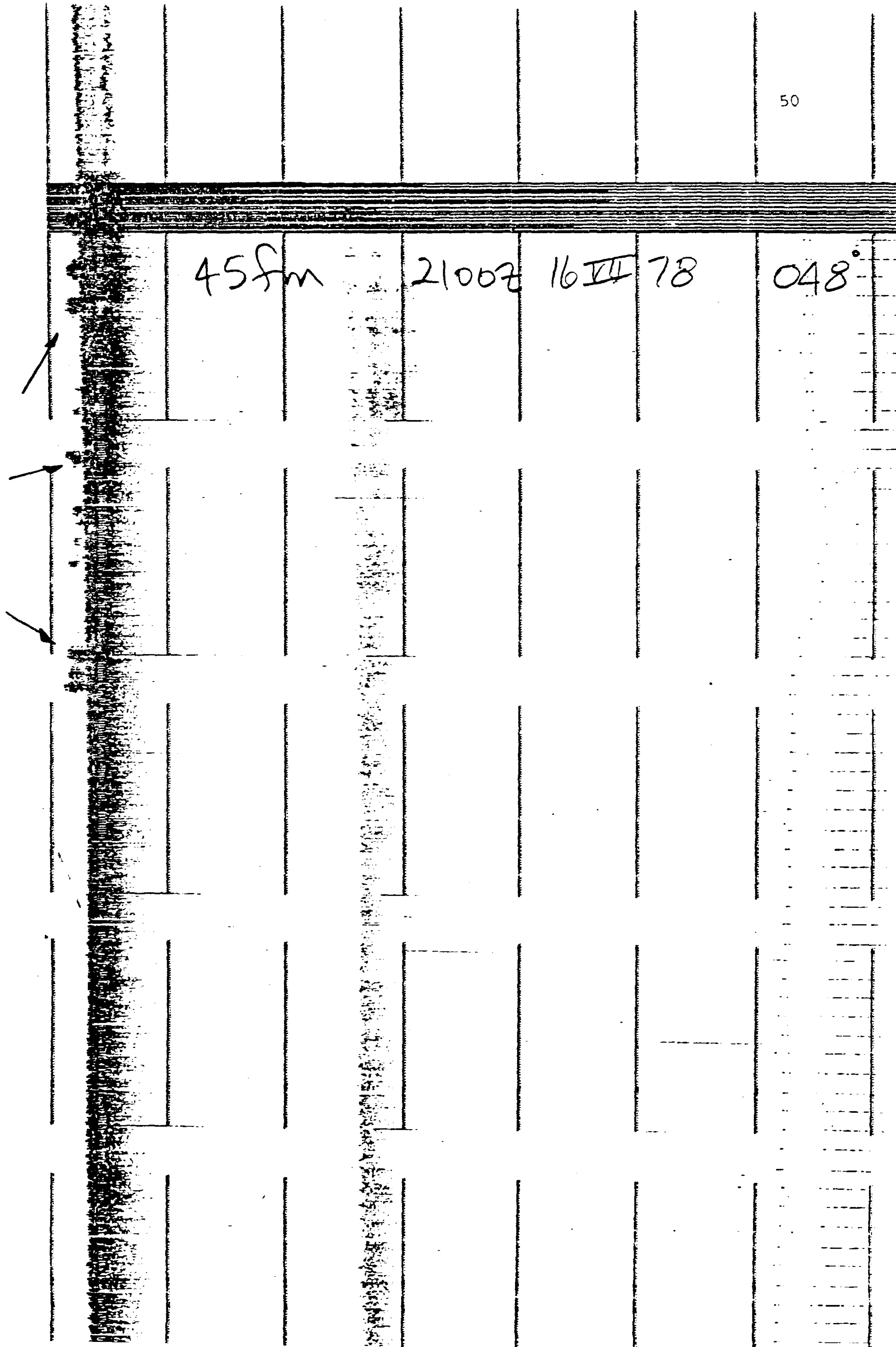
At two locations along the seismic lines dark blobs or oval-shaped reflections were observed on the 3.5 kHz records above the water bottom

(Figs. 36 and 37). Similar features observed off the Texas and Florida coasts in the northern Gulf of Mexico have been interpreted as gas seeps or large rising gas bubbles (Addy and Worzel, 1979; Watkins and Worzel, 1978). The similarity of these features here with the Gulf examples suggest that they may represent gas rising from the sediments.

DISCUSSION

The seismic data presented here show certain features that have to be reconciled with any model for the evolution of the Costa Rica forearc area. Perhaps the main unanswered question is the age and nature of the thick slope apron and the underlying accretionary zone seen on the seismic data in the offshore region. Is the slope apron equivalent to the entire Upper Cretaceous to recent sedimentary section observed on the Nicoya Peninsula? It has about the same overall thickness (1000 to 2000 m). Cretaceous rocks were penetrated in the offshore region of Guatemala (Seely, 1979, and von Huene, 1980). If the slope apron is Upper Cretaceous and younger, then the top of the accretionary zone as well as the prominent unconformity just offshore may represent the top of the Nicoya complex, i.e., the top of Jurassic-Cretaceous oceanic crust. Original emplacement of this crust must have taken place prior to deposition of the overlying sediments and then later been uplifted to its present configuration. The age of the top of the accretionary zone may vary and become younger downdip, as in places the slope apron appears to downlap onto the zone. Thus, the lower part of the zone may have been emplaced by accretionary processes later than the zone further updip.

Alternatively, the slope apron may consist of a much younger sedimentary

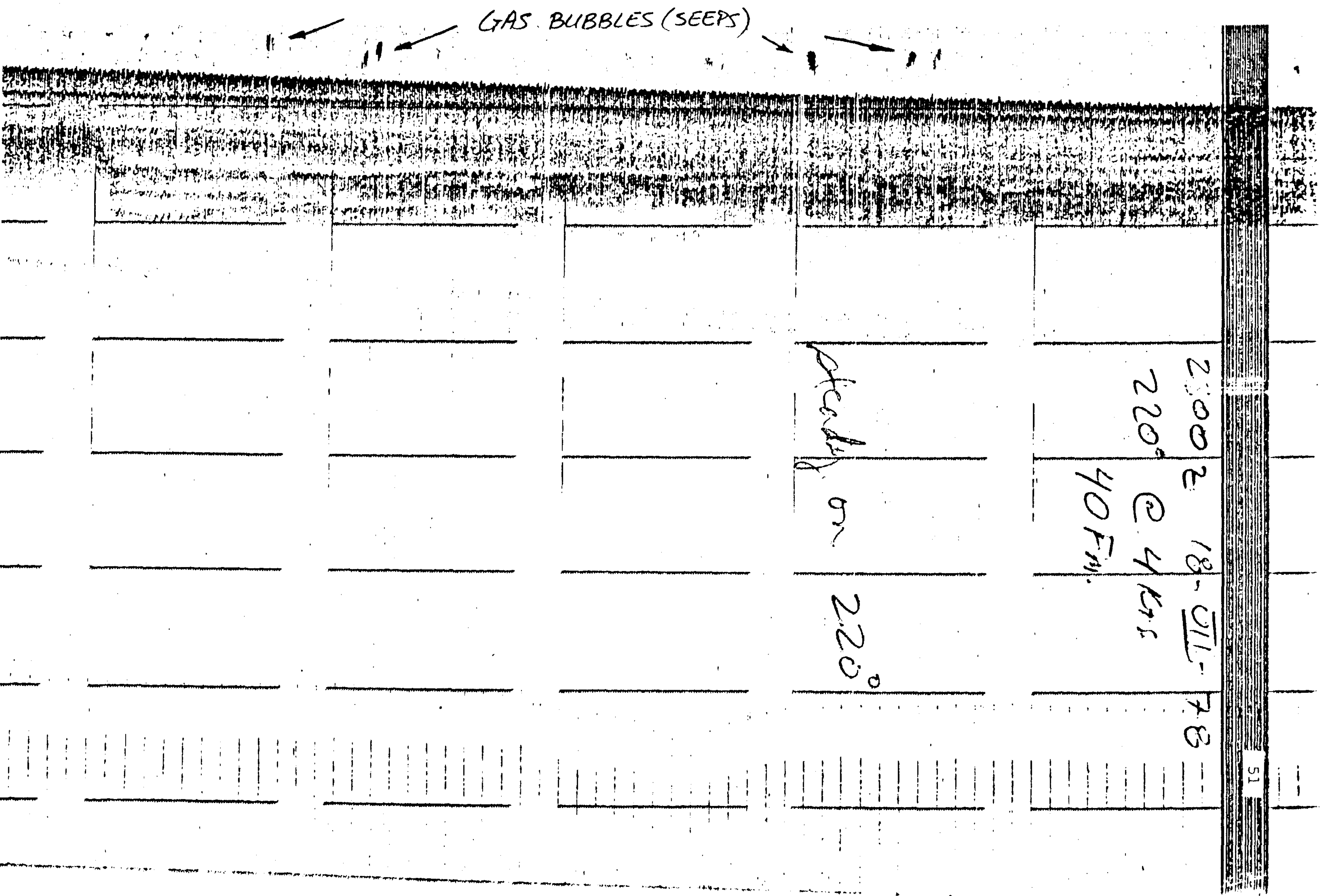


IG-29-3 16 July 1978 NCY-1 TIME: 2100Z

FIG. 36

IG-29-3 18 July 1978 NCY-7 TIME: 2300 Z

FIG. 37



sequence of Early to Late Tertiary age. The prominent unconformity and the top of the accretionary zone, therefore, may represent the top of a highly-deformed sequence of older late Cretaceous-Early Tertiary sedimentary rocks. Regardless of its age and origin, the slope apron is a persistent feature all along the Costa Rica margin and represents deposition in basins surrounding and seaward of uplifted blocks of ocean crust now exposed on the Nicoya and Osa Peninsulas and onshore Costa Rica in the area between the peninsulas.

The Costa Rica margin is a complex forearc region and is much more irregular than the relatively smooth and simple margin to the north off Nicaragua and Guatemala (Fig. 1). Part of this is probably due to the segmentation of the margin associated with normal subduction processes, as discussed earlier. This complexity, however, could be due, in part, to the collision of the Cocos Ridge. Observations that suggest the Ridge is affecting the margin include: (a) the rapid shallowing of the trench, (b) the presence of uplifted blocks within the slope, (c) the dying-out of volcanoes onland to the south, and (d) the shallowing of the Benioff Zone south of the Nicoya Peninsula (T. Matsumoto, personal communication). The latter two observations are characteristic of other areas where ocean plateaus intersect margins.

The geologic evolution of the Costa Rica margin is still somewhat speculative, and there are many ideas as mentioned earlier. The scenario preferred here follows Lundberg (in press, a) and is summarized below. Subduction probably began within an oceanic plate sometime in late Cretaceous time. Slices of a Jurassic-Cretaceous-ocean crust were imbricated and uplifted gradually forming a deep-water forearc basinal area between the trench and the arc. Deep-water volcanic sediments were deposited in this area from Late Cretaceous through Eocene, although carbonates were deposited on local highs. During Eocene time there was a major uplifting and deformation of the forearc region to about its present configuration. This included emplacement of the Nicoya and Osa Peninsulas. Since then relatively shallow-water sequences were deposited along the shelf areas and around the peninsulas, while deep-water sedimentation continuued on the slopes. Subduction and arc-volcanism probably has persisted, at least periodically, since Late Cretaceous.

In conclusion, the new seismic data presented here give an excellent picture of the offshore forearc region off Costa Rica. It shows a very complex history, and the observations noted have to be explained in any model for the geologic evolution of the region. There is still much we do not know or understand, and there is more interpretation of these data needed. For example, a more detailed analysis of the seismic data with respect to the onland geology will be conducted in conjunction with Mr. Neil Lundberg. In addition, it is hoped that additional Deep Sea Drilling Project holes will be drilled offshore Costa Rica which will provide important ground truth for the seismic data. For example, shallow drill holes could identify: 1) the contact between the downgoing ocean crust and the overlying lower slope rocks, 2) the top of the accretionary zone, 3) the nature and age of the slope apron, 4) the nature of the prominent bulge along the lower slope, 5) the origin of the uplifted blocks within the slope, and 6) the age of prominent unconformity just offshore. All of these data will play an important part in improving our understanding of processes occurring along convergent margins.

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