Los Angeles Region Seismic Experiment (LARSE), California - Off-shore Seismic Refraction Data

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SUMMARY

Nine Ocean Bottom Seismometers (OBSs) were deployed in the Inner California Borderland as part of the Los Angeles Region Seismic Experiment (LARSE). The data recorded by these OBSs were intended to delineate the offshore continuation of crustal structure under the Los Angeles Basin. The experiment, conducted in October 1994, was a cooperative study involving scientists from the U.S. Geological Survey, Caltech, the University of Southern California, the University of California Los Angeles, and the Southern California Earthquake Center (SCEC). The offshore wide-angle seismic experiment was the first such experiment in the area since 1958. The data quality recorded on the OBSs was very good with high signal-to-noise ratio on PmP arrivals in the majority of the OBSs. The total OBS data recovery rate for both deployments was about 80%. This report details the experimental design, the data format, the processing steps and other information pertinent to data analysis and modeling. It also presents seismic refraction records of the offshore area recorded by OBS and selected surrounding land stations.

A World-Wide-Web site has been established for the OBS component of the LARSE experiment showing the location of the experiment, samples of the data, and a short version of this report. The site can be found under http://obs.er.usgs.gov.

RATIONALE FOR THE EXPERIMENT

Combined offshore-onshore seismic experiments have become standard in recent years, because of the understanding that geological provinces cross from land to sea, and because marine air-gun sources are safe, highly repeatable, and inexpensive relative to land explosions (Brocher, 1995). The LARSE experiment recorded air-gun blasts generated by the R/V Ewing at seismographs deployed on land along two north-south lines crossing the Los Angeles region. The OBS component, designed to give the seismic velocity structure under the seismic source, is needed for accurate analysis of the land portion of the lines.

A second reason for the offshore component of the experiment is to delineate the seismic velocity structure of the offshore California Borderland province. An accurate velocity model there should enable refinements of the velocity model used to locate earthquakes. An accurate velocity model can be used to predict focusing of energy from earthquakes caused by low-velocity regions, favorably oriented seismic reflectors, and local site-amplification.

There has previously been only one large-scale refraction experiment offshore the Los Angeles basin, but the data were sparse, were not digitally recorded, and were analyzed by one-dimensional ray-tracing models (Shor and Raitt, 1958). The crust was determined to be 24-km-thick in the area between Catalina and San Clemente Islands increasing to 30 km on shore and decreasing to 18 km under the Patton Ridge close to the continent-ocean boundary (Shor and Raitt, 1958). The crust in their model had a P-wave velocity of 6.7±0.1 km/s below a depth of 6 km across the entire Borderland province. Because of the geological structure of the area (thin or missing sedimentary cover underlain by the highly diffractive Catalina Schist), multichannel seismic reflection (MCS) techniques have failed to image the deep crust (Bohannon and Geist, in press). Wide-angle reflection and refraction techniques retain the high density of ray paths that characterize MCS techniques, but are expected to yield larger amplitude reflections according to ray theory, as the critical angle of incidence is approached or exceeded.

EXPERIMENTAL DESIGN

Two offshore-onshore lines, oriented north-south and centered on the Los Angeles basin at the epicenters of the 1933 Long Beach, the 1987 Whittier-Narrows, and the 1994 Northridge earthquakes, were recorded during the experiment (Figure 1). The onshore-offshore lines were

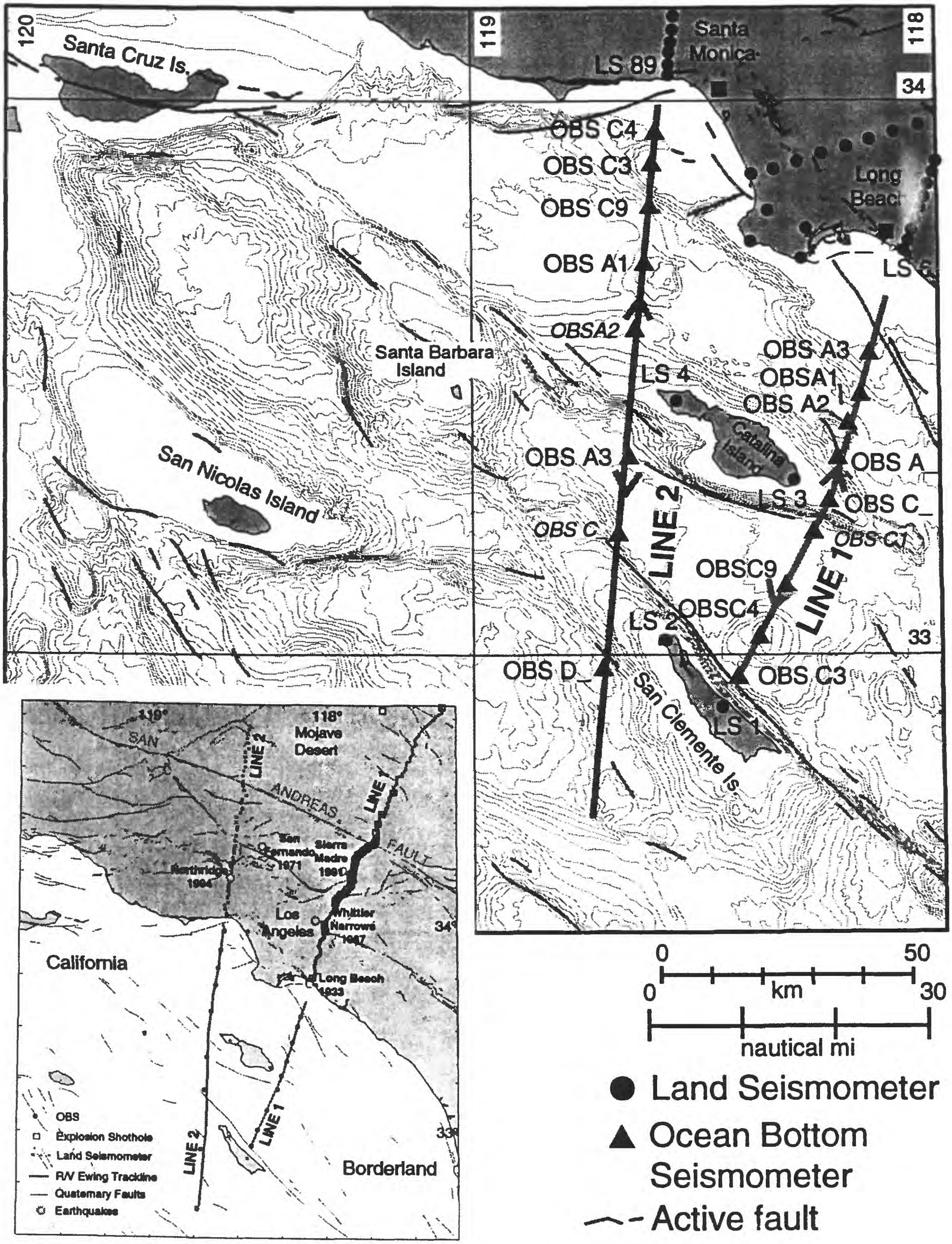


Figure1. Location of offshore seismic profiles. In Italic - OBS which did not record data.
Inset - Overview of offshore-onshore part of the experiment and locations of earthquakes.

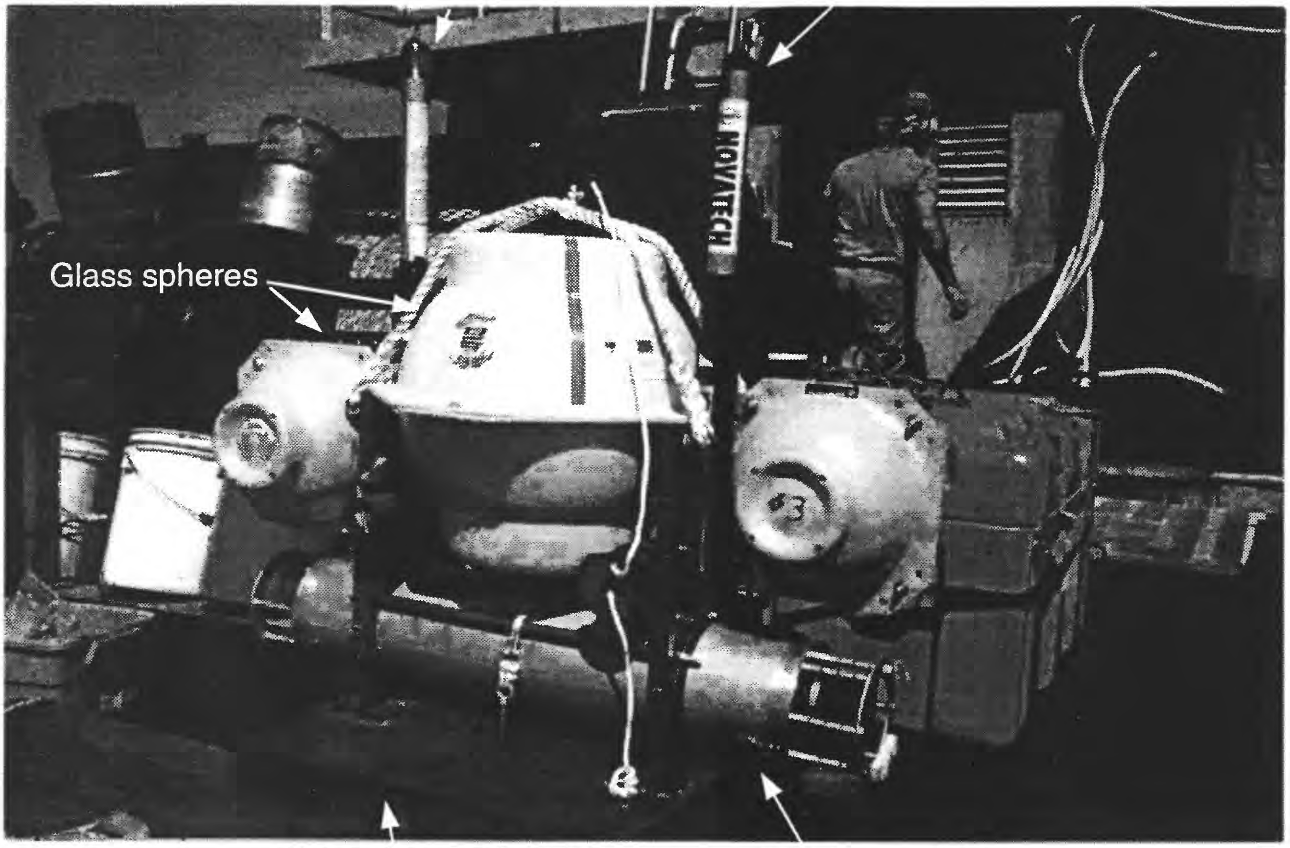
each 200-250 km long, with the offshore lines being between 90 and 150 km long, respectively. The offshore section of Line 1 extended from Seal Beach to San Clemente Island crossing the Catalina Ridge near the SE tip of Catalina Island (Figure 1). The offshore section of Line 2 extended from Santa Monica to 40 km south of the ridge containing San Clemente Island (San Clemente Ridge) passing near the NW tips of Catalina and San Clemente Islands. The onshore parts of the lines were recorded by 170 PASSCAL Reftek recorders and the offshore parts were recorded by the OBSs and by 4 PASSCAL Reftek stations on San Clemente and Catalina Islands.

The *R/V Maurice Ewing*'s 20-element air gun array, totaling 137.7 liters (8470 cu. in.), was used as a seismic source for the wide-angle seismic recordings (Brocher et al., 1995). The array, composed of Bolt air guns, was generally towed at depths between 8 and 10 meters. The ship-to-gun distance varied for each gun to minimize fouling the air-gun towing harnesses and to optimally separate the air bubbles created by the air gun array: the center of the air gun array was towed approximately 87.4 meters behind the Magnavox Global Positioning Satellite (GPS) receiver of the ship. The width of the air gun array across the beam of the ship was 33.8 meters. The sizes of the air gun chambers varied from 145 cu. in. (2.4 liters) to 875 cu. in. (14.2 liters) to provide a tuned outgoing source wavelet. Air gun shot times recorded in the navigation files were from the air gun fire command time determined from a Magnavox GPS clock. Given the less than a millisecond jitters in the air gun firing times, these shot times are considered accurate to within a millisecond. The *Ewing* fired the array at a slow rate (every 60 and 90 seconds along Lines 1 and 2, respectively) to minimize acoustic-wave interference from previous shots in the OBS data (Table 1). These rates correspond to shot intervals of ~150 meters and ~225 meters, respectively. The *Ewing* repeated portions of these lines up to 5 additional times with a repetition rate of 20 seconds (which corresponds to ~50 meters shot interval) to enhance the fold of the wide-angle data recorded onshore. Multichannel seismic reflection data were also recorded during these additional passes by the Ewing's 4.2-kilometers, 160-channel, digital streamer.

The OBSs were deployed from and recovered by the *R/V Yellowfin*, a 76-foot vessel operated by the Southern California Marine Institute, a consortium of universities in Southern California, and based in San Pedro, California. Seven of the OBSs were operated by the USGS Eastern Marine and Coastal Team, Northeastern Section; the two additional OBSs were loaned for the LARSE experiment by Dalhousie University, Halifax, Nova Scotia (Figure 2). The sensors, used by the two different OBSs were nearly identical, yielding nearly matched instruments for the experiment. Separate OBS deployments were made along Lines 1 and 2 (Table 2). Each OBS deployment recorded air gun signals only along the line on which it was deployed. Shots were recorded continuously from a pre-programmed time on four channels (vertical geophone, two horizontal geophones, and a hydrophone). USGS OBS data were recorded at a sampling interval of 10 milliseconds and Dalhousie OBS data were recorded at a sampling interval of 5.73 milliseconds. Data from USGS OBSs were later separated to 60 sec long traces starting after each shot, and those of the Dalhousie OBS to 30 sec long traces. For the most part, the OBSs were concentrated on the northern ends of these lines, to help resolve the velocity structure nearest the Los Angeles Basin. One OBS on the Line 2 deployment was deployed to the southwest of San Clemente Island in an attempt to record reversed upper mantle refractions (Pn).

LOG OF THE EXPERIMENT

Nine OBSs along Line 1 were deployed on 12 October 1994 after being programmed to begin recording at 1600 UTC on JD 286 (0900 L on 13 October 1994). These OBSs recorded during both OBS and MCS passes of Line 1 (Lines 01 and 01R) made by the *Ewing*, and were recovered in the night and morning of 14-15 October 1994. Eight OBSs were immediately recovered from this deployment and all 8 provided useful data for Lines 01 and 01R (as well as for part of Line 01X). OBS C1 was found floating at the surface after being lost for about 4 days. This OBS apparently did not stay attached to its anchor and released shortly after impacting the sea floor,



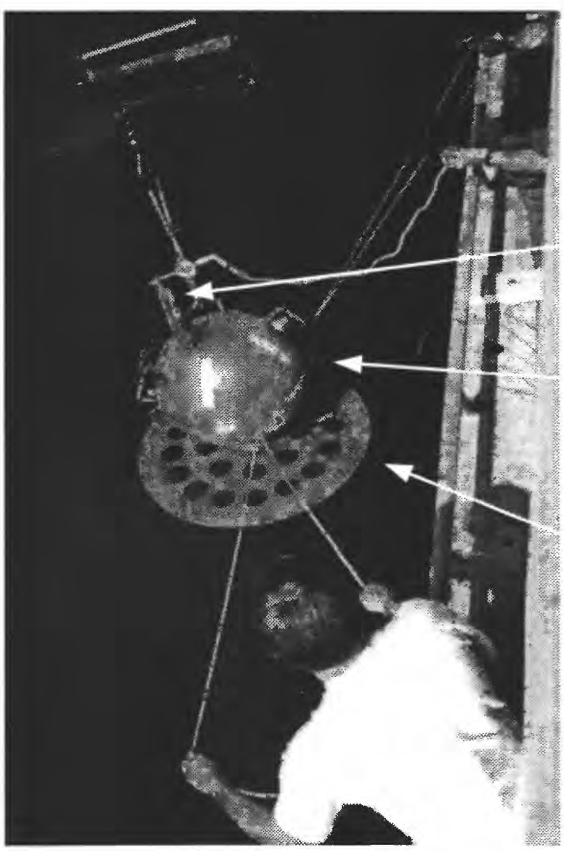


Figure 2. Photographs of Dalhousie University OBS ready to be deployed (above) and USGS OBS being deployed (left).

recording only 10 shots of Line 01. The other OBSs recorded a total of 653 shots during Line 01 and 2310 shots during Line 01R.

The remaining eight OBSs were deployed along Line 2 between 0900 and 1800 UTC on JD 290 (0200 and 1100 L on 17 October 1994), and were programmed to begin recording at 0200 UTC on JD 291 (1900 L on 18 October 1994). The OBSs were recovered between 0215 and 1420 UTC on JD 292 (night and morning of 19-20 October) and thus recorded both OBS and MCS passes of Line 2 (Lines 02R and 02X); four OBSs recorded at least part of MCS Line 02Y (Table 1). Two OBSs, C9 and A2, were not immediately recovered from this deployment (Table 2). Both were found floating at the sea surface after the LARSE MCS experiment ended. OBS A2 recorded 100 shots (12%) of Line 02R before it released prematurely. OBS C9 stayed on the sea floor for nearly a day, and recorded 550 shots of Line 02R (representing 66% of the line). OBS C_ failed to record any useful data during this deployment (Table 2). The other OBSs recorded a total of 721 shots during Line 02R and 1296 shots during 02X.

TABLE 1. Start and End Times and locations of lines shot by R/V *Ewing* and recorded by OBS

	Start of Line			End of Line		
Line No.	UTC Day:HrMn	Lat. (N) Deg. Min.	Long. (W) Deg. Min.	UTC Day:HrMn	Lat. (N) Deg. Min.	Long. (W) Deg. Min.
01*	286:1849	33 38.191	118 07.055	287:0541	32 56.869	118 25.333
01R	287:1155	33 49.475	118 07.194	288:0124	33 37.276	118 11.621
01X	288:0128	33 36.951	118 11.505	288:0632	33 15.103	118 15.692
02R**	291:0155	32 38.363	118 43.386	291:1956	33 59.187	118 35.040
02X	291:2052	33 58.996	118 34.911	292:0404	33 26.080	118 40.439
02Y	292:0405	33 26.060	118 40.465	292:1231	33 59.090	118 35.130

* 60 sec shot time interval
** 90 sec shot time interval

TABLE 2. Locations and elevations of Ocean Bottom Seismometer and land stations

Line 1				Line 2			
OBS Name	Latitude (N) Deg. Min.	Longitude (W) Deg. Min.	Depth (m)	OBS Name	Latitude (N) Deg. Min.	Longitude (W) Deg. Min.	Depth (m)
				LS89	34 04.7350	118 34.8167	-480%
A3	33 34.0844	118 08.7095	97	C4	33 58.6342	118 34.9445	77
A1	33 31.1492	118 09.8185	321	C3	33 53.0789	118 36.0271	79
A2	33 26.5097	118 11.5804	723	C9*	33 47.8420	118 37.0280	833
A_	33 21.0082	118 13.4897	711	A1	33 42.9050	118 37.8090	705
C_	33 16.8277	118 15.1957	177	A2*	33 35.2470	118 39.3110	618
C1*	33 12.8067	118 16.5421	1134	LS4	33 26.8900	118 32.8500	-534%
C9	33 06.7002	118 20.1462	1158	A3	33 21.9648	118 40.6503	1200
C4	33 01.0848	118 23.2386	798	C_#	33 12.4439	118 41.3244	1330-1340
C3	32 56.3934	118 25.2850	1191-1196	LS2	33 00.5200	118 34.0466	-159%
LS1	32 52.6583	118 27.0350	-528%	D_	32 55.2289	118 42.5562	1210-1215

*OBS was not immediately recovered but was found drifting a few days after the others were retrieved. C9 recorded useful data on line 2 before drifting off, but Line 1 C1 and Line 2 A2 did not.
#OBS failed to record data.

When a range of depths is given, the depth-sounder on the *Yellowfin* could not provide more accurate readings at these depths.
%Land stations (designated by L#) have negative depth. Reftek elevations for stations L4 and L89 are relative to the WGS84 spheroid. At Reftek L89, Geoid is 34.9 m below spheroid, and at L4 -36.3 m, hence these amounts were added to the elevation. Elevations for Stations L1 and L2 were taken off the topographic map.

The premature releases of the OBSs were caused by a manufacturing defect (hydrogen embrittlement) of the plated steel springs, which tie the OBSs to their bottom weight. As a result, springs ruptured spontaneously and the OBS floated to the surface.

SPECIFICATIONS OF THE USGS OBS

Dimensions	width	Height	Weight in air
Sphere and external sensors	0.69 m (27")	0.97 m (38")	92 kg (248 lb.)
at launch (with anchor)	1.02 m (40")	0.97 m (38")	119 kg (320 lb.)

Release
12.5 kHz Acoustic command with range capabilities.

Sensors
3 axis gimbaled 4.5 Hz geophones (Mark Product L-15B) hard mounted inside the sphere, 1 external hydrophone OAS E-2S.

Recording system
continuous digital recording at 100 samples/sec from a pre-programmed start time on 4 channels (3 geophones +1 hydrophone). Data logger - "Tattletale 6" with 1 MByte memory buffer and 200 MByte of hard disk.

Dynamic range
72 dB (AD converter) + 30 dB step gain range for each data point.

Data handling
Binary with header information for each 1 MByte of data. Data is transferred from the hard disk to an Exabyte tape drive after each deployment via a 486 PC.

Clock
Oven crystal oscillator accurate to 10^{-8}. Oscillators are interfaced with GPS clock for accurate calibration before and after deployment.

Power supply
72 Alkaline batteries providing +24 V, +12 V, and -12 V for 10 days deployment.

SPECIFICATIONS OF THE DALHOUSIE UNIVERSITY OBS

Housing/Platform
Uses existing design of Bedford Inst. of Oceanography OBS with a maximum water depth of 5 km. Weight in air: instrument - 82 kg; anchor - 55 kg. Size - 1.1 m high; 1.2 m long; 0.6 m wide.

Release
12.5 kHz Acoustic command + timed backup

Sensors

3-component geophone package (oil filled): 4.5 Hz (Mark L-15B; 380 Ohm coil w/ 0.7 damping). Hydrophone (OAS E-2SD)

Sampling rates / dynamic range
23, 11.5, 5.7, 2.9, 1.4 milliseconds @ 16 bit (AD7716 Sigma-Delta ADC)

Gain
Fixed settings hardware selectable geophones (69-93 dB); hydrophone (46-70 dB)

Data storage
2 Mb RAM stored as separate files on 540 Mb Connor HD w/ OTAK adapter to TT7. Capable of recording 4.6 days @ 5.7344 milliseconds sampling of 4 channels (16 bit). Data is transferred to a 486PC via TT7 parallel interface to AT-DIO-24 (100 kbyte/s).

Clock
Austron 1115 OCXO 5 MHz (drift<1 milliseconds/day)

Power supply
4 C-cell lithium (clock). Estimated lifetime >10 days; 12 D-cell NiCad (disk drive); 10+8, D-cell alkaline (analog+digital) acoustic release; 2, 9-volt alkaline (electronics); 4+4, 9-volt alkaline (pinger+release).

COMMENTS ON DATA COLLECTED BY DALHOUSIE OBS

(1) Data was separated into separate files for the following OBS and lines: OBS C_: Line 01 (complete), 01R (complete), 10X (complete); OBS A_: Line 01 (complete), 01R (shots 105-610 only); OBS D_: Line 02R (complete), 02X (shots 101-1100 only); OBS C_: no data. These data have also been archived by Dr. Keith Louden, Dalhousie University in Halifax, Nova Scotia. Data length for each trace is 30 sec beginning at the time of the shot, but Dr. Louden can produce longer data lengths upon request.

(2) Data were slightly clipped for very close shots. Some traces have small dc-biases.

(3) In converting from the internal OBS data files to SEGY, there are few (5-10) missing shots. If a shot occurred while the data logger was writing to the hard disk, the shot would not have been recorded. Corrected files with gaps inserted in the proper offsets will be available shortly upon request from the senior author.

DATA FORMAT

Trace header format on SEGY files of all OBS files are as follows:

Byte position 1 = trace # (a number from 1 to the # traces in the file).
Byte position 5 = trace # as above.
Byte position 9 = shot # (from navigation data).
Byte position 13 = channel # (1 = vertical geophone, 2 and 3 = horizontal geophones, and 4 = hydrophone).
Byte position 29 = trace id code (1 for seismic data)
Byte position 31 = # of vertically stacked traces (1 for 1 trace)
Byte position 33 = # of horizontally stacked traces (1 for 1 trace)
Byte position 35 = data use (1 for production)
Byte position 37 = Shot-receiver offset (Offsets are negative for all shots occurring south of each OBS location and positive for all shots occurring north of each OBS location)

Byte position 41 = receiver elevation (negative value of the OBS depth)
Byte position 65 = water depth of receiver (OBS depth)
Byte position 73 = source longitude (in seconds)
Byte position 77 = source latitude (in seconds)
Byte position 81 = OBS longitude (in seconds)
Byte position 85 = OBS latitude (in seconds)
Byte position 89 = coordinate units (2 for seconds of arc)
Byte position 109 = delay recording time (0 in this case)
Byte position 115 = # samples in this trace
Byte position 117 = sample interval (in microsecs, e.g., 10,000 or 5,733)
Byte position 119 = gain type (1 for fixed)
Byte position 125 = correlated (1 for not correlated)
Byte position 141 = alias filter frequency (in hertz)
Byte position 143 = alias filter slope (dB/octave)
Byte position 157 = year of shot
Byte position 159 = day of year (Julian)
Byte position 161 = hour of day
Byte position 163 = minute
Byte position 165 = second
Byte position 167 = time basis code (2 for GMT - GMT used for all time references)
Byte position 169 = trace weighting factor (data values are recorded with the least significant bit corresponding to 10's of microvolts for a weight factor of 14)
Byte position 181 = milliseconds of the shot time

The following header locations were mapped, when the SEGY tapes were read into the Promax 5.1 software:
Byte position 53 = receiver elevation
Byte position 81 = receiver longitude
Byte position 85 = receiver latitude
Byte position 155 = OBS Channel number (1-4).

The Ewing's navigation files in ASCII text have the following format:

94 286 18:49:17.736 00101 N 33 38.1910 W -118 07.0551 LA01
yr JD time (h:m:s) shot # latitude longitude line #
where yr - year , JD - Julian day.

RECORD SECTIONS

We present wide-angle seismic sections recorded by the instruments listed in Table 2 for Line 1 (Figures 3-11) and Line 2 (Figures 13-21). The sections were recorded by the vertical geophone of the OBSs (channel 1) and of the land seismometers (PASSCAL Reftek). For the OBSs, data from channel 4 (hydrophone) may have slightly higher frequency content at small offset than channel 1, but their amplitudes decay more rapidly with offset. The quality of data from channels 2 and 3 (horizontal geophones) is generally poor. Denser data (every 50 m) were recorded by all instruments during other passes of the ship over the profiles (Lines 01R, 01X, 01Y, 02X, 02Y), but the data are similar in quality to the data presented here.

We also include seismic reflection profiles for these two lines on which we annotated locations of the OBSs and the projected locations of the land instruments. The MCS data for Line 01 (Figure 12) are a brute stack (courtesy of Kim Klitgord, USGS). The profile for Line 02 (Figure 22) is a single-channel monitor extracted aboard the R/V *Ewing* from channel 150, which is 412.5 m behind the center of the airgun array.

The processing sequence for the record sections presented in Figures 3-11 and 13-21 is as follows:

- Reading SEGY tape
- Modification of header location definition
- Linear Moveout correction at 6 km/s (except for Reftek data)
- Trace DC removal
- Minimum phase spiking deconvolution
- Butterworth band pass filter 1-3-15-18 Hz
- 2-D spatial filter over 3 traces and 3 time samples (The weight of the filtered sample is double that of the surrounding 9 samples)
- Trace equalization
- Automatic gain control with a 500 milliseconds window
- Wiggle trace and variable area plot with a section gain of 90 and a clip of 140

DATA REPOSITORY

Data are available for all four channels of each OBS for the lines listed in Table 2. Please contact the senior author at tel. 508-457-2396. Additional copies reside at the USGS in Menlo Park (with Dr. Gary Fuis, tel. 415-329-4758) and at the Southern California Earthquake Center (with Dr. David Okaya, tel. 213-740-7452). Data from the Dalhousie instruments are also available from Dalhousie University (Dr. Keith Louden, tel. 902-424-3557).

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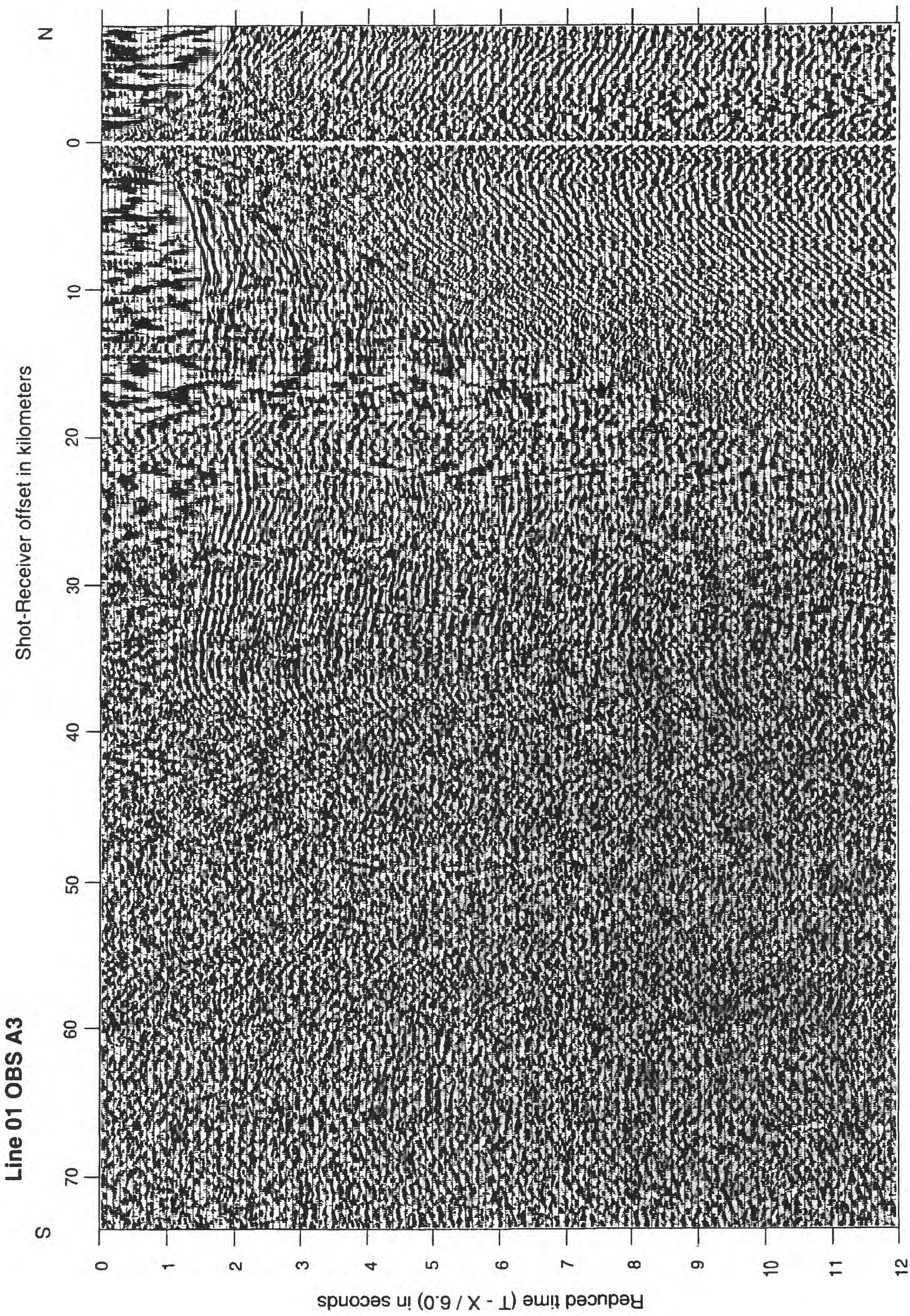
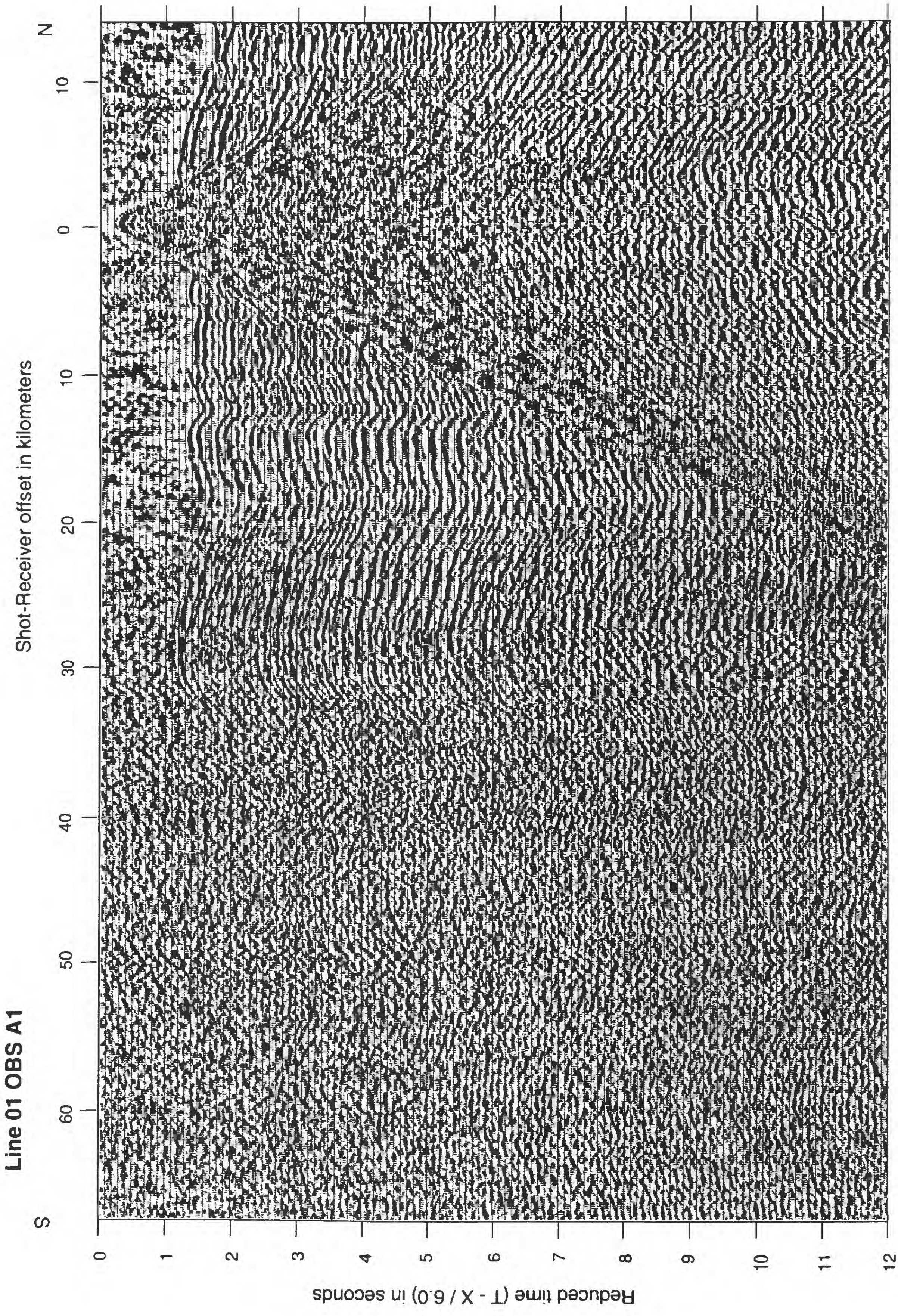
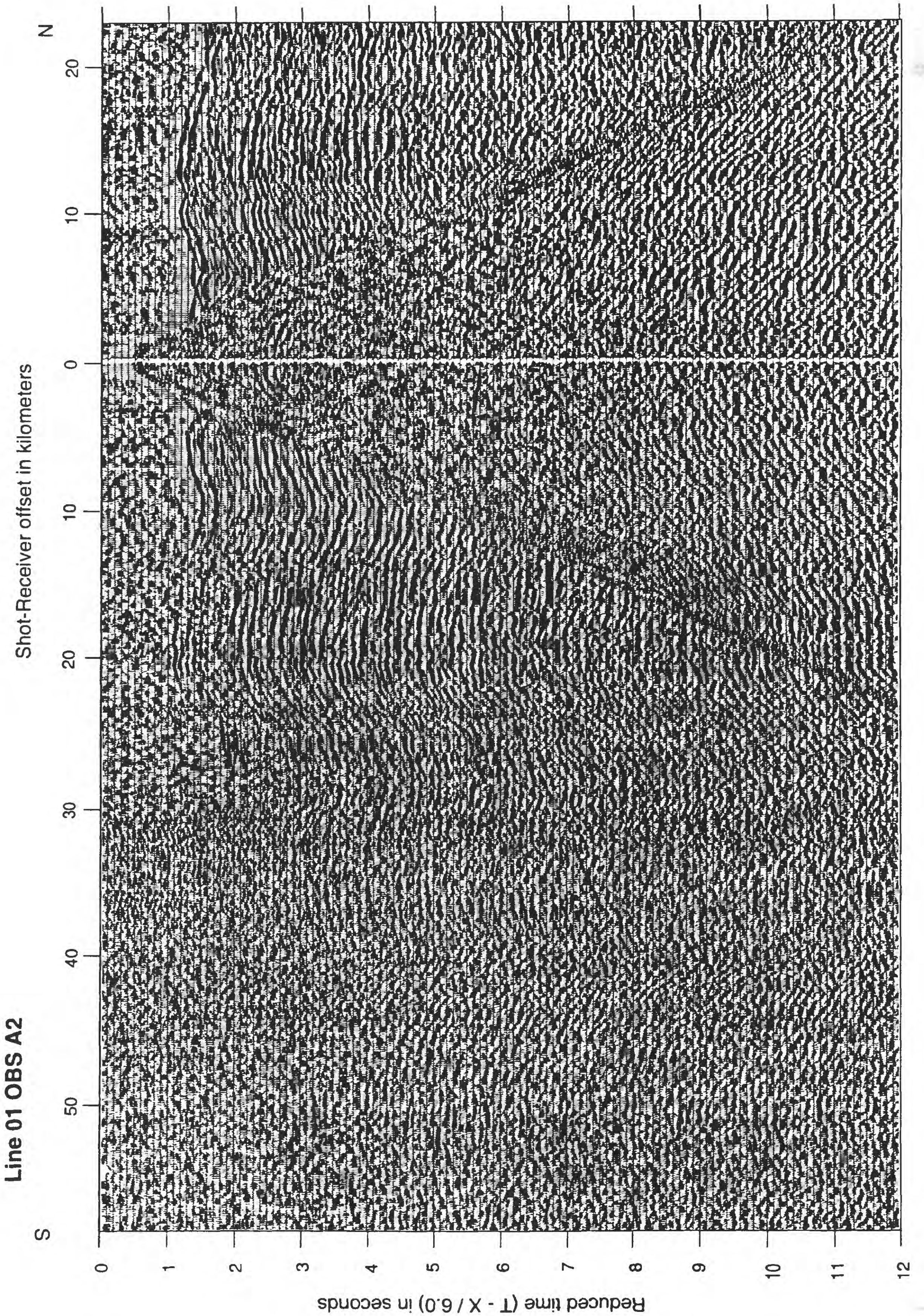

Line 01 OBS A3
Shot-Receiver offset in kilometers
N
S
0
10
20
30
40
50
60
70
Reduced time (T - X / 6.0) in seconds
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 3



Line 01 OBS A1
Shot-Receiver offset in kilometers
S
N
60
50
40
30
20
10
0
10
Reduced time (T - X / 6.0) in seconds
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 4



Line 01 OBS A2
Shot-Receiver offset in kilometers
S
N
50
40
30
20
10
0
10
20
Reduced time (T - X / 6.0) in seconds
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 5.

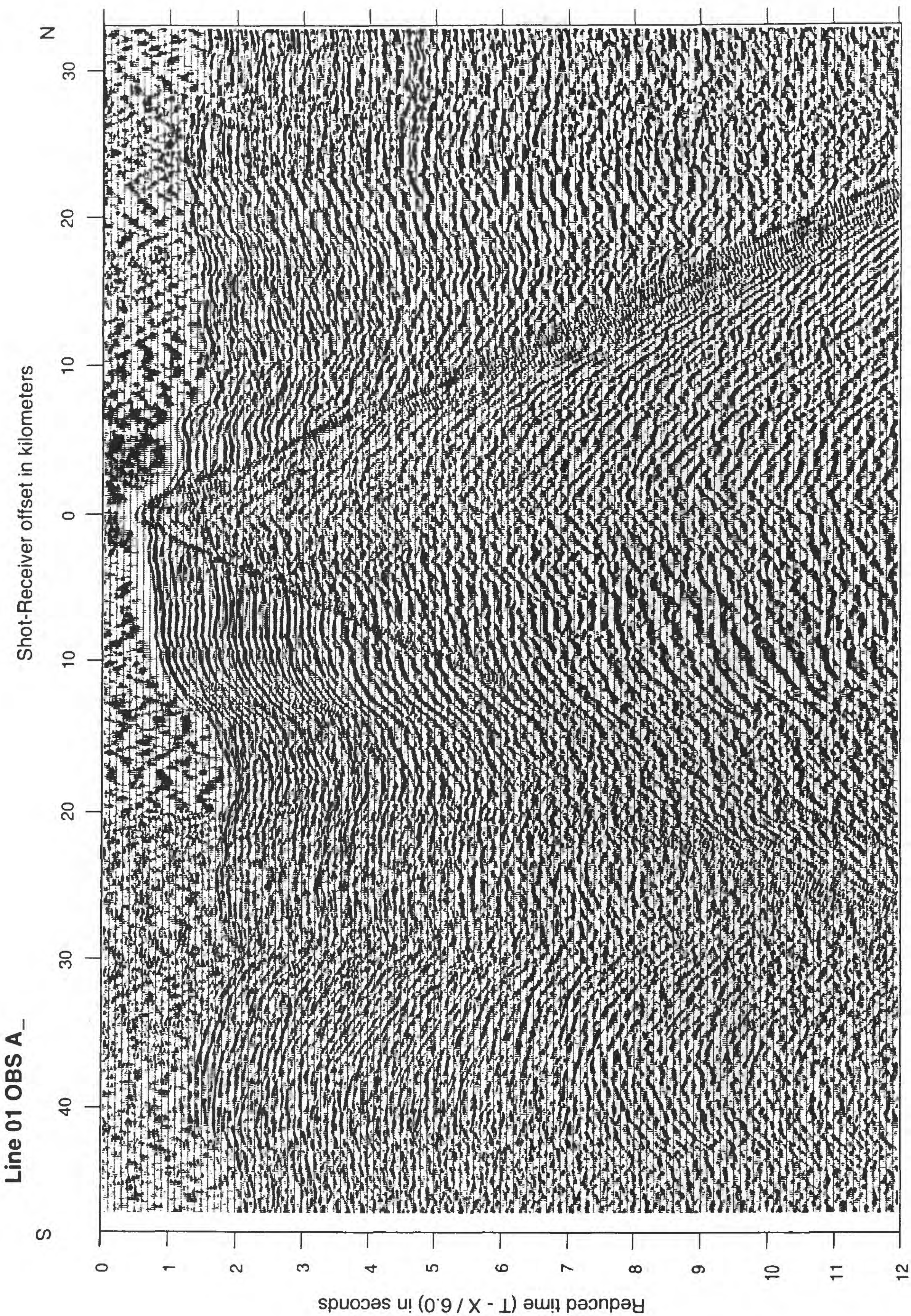
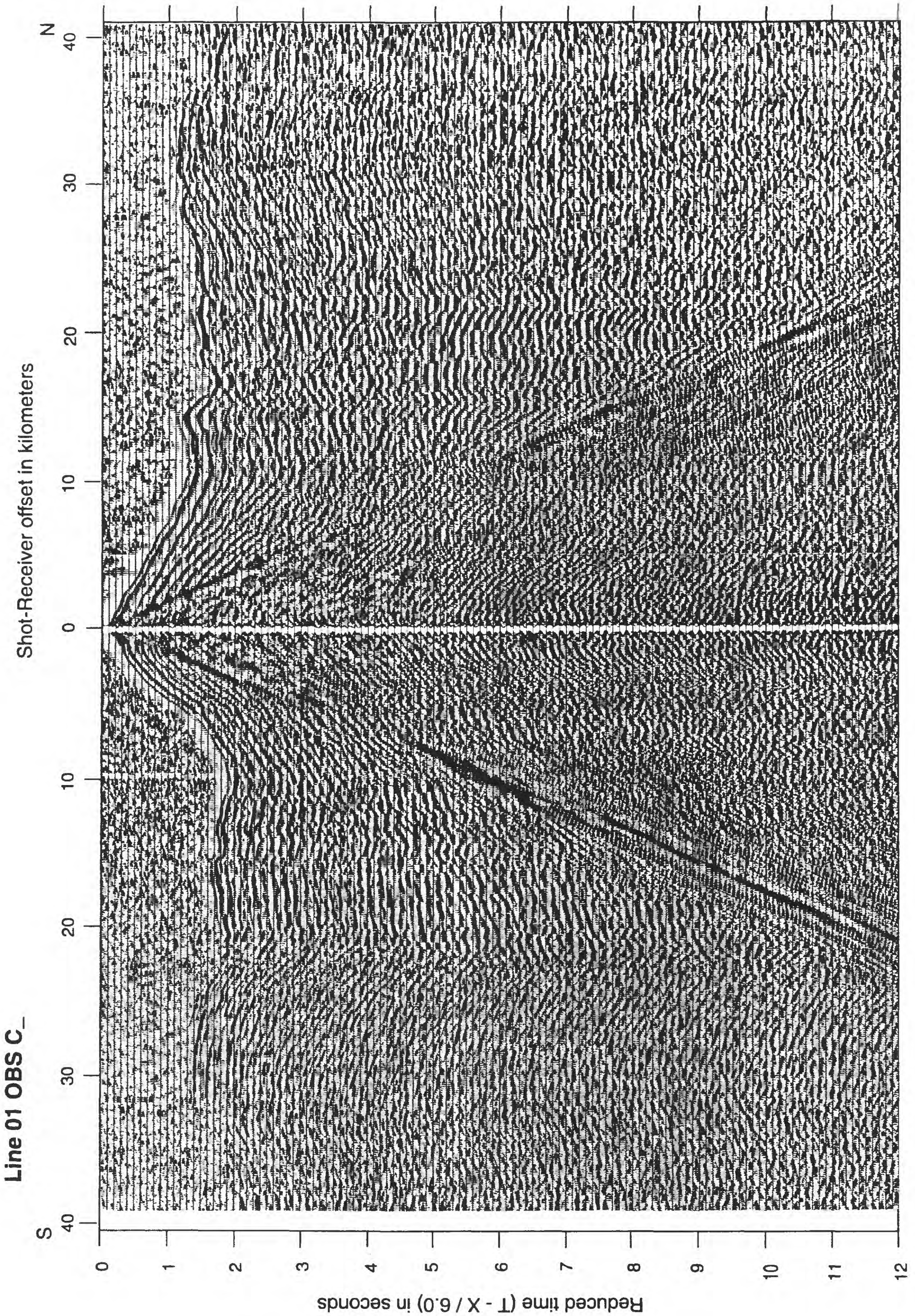
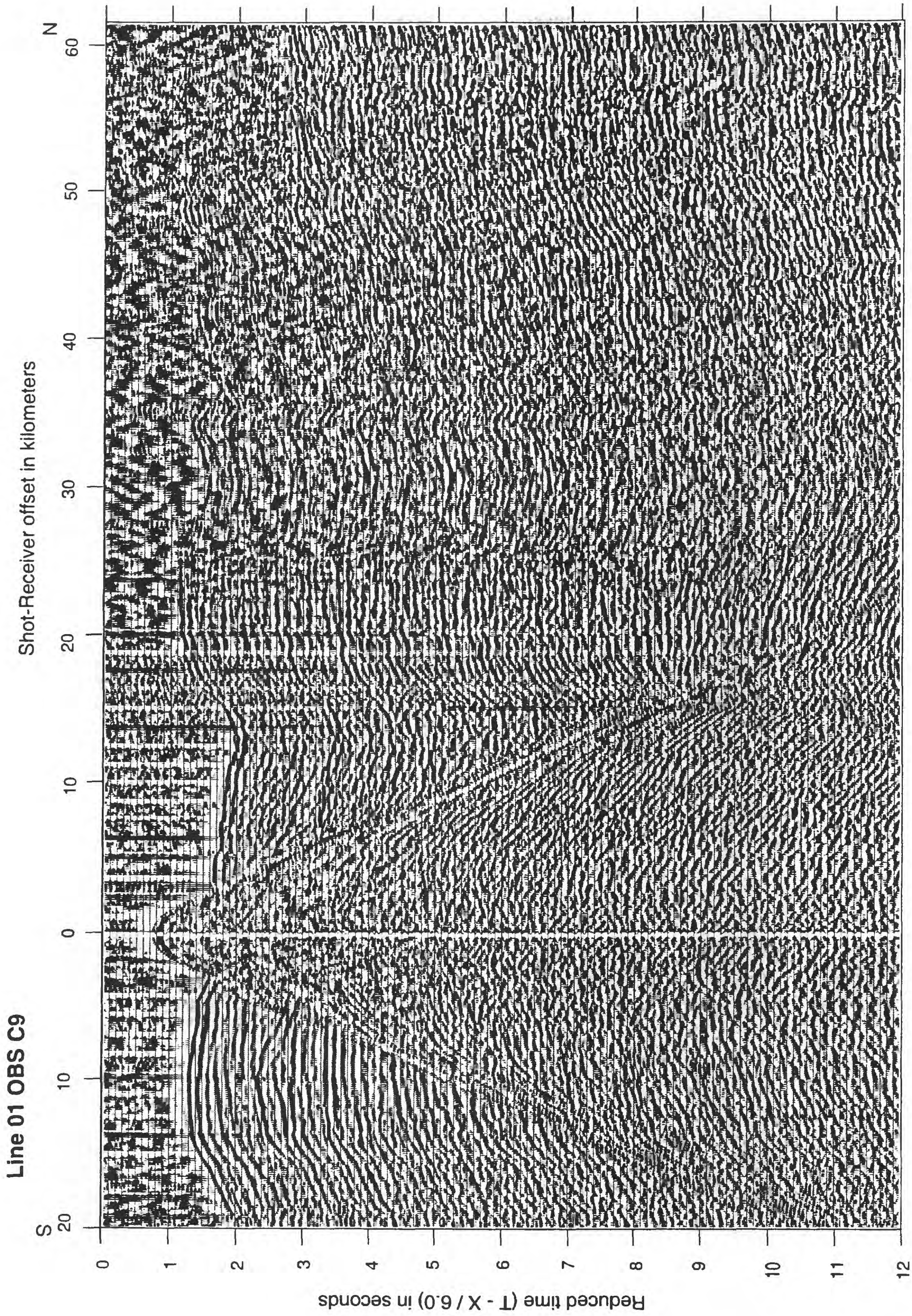

Line 01 OBS A_
Shot-Receiver offset in kilometers
S
N
40
30
20
10
0
10
20
30
Reduced time (T - X / 6.0) in seconds
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 6.



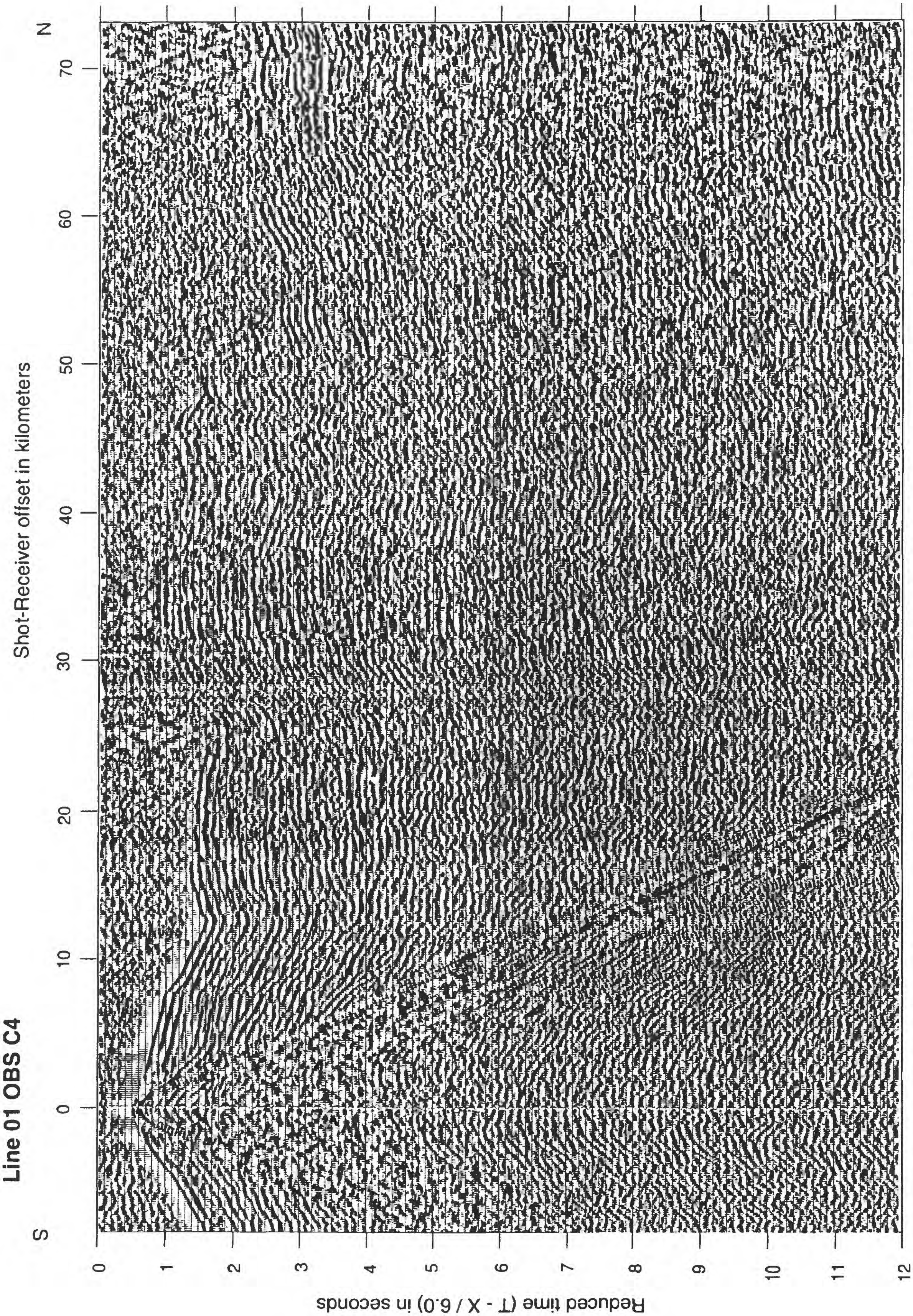
Line 01 OBS C_
Shot-Receiver offset in kilometers
S
N
40
30
20
10
0
10
20
30
40
Reduced time (T - X / 6.0) in seconds
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 7.



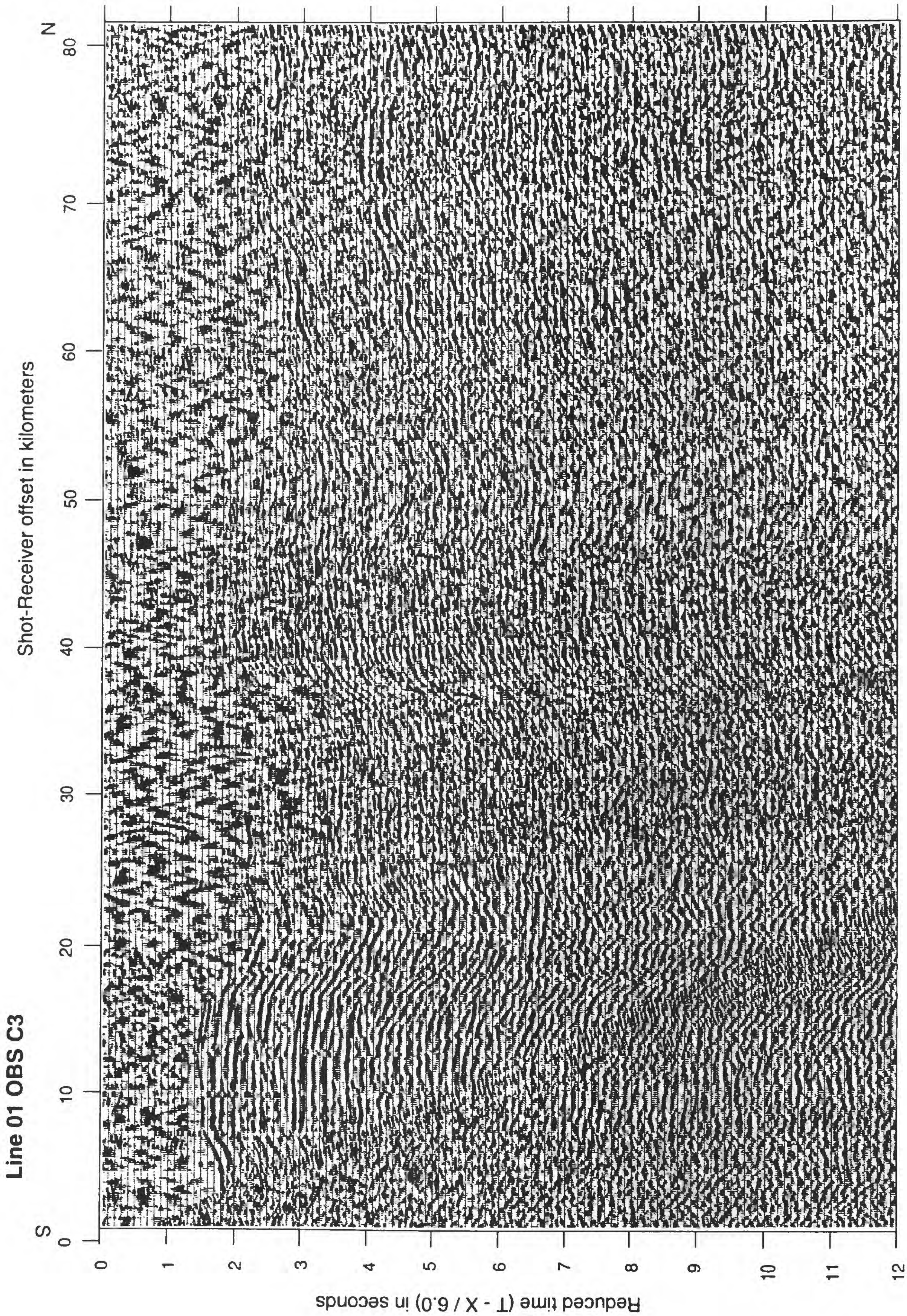
Line 01 OBS C9
Shot-Receiver offset in kilometers
S
N
20
10
0
10
20
30
40
50
60
Reduced time (T - X / 6.0) in seconds
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 8.



Line 01 OBS C4
Shot-Receiver offset in kilometers
S
N
0
10
20
30
40
50
60
70
Reduced time (T - X / 6.0) in seconds
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 9.



Line 01 OBS C3
Shot-Receiver offset in kilometers
S
N
0
10
20
30
40
50
60
70
80
Reduced time (T - X / 6.0) in seconds
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 10.

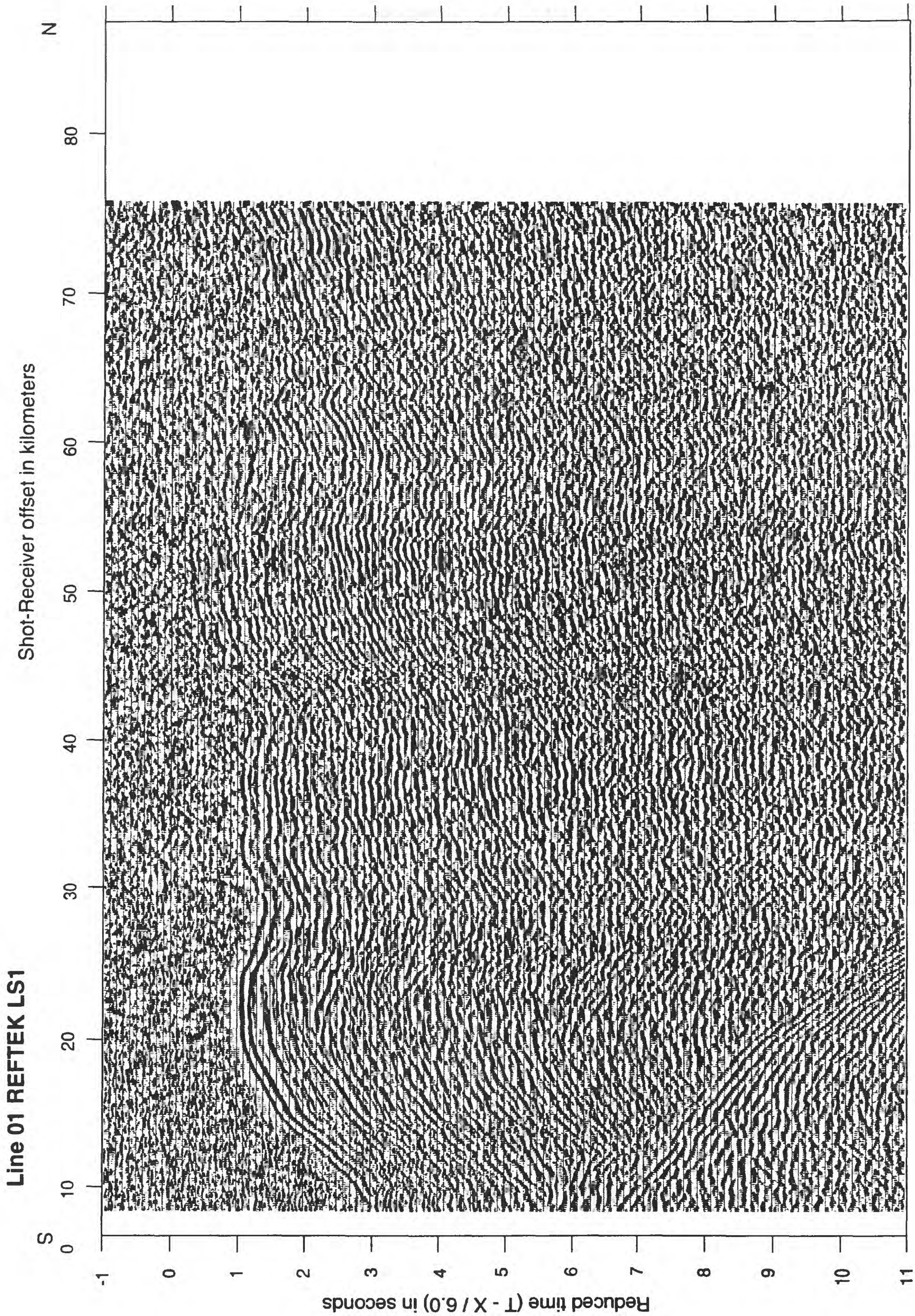
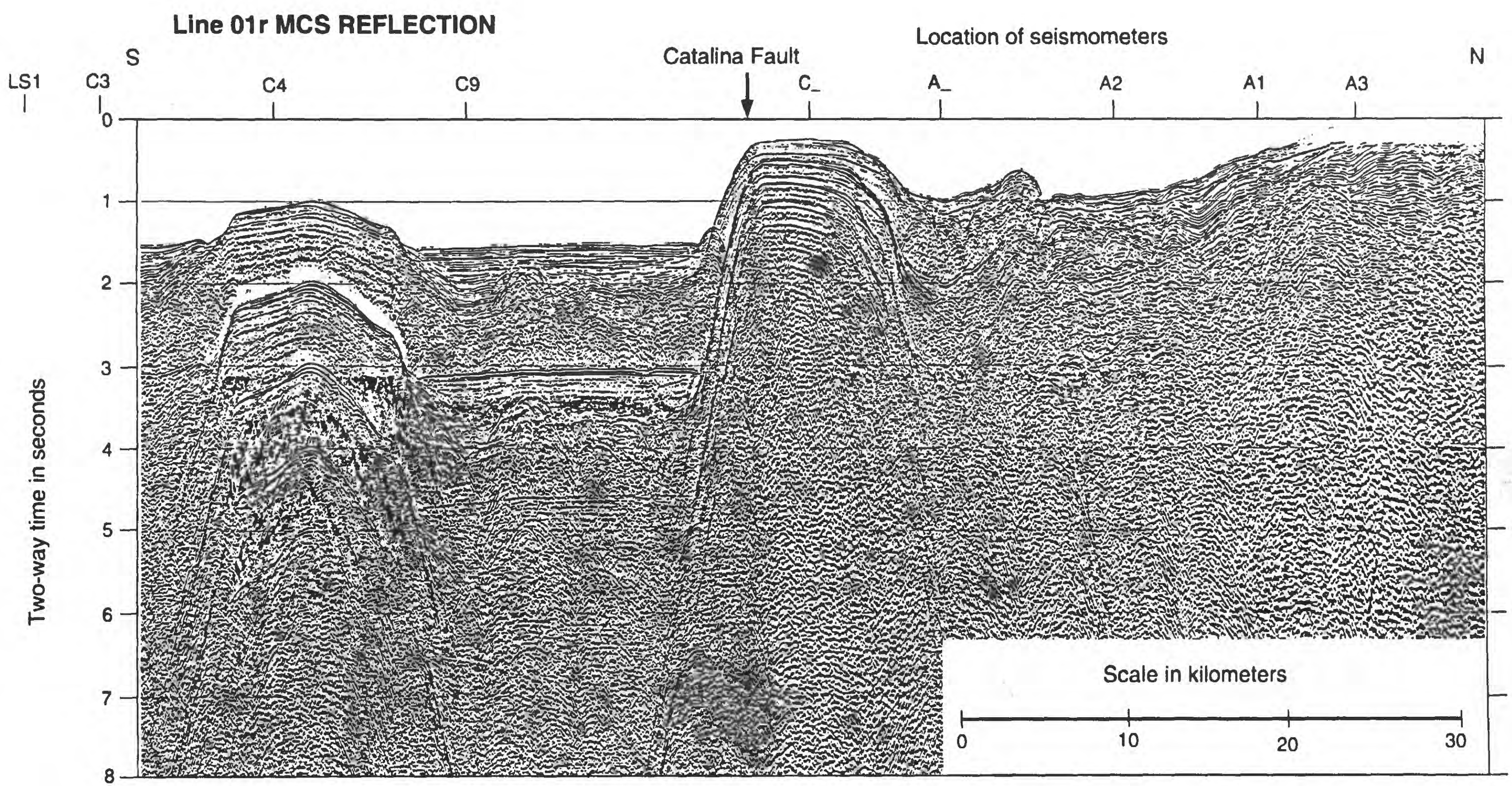

Line 01 REFTEK LS1
Shot-Receiver offset in kilometers
S
N
0
10
20
30
40
50
60
70
80
Reduced time (T - X / 6.0) in seconds
-1
0
1
2
3
4
5
6
7
8
9
10
11

Figure 11.



Line 01r MCS REFLECTION
Location of seismometers
S
N
Catalina Fault
LS1
C3
C4
C9
C_
A_
A2
A1
A3
Two-way time in seconds
0
1
2
3
4
5
6
7
8
Scale in kilometers
0
10
20
30

Figure 1

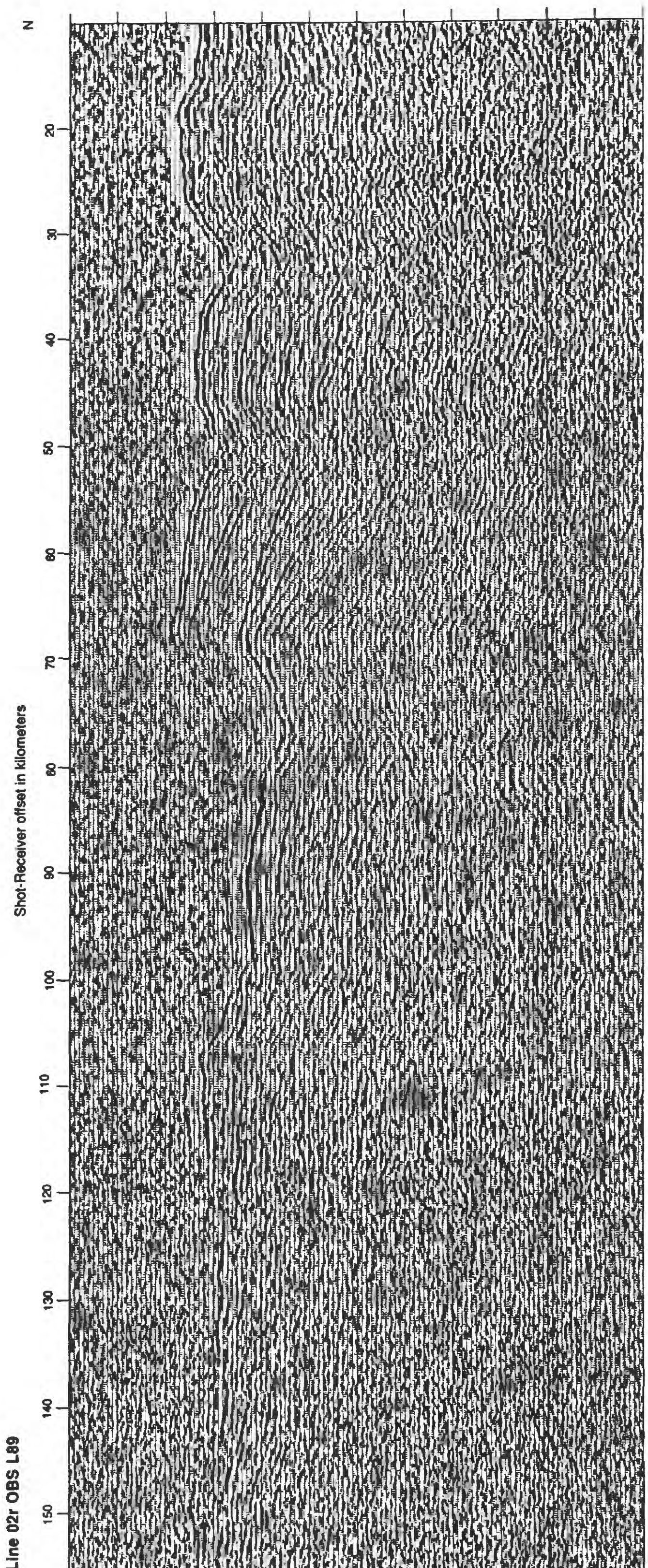

Line 02r OBS L89
Shot-Receiver offset in kilometers
Reduced time (T - X / 6.0) in seconds
N
S

Figure 13.

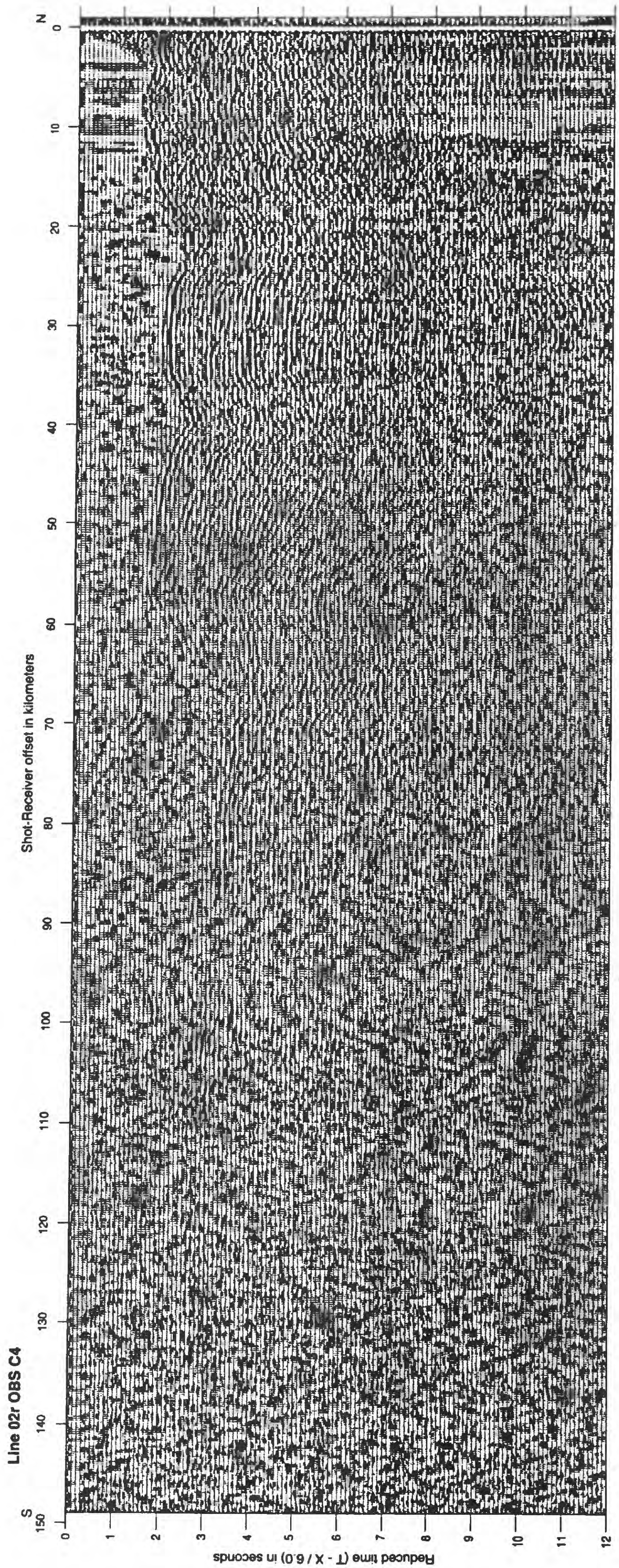

Line 02r OBS C4
Shot-Receiver offset in kilometers
Reduced time (T - X / 6.0) in seconds
N
S

Figure 14.

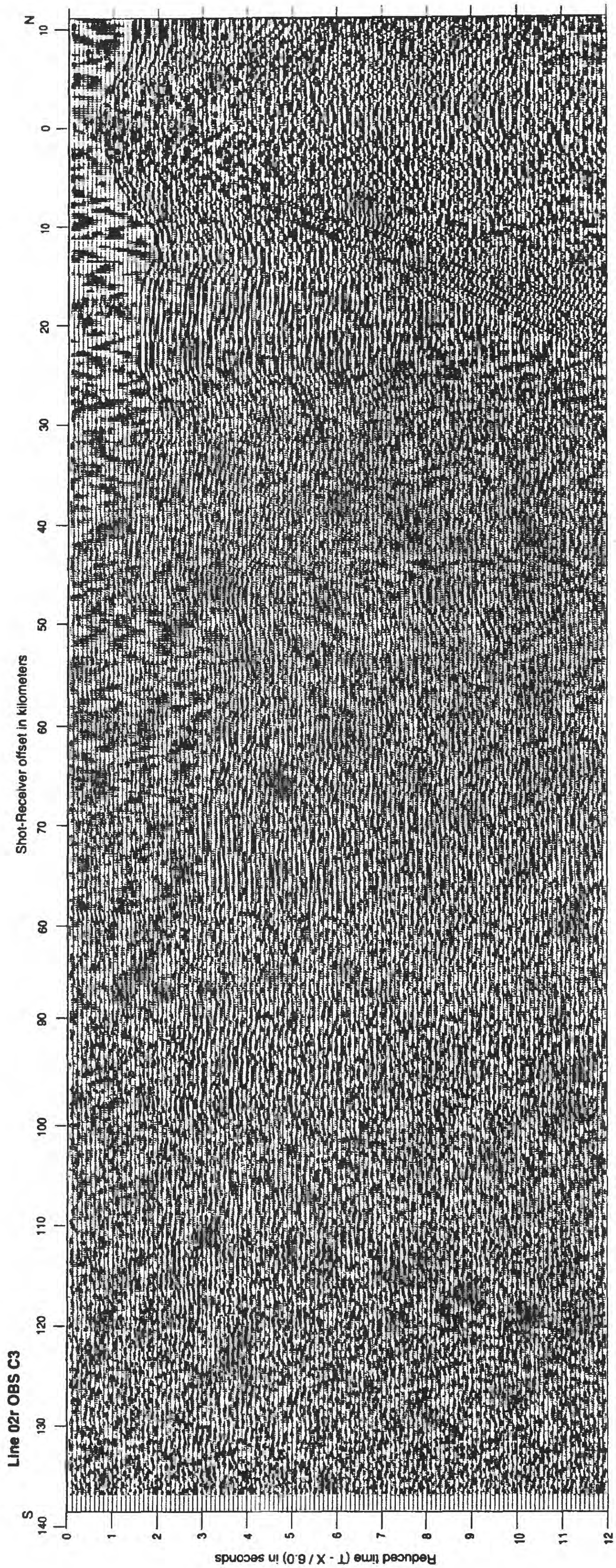

Line 02r OBS C3
N
S
Shot-Receiver offset in kilometers
Reduced time (T - X / 6.0) in seconds

Figure 15.

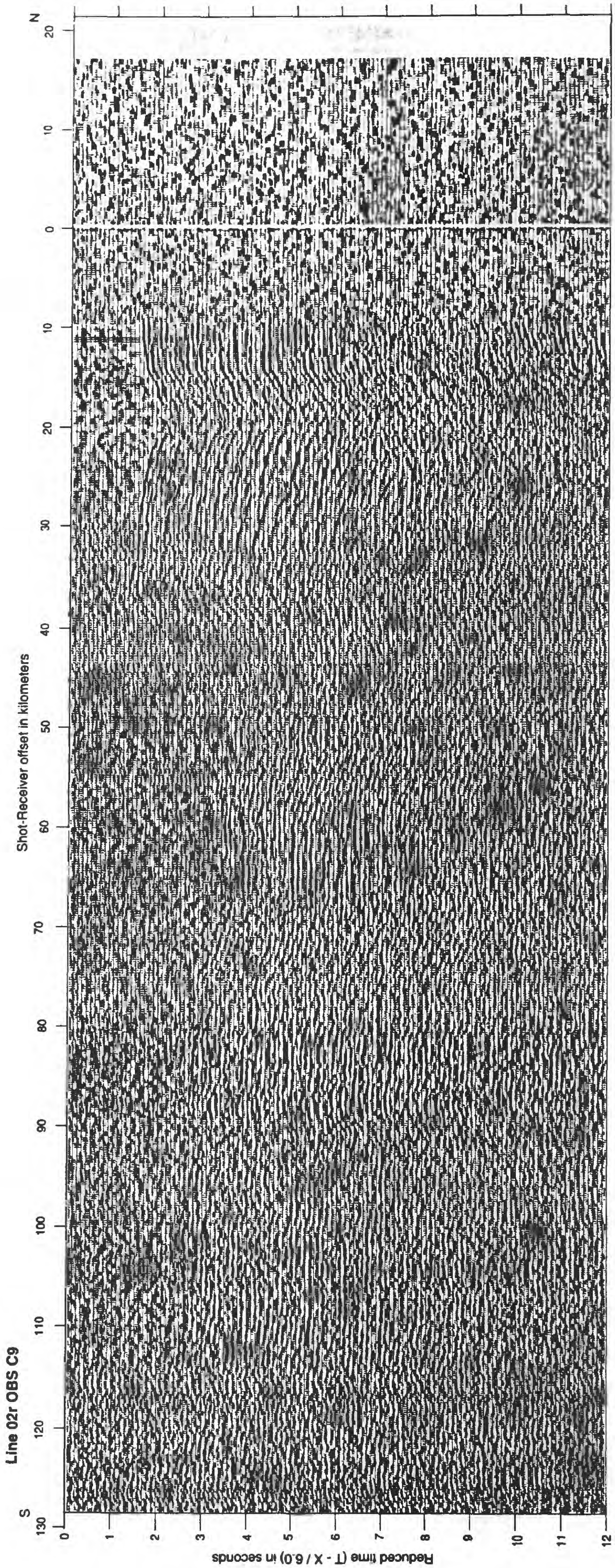

Line 02r OBS C9
Shot-Receiver offset in kilometers
Reduced time (T - X / 6.0) in seconds
N
S

Figure 16.

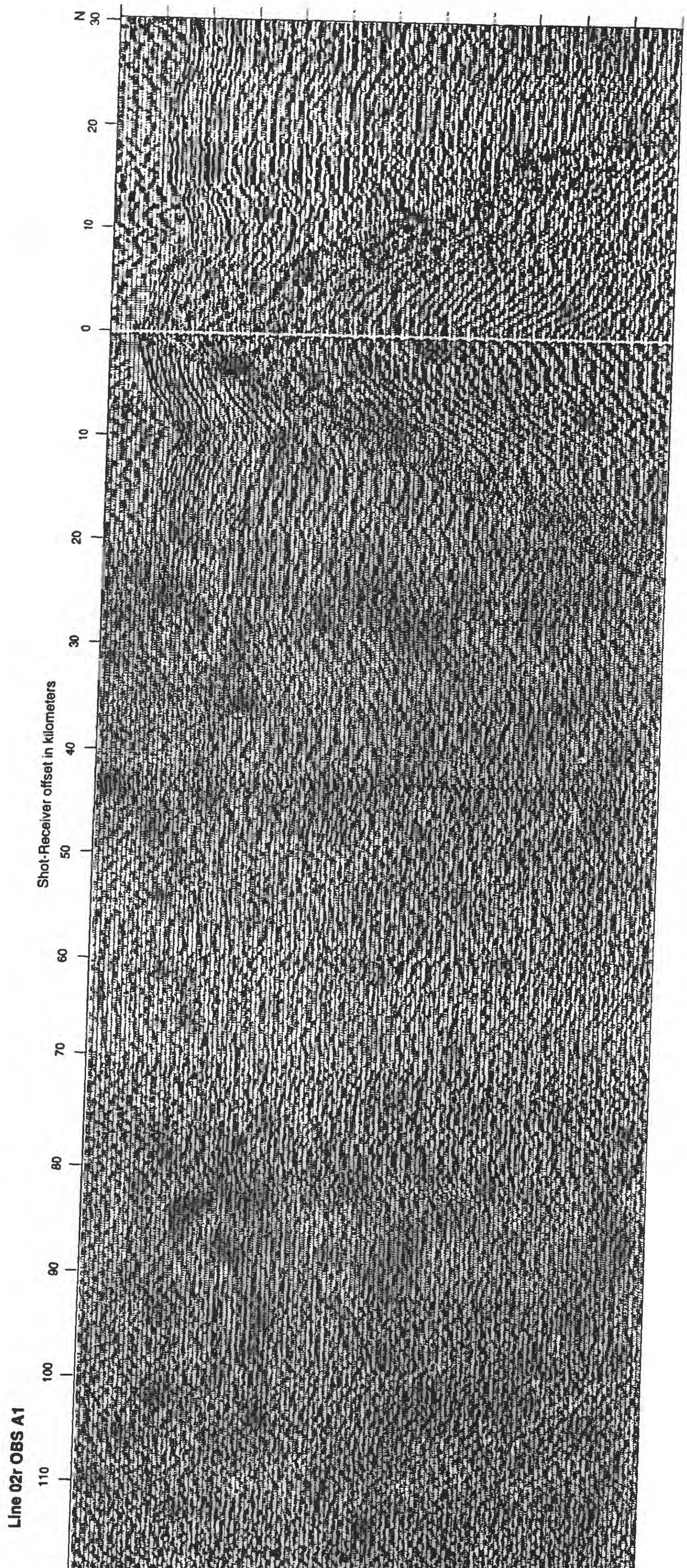
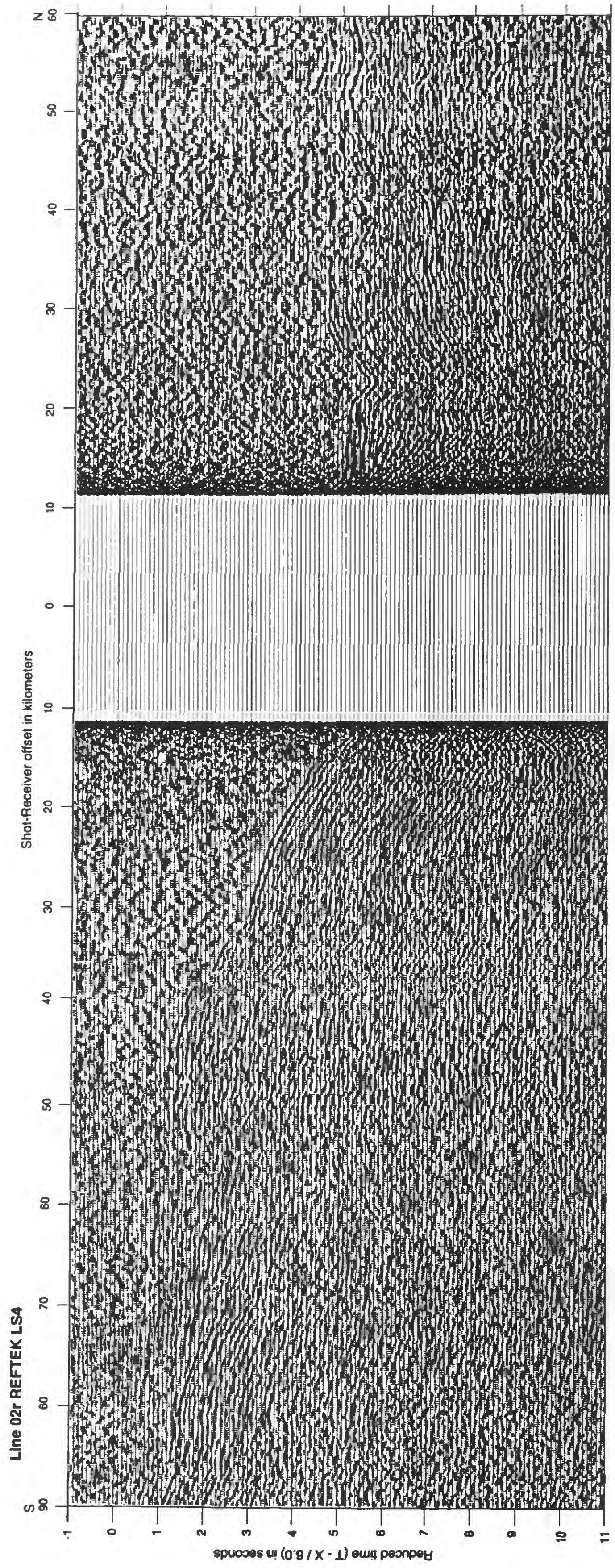

Line 02r OBS A1
Shot-Receiver offset in kilometers
Reduced time (T - X / 6.0) in seconds
S
N

Figure 17



Line 02r REFTEK LS4
Shot-Receiver offset in kilometers
Reduced time (T - X / 6.0) in seconds
N
S

Figure 18.

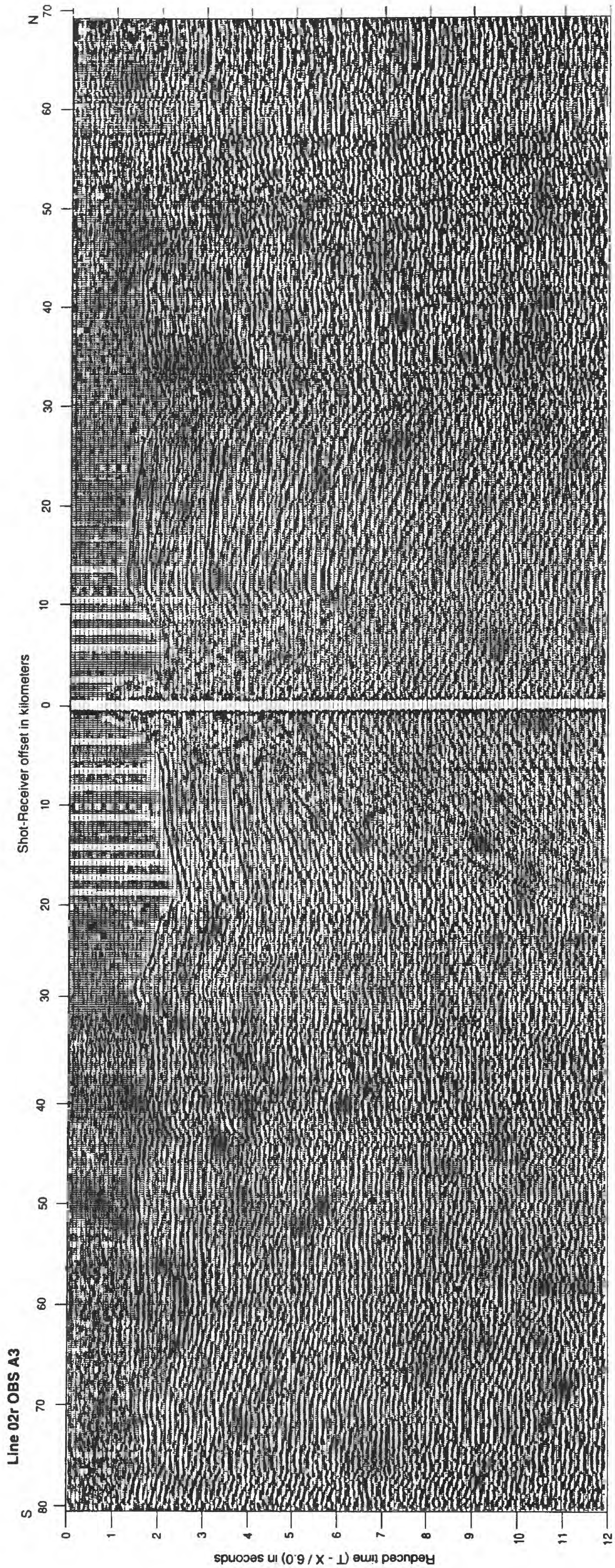

Line 02r OBS A3
S
N
Shot-Receiver offset in kilometers
Reduced time (T - X / 6.0) in seconds

Figure 19

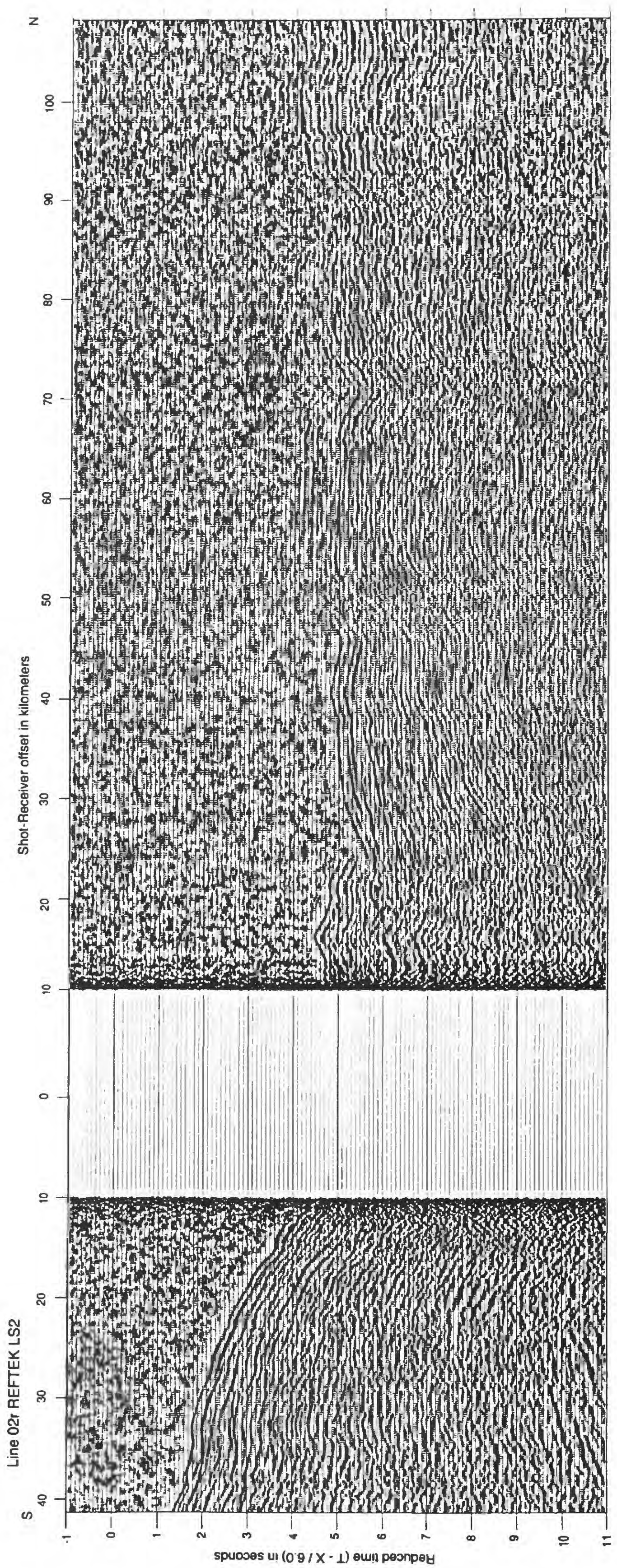
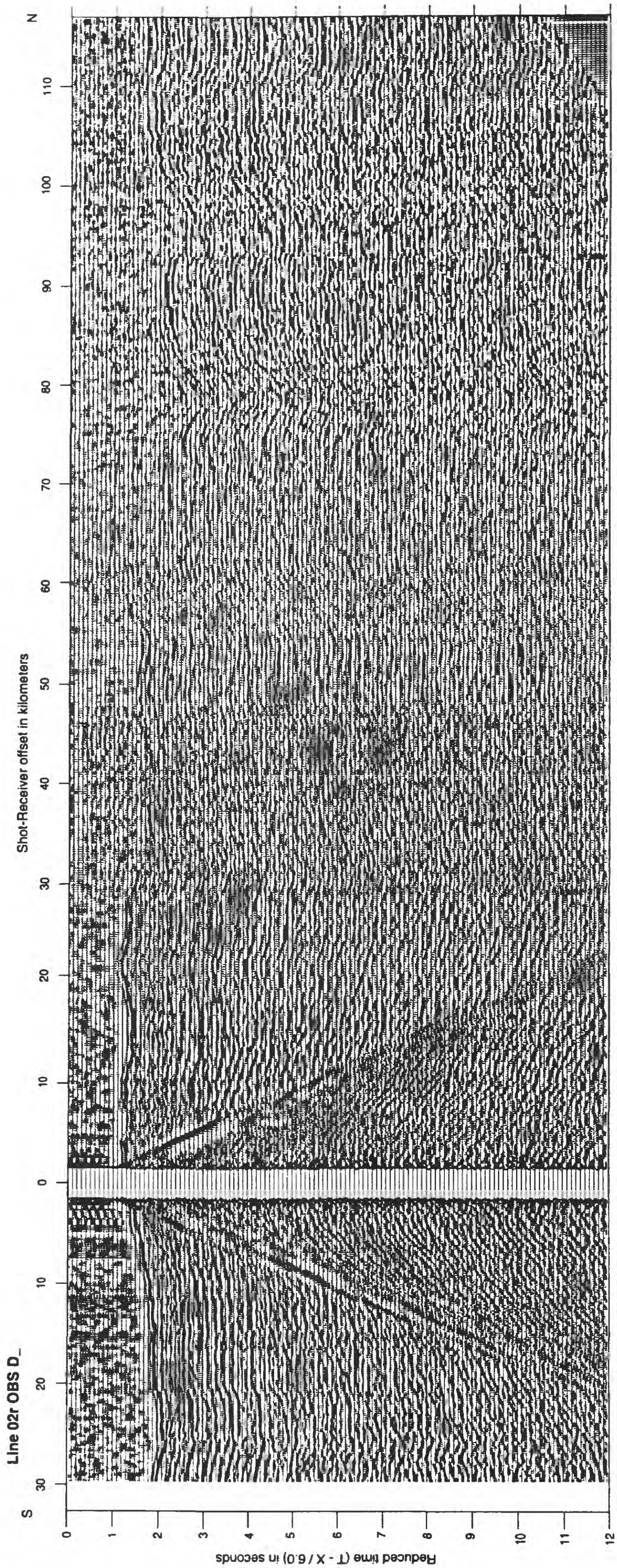
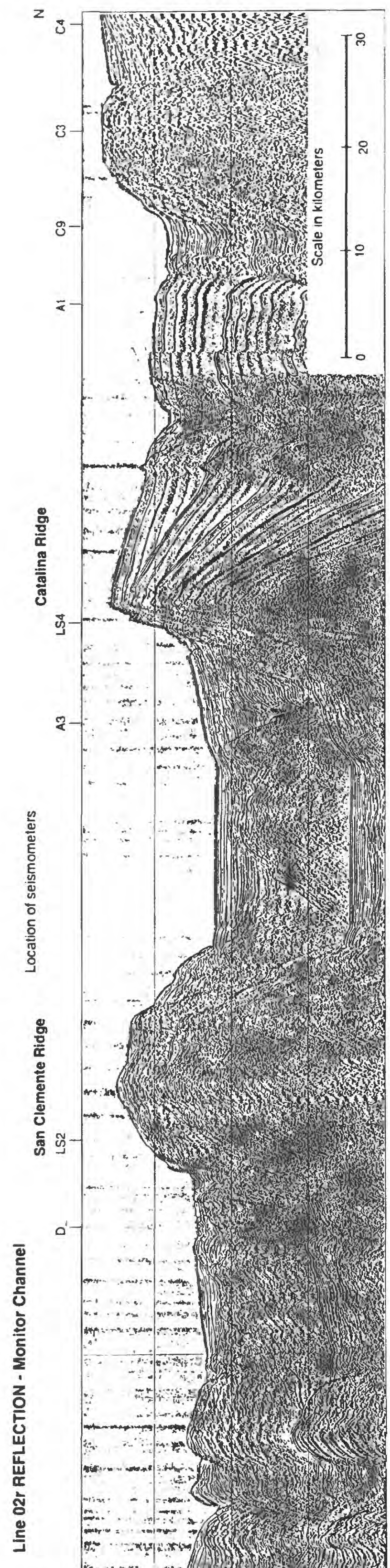

Line 02r REFTEK LS2
S
N
Shot-Receiver offset in kilometers
40 30 20 10 0 10 20 30 40 50 60 70 80 90 100
Reduced time (T - X / 6.0) in seconds
-1 0 1 2 3 4 5 6 7 8 9 10 11

Figure 20.



Line 02r OBS D_
Shot-Receiver offset in kilometers
S
N
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
Reduced time (T - X / 6.0) in seconds
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 21.



Line 02r REFLECTION - Monitor Channel
S
N
San Clemente Ridge
Location of seismometers
Catalina Ridge
D
LS2
A3
LS4
A1
C9
C3
C4
Scale in kilometers
0
10
20
30
Two-way time in seconds
0
1
2
3
4

Figure 22.