UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DATA REPORT FOR THE 1990 SEISMIC REFLECTION/REFRACTION EXPERIMENT IN THE BROOKS RANGE, ARCTIC ALASKA

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OPEN-FILE REPORT 93-265

Menlo Park, California
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1993

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INTRODUCTION

In the summer of 1990, the U.S. Geological Survey, Rice University, the Geological Survey of Canada, and IRIS/PASSCAL jointly conducted a seismic experiment across the Brooks Range, Arctic Alaska. The goal of the experiment was to produce a high-resolution image of the crust and upper mantle of the Brooks Range and flanking geologic provinces (Koyukuk basin and North Slope; Figures 1 and 2) by combining refraction and reflection techniques. The U.S. Geological Survey and Rice University jointly led the planning of the experiment, which began in 1985, and also the field execution of the experiment, which occurred in June and July 1990. Persons from the Geological Survey of Canada, IRIS/PASSCAL, University of Alaska, University of Wyoming, Purdue University, and the Air Force Geophysics Laboratory participated in the field. This experiment completes the seismic investigations of the U.S. Geological Survey's Trans-Alaska Crustal Transect (TACT) program, a multidisciplinary investigation of the crust and upper mantle of Alaska from the Pacific to Arctic Oceans along the oil-pipeline corridor (see summary in Nokleberg and Fisher, 1989). Other seismic data reports from TACT are summarized in Table 1. The 1990 Brooks Range experiment represents the first instance in which refraction and reflection techniques are merged in TACT investigations. This experiment also adds an important geophysical dimension to ongoing geologic studies of the Brooks Range at Rice University (see, for example, Oldow and others, 1987).

We used a 700-channel seismograph system (consisting of four different types of instruments) to record 63 shots (Table 2) at 44 separate shotpoint locations (Figures 3). The instruments included 35 PASSCAL Ref Tek 72A-02's, each recording 6 channels, 190 Stanford University Seismic Group Recorders (SGR's), 120 USGS Seismic Cassette Recorders (SCR's), and 180 Geological Survey of Canada Portable Refraction Seismographs (PRS1's). (See below for a detailed description of these seismic recorders.) All seismographs recorded only vertical-component motion. The instruments were deployed five times in abutting and overlapping arrays, producing a 315-km-long profile (Figures 1, 2, 3). Instrument spacing was nominally 100 m. Both small shots (100-600 lbs) and large shots (1500-4000 lbs) were fired to produce a vertical-incidence to wide-angle refraction-reflection data set with continuous offset coverage from 0 km to more than 200 km. Data recovery was about 95 percent, and signal-to-noise ratios were excellent from most shots. The data have been archived at the National Geophysical Data Center in Boulder, Colorado and at the IRIS Data Center in

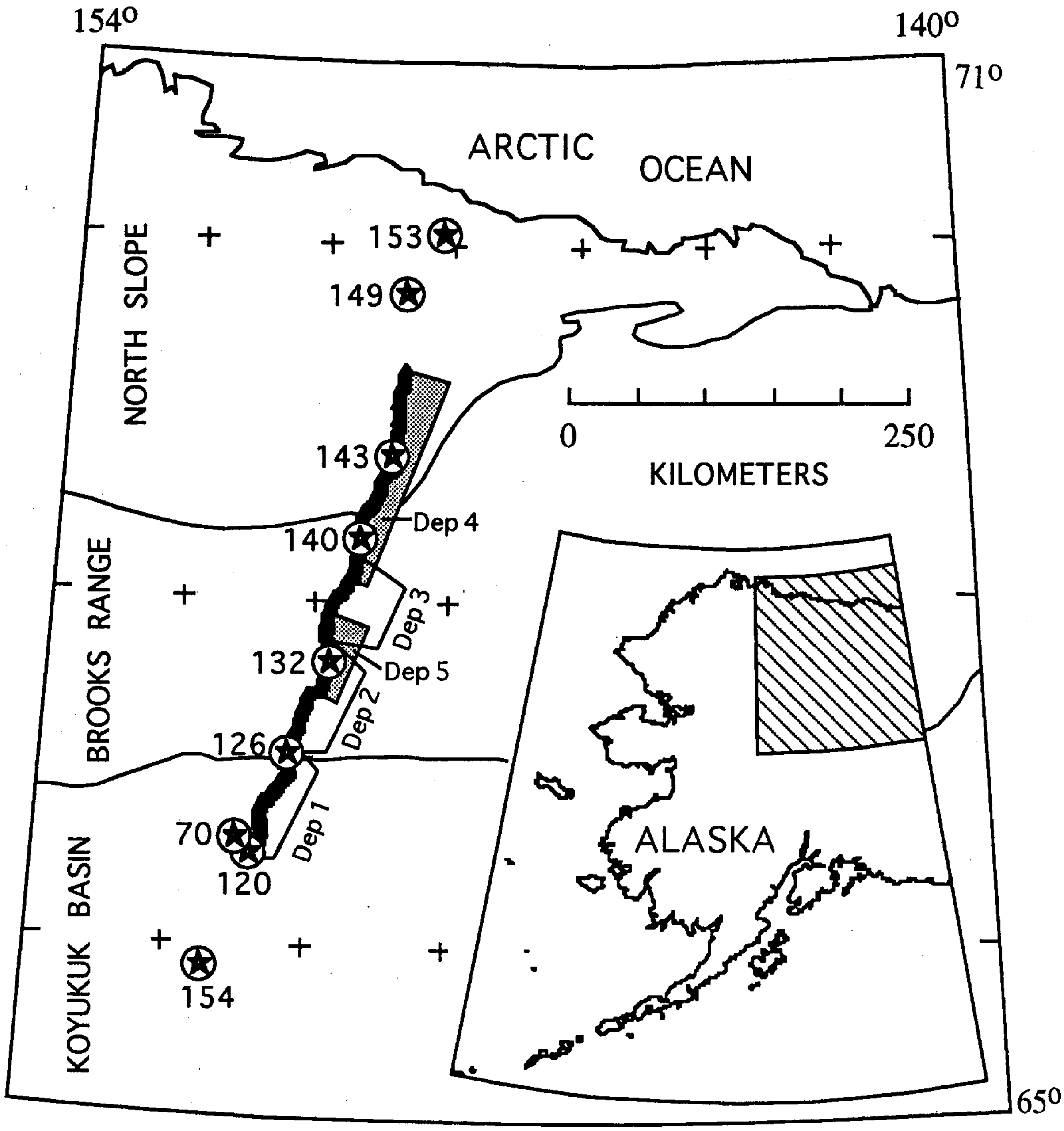

Figure 1. Experiment map showing all instrument locations (triangles) and selected shotpoint locations (circled stars with shotpoint location number). Brackets delineate extent of the deployments.

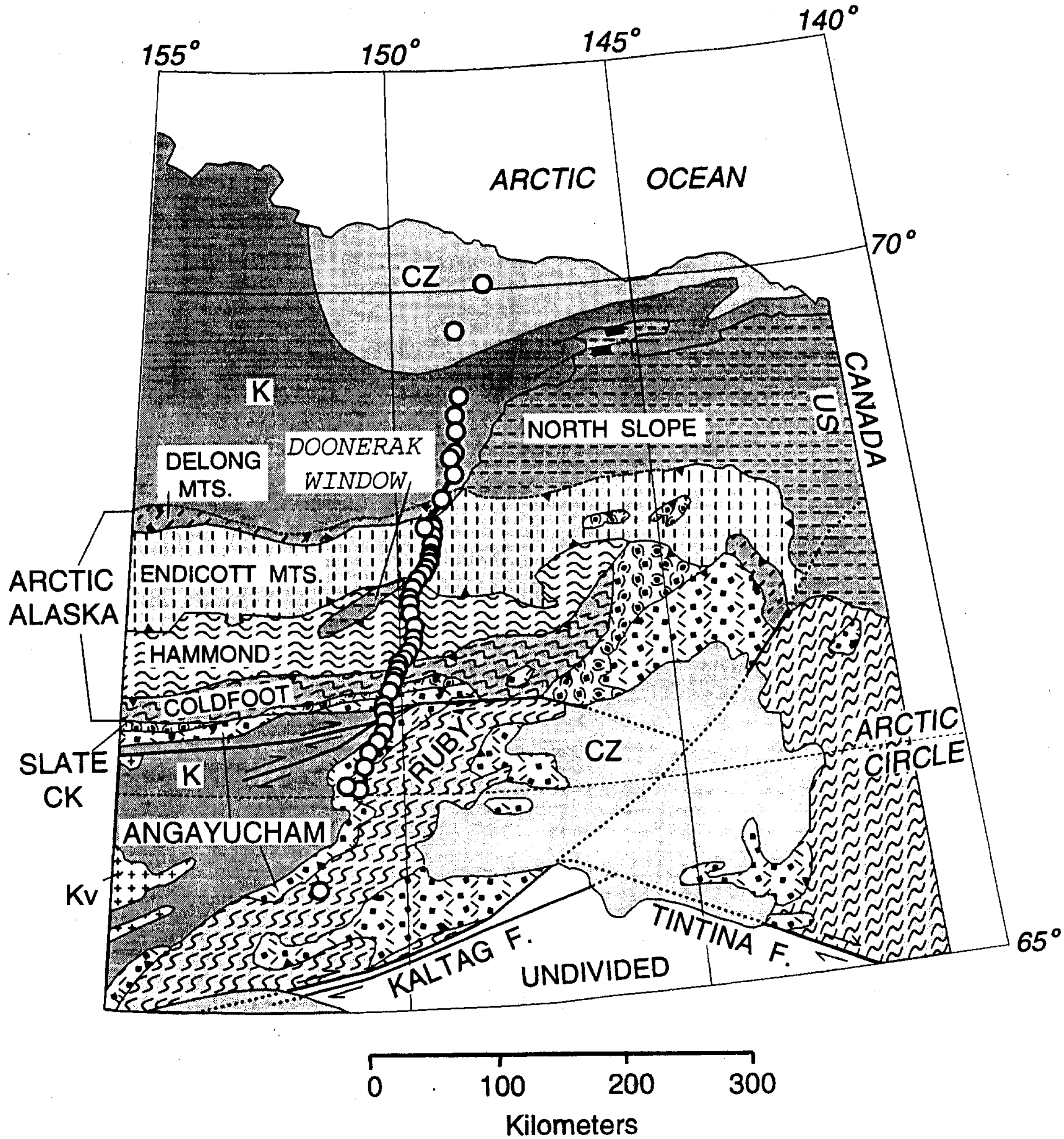

Figure 2. Experiment location map, showing terranes and subterranes. Circles represent shotpoint locations. From south to north terranes include the Ruby, Angayucham, Slate Creek, and Arctic Alaska terranes. Subterranes of the Arctic Alaska terrane include the Coldfoot, Hammond, Endicott Mts., Delong Mts. and North Slope subterranes.

TABLE 1

Seismic data reports produced under the U. S. Geological Survey's Trans-Alaska Crustal Transect (TACT) program

REGION OF ALASKA/ DATE(S) OF AQUISITION	DATA TYPE	DATA REPORT
Gulf of Alaska/ 1988	Marine reflection/ refraction	Brocher and Moses, 1990
Southern Alaska/ 1984, 1985	Land refraction	Daley and others, 1985 Meador and others, 1986 Wilson and others, 1987 Wilson, 1987
	Land reflection	Fisher and others, 1989
Central Alaska/ 1987	Land refraction	Beaudoin and others, 1989 Goldman and others, 1992
Northern Alaska/ 1990	Land reflection/ reflection	This report

TABLE 2 SHOT LIST

SHOT	LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)	DEPTH (m)	CHARGE (lbs)	SHOT TIME J-DAY	SHOT TIME HR:MIN:SEC
1	154	65.883474	-151.422256	453	2.4	2500	193	06:00:00
2	120	66.557153	-150.811307	357	18.3	1500	193	06:02:00
3	122	66.818726	-150.675938	326	15.2	600	193	06:03:00
4	124	66.972430	-150.334079	444	12.5	200	193	06:04:00
5	170	67.082496	-150.357750	368	14.3	200	193	06:05:00
6	140	68.382100	-149.467612	811	4.0	4000	193	06:06:00
7	121	66.717523	-150.670852	327	17.4	600	193	09:02:00
8	123	66.894944	-150.512740	387	15.2	200	193	09:03:00
9	125	67.039388	-150.304716	522	15.8	600	193	09:04:00
10	126	67.142029	-150.333568	335	4.0	2500	193	09:05:00
11	132	67.680728	-149.740251	474	17.7	2500	193	12:04:00
12	120	66.557153	-150.811307	357	16.8	2500	196	06:00:00
13	127	67.232044	-150.222638	334	14.3	600	196	06:02:00
14	171	67.324269	-150.153394	370	13.1	200	196	06:03:00
15	130	67.435596	-150.092280	389	12.8	600	196	06:04:00
16	132	67.680728	-149.740251	474	14.6	1500	196	06:05:00
17	140	68.382100	-149.467612	811	4.0	2500	196	06:06:00
18	126	67.142029	-150.333568	335	4.0	1500	196	09:00:00
19	128	67.292665	-150.163629	370	16.8	600	196	09:02:00
20	129	67.398463	-150.087932	443	13.1	200	196	09:03:00
21	172	67.459744	-150.039080	381	14.0	100	196	09:04:00
22	143	68.848389	-148.905796	473	8.5	3500	196	09:05:00
23	124	66.972430	-150.334079	444	8.5	200	196	09:07:00
24	70	66.601460	-150.989089	224	3.0	4000	203	05:00:00
25	175	68.012652	-149.727377	741	17.7	200	203	05:02:00

TABLE 2 SHOT LIST (continued)

SHOT	LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)	DEPTH (m)	CHARGE (lbs)	SHOT TIME J-DAY	SHOT TIME HR:MIN:SEC
26	176	68.087215	-149.561513	1057	12.8	200	203	05:03:00
27	138	68.172276	-149.440437	1052	13.4	200	203	05:04:00
28	139	68.375031	-149.317897	832	15.2	1500	203	05:05:00
29	142	68.567661	-149.166966	907	7.6	600	203	05:06:00
30	126	67.142029	-150.333568	335	4.0	2500	203	08:00:00
31	136	67.953935	-149.776641	663	12.8	200	203	08:02:00
32	137	68.052783	-149.613887	980	15.8	600	203	08:03:00
33	177	68.132094	-149.438985	1204	13.1	200	203	08:04:00
34	178	68.217446	-149.391466	997	15.2	600	203	08:05:00
35	143	68.848389	-148.905796	473	8.5	2500	203	08:06:00
36	132	67.680728	-149.740251	474	13.4	1500	203	11:00:00
37	130	67.435596	-150.092280	389	10.1	200	203	11:01:00
38	135	67.885910	-149.814978	610	12.5	200	203	11:02:00
39	126	67.142029	-150.333568	335	4.0	4000	200	05:00:00
40	142	68.567661	-149.166966	907	7.6	600	200	05:02:00
41	179	68.247330	-149.420864	952	15.8	600	200	05:03:00
42	141	68.406008	-149.326622	859	15.2	1000	200	05:04:00
43	189	69.282368	-148.737392	246	18.6	2500	200	05:05:00
44	153	70.078227	-148.173320	13	2.4	3500	200	05:06:00
45	145	69.033481	-148.852984	383	2.1	1000	200	07:30:00
46	180	68.313317	-149.346289	910	14.9	600	200	07:31:00
47	188	69.146067	-148.830549	293	19.8	200	200	07:32:00
48	149	69.744689	-148.787624	98	2.7	3000	200	07:33:00
49	186	68.876024	-148.854803	440	14.3	200	200	10:00:00
50	132	67.680728	-149.740251	474	15.5	3000	200	10:01:00

TABLE 2 SHOT LIST (continued)

SHOT	LOCATION NUMBER	LATITUDE	LONGITUDE	ELEV (m)	DEPTH (m)	CHARGE (lbs)	SHOT TIME J-DAY	SHOT TIME HR:MIN:SEC
51	139	68.375031	-149.317897	832	13.1	2000	200	10:02:00
52	150	68.730744	-148.929179	556	2.7	600	200	10:03:00
53	136	67.953935	-149.776641	663	12.8	250	205	05:00:00
54	134	67.844424	-149.816350	577	13.1	600	205	05:01:00
55	133	67.775798	-149.783164	547	16.2	600	205	05:02:00
56	132	67.680728	-149.740251	474	15.5	200	205	05:03:00
57	135	67.885910	-149.814978	610	12.5	120	205	05:04:00
58	174	67.594497	-149.786844	453	16.2	600	205	07:00:00
59	173	67.555575	-149.836354	465	16.8	600	205	07:01:00
60	131	67.501135	-149.854582	432	13.7	200	205	07:02:00
61	172	67.459744	-150.039080	381	14.0	120	205	07:03:00
62	127	67.232044	-150.222638	334	14.3	120	206	05:01:00
63	126	67.142029	-150.333568	335	4.0	240	206	05:04:00

Note: Shot depths less than 9 m correspond to lake shots; all other shots were drill-hole shots.

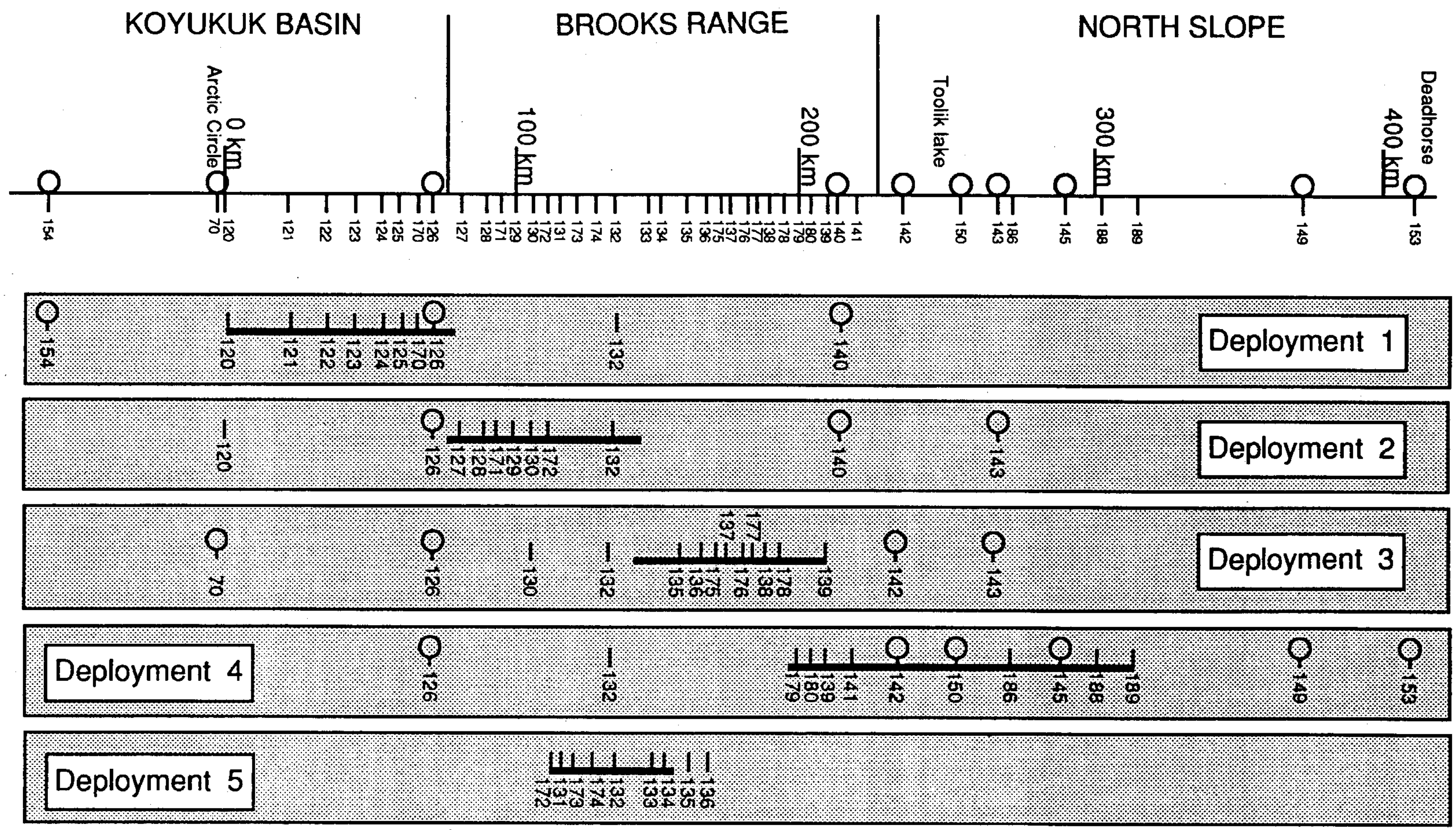

Figure 3. Schematic diagram of experiment. Numbered short lines represent drill-hole shotpoints and short lines with attached circles represent lake shotpoints. Shotpoint location numbers are listed opposite each shotpoint.

Seattle, Washington. SEGY-format tapes recorded at 6250 BPI are available from:

NOAA
National Geophysical Data Center
E/GC1
325 Broadway
Boulder, CO 80303

Telephone: (303) 497-6123

The data are also available through the IRIS Data Management Center at:

IRIS DMC
1408 NE 45th Street
Seattle, WA 98105

Telephone: (206) 547-0393

A description of the tape format and headers is given below in the Data Processing section.

GEOLOGIC SETTING

The following is summarized from Oldow and others(1987), Grantz and others (1991), and Moore and others (1989). The Brooks Range and North Slope consists of North American continental-marginal rocks, and the Koyukuk basin consists of island-arc and ocean-basin rocks. In a general way, rocks in the northern Brooks Range are younger (Miss.-Jur.), stable-shelf, marine and non-marine sedimentary rocks, and rocks in the southern Brooks Range are older (Precamb.-Dev.), deeper-water, continental-marginal sedimentary rocks. Metamorphic grade increases toward the south to greenschist-blueschist(?) grade. Rocks of the Brooks Range were telescoped and thrust beneath oceanic rocks of the Koyukuk basin, beginning in the Early Cretaceous, as the Canada basin opened to the north. Sediments eroded from the uplifting range were deposited chiefly in the Coleville foredeep basin on the North Slope. Uplift and compression continued into the Cenozoic in the north part of the Range, including the vicinity of the Doonerak window. Collapse and extension of unknown magnitude interpreted as mid-Cretaceous age occurred in the south part of the range (see also Miller and Hudson, 1991; Oldow and others, 1991).

The Brooks Range and North Slope comprise the Arctic Alaska terrane, which has been subdivided, from north to south, into the North Slope, Endicott Mountains, Hammond (or Skajit), and Coldfoot (or Schist) subterranes (Figure 2). On the south, the Arctic Alaska terrane is separated from the Angayucham terrane, consisting of oceanic crust and ultramafic rocks, and the basinal rocks of the Koyukuk basin by melange of the Slate Creek terrane. Vergence is to the north in the Brooks Range structures. The North Slope subterrane is exposed both on the North Slope, where it is overlain by and locally over thrust upon the sedimentary rocks of the Coleville basin, and in the Doonerak window, which is located on an antiform in the central Brooks Range near the contact between the Endicott and Hammond subterranes.

Two cross sections that represent prior, testable models of Brooks Range structure (Oldow and others, 1987; Moore and others, 1991) are reproduced in Figure 4. These both show the following features in the central and northern Brooks Range: (1) the Endicott Mountains allochthon is a lens-shaped body on the north limb of the Doonerak antiform, with internal, north-verging thrust faults; (2) the rocks beneath the Endicott Mountains allochthon include sedimentary rocks of the Coleville basin (explicitly shown in Figure 4A) and displaced rocks of the North Slope subterrane; (3) the Doonerak antiform is underlain by deformed, lens-shaped bodies of rock; and (4) the "master" decollement is subhorizontal beneath the southern North Slope and Endicott Mountains allochthon, but ramps downward on the south side of the Doonerak antiform. The dimensions of rock bodies and depths of interfaces are similar between the two cross sections, although Figure 4B is admittedly schematic. The cross sections differ primarily in interpretation of stratigraphic and structural separation of the Endicott Mountains and Hammond (Skajit) subterranes. The cross section of Grantz and others (1991) is also similar to Figures 4A and 4B, although the depth to the "master" decollement is shallower (< 10 km) and the package of displaced Coleville basin and North Slope rocks beneath the Endicott Mountains allochthon is much thinner (< 2 km).

EXPERIMENT PLANNING AND DESIGN

The 1990 Brooks Range experiment was conceived in 1984 during a planning session for the Trans-Alaska Lithosphere Investigation at the Seismological Society of America annual meeting in Anchorage, Alaska (see Stone

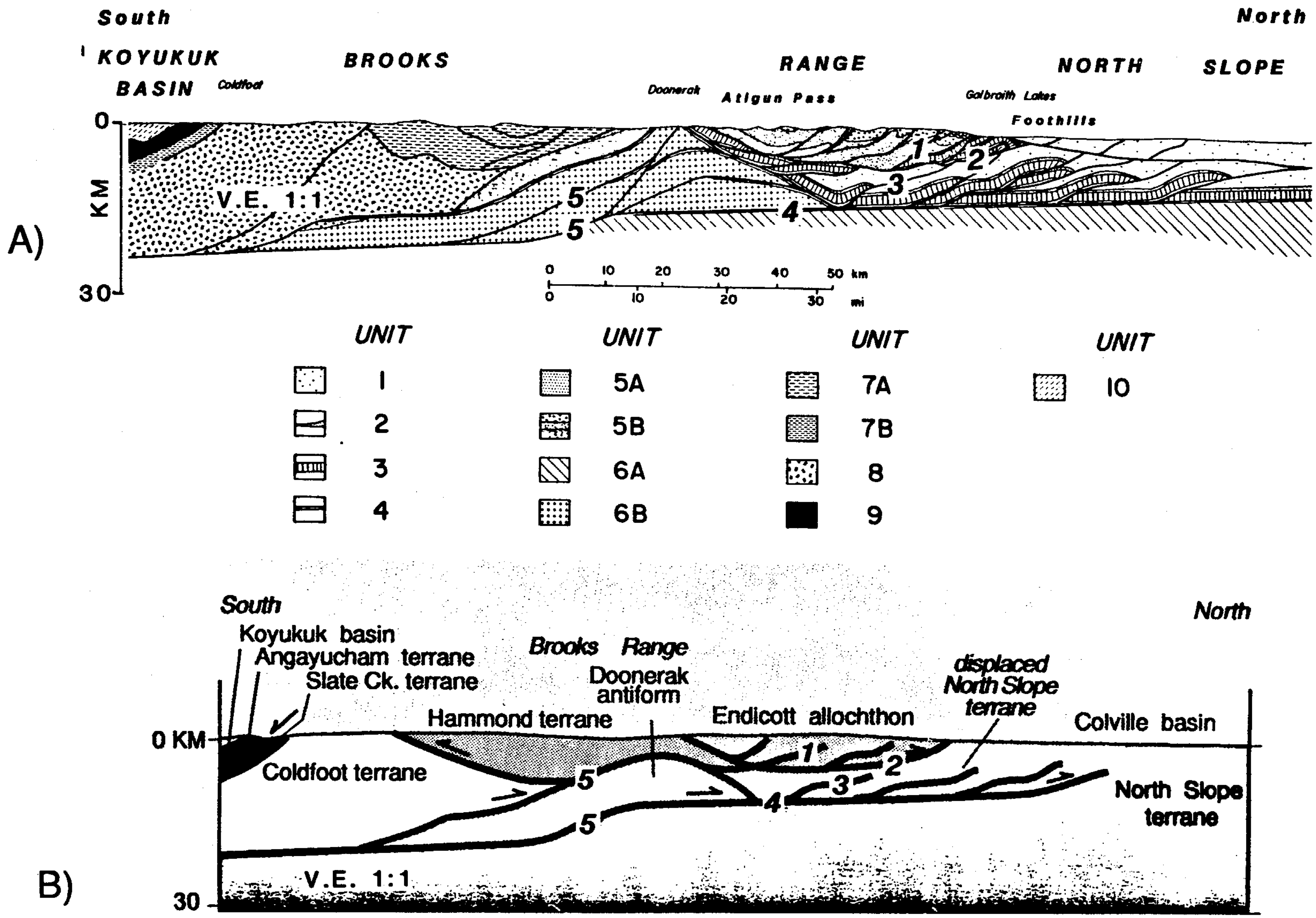

Figure 4. Two possible models for a cross section of the Brooks Range. The explanation is given on the following page.

Explanation for Figure 4.

a) Cross section from Oldow and others (1987: Atigun Pass Transect, Section IIA). Numbered units are 1--Coleville basin sediments; 2--Sadlerochit Group, Shublik Fm., and Kingak Fm.; 3--Lisburne Limestone; 4--Kayak Shale and Kekiktuk Conglomerate; 5A--(not present); 5B--Endicott Mountains Allochthon: Kanayut Conglomerate, Hunt Fork Shale, and Beaucoup Fm.; 6A--Neruokpuk Fm. (basement of North Slope subterrane); 6B--Apoon Fm. (basement of North Slope subterrane seen in Doonerak Window); 7A--Skajit Allochthon; 7B--Rosie Creek Allochthon (oceanic rocks); 8--Schist belt (Coldfoot subterrane); 9--Angayucham subterrane (ophiolite); 10--Cretaceous sedimentary rocks of the Koyukuk basin.
b) Schematic cross section from Moore and others (1991). Numbers on both cross sections 4A and 4B indicate reflecting horizons that are seen in the data (see Levander and others, 1991; Fuis and others, 1991)

et al, 1986). As a first step in the seismic program, we conducted a field trip to the Brooks Range in 1985 to scout refraction shotpoints along the oil-pipeline corridor. During the field trip, we identified and flagged 16 shotpoints and several alternates. Shotpoints required either a biologically dead lake that could be reached by truck or helicopter, or a hard (land) site that could be reached by a truck-mounted drill rig. Hard sites were usually limited to highway turnouts or quarries used during pipeline construction. These sites, however, were frequently too close to the pipeline to safely detonate charges of the size needed for crustal exploration (100-4000 lbs). Potential lake shotpoints were scouted at a later time (1988). We were forced to use shallow lakes (less than 3 meters) for two reasons: 1) deeper lakes are rare and 2) fish can survive over winter in lakes deeper than the freeze-down depth of about 3 meters, and are almost invariably present in such lakes.

In 1987, during a TACT seismic experiment in central Alaska, we began collecting data for an environmental assessment report. To compete environmental assessment studies and to investigate data acquisition and logistical problems anticipated in the Arctic, a pilot seismic experiment was conducted in 1988 - sponsored by IRIS and the USGS (Levander and others, 1988). Radio-controlled Seismic Group Recorders (SGR's) (loaned to Rice/PASSCAL by AMOCO Corporation) were used to record a 50-km-long reversed reflection/refraction profile with receivers spaced 150 to 300 m apart and 3 in-line shot points spaced 15-20 km apart. One offset (80-90 km) lake shot was fired to test long range seismic transmission from a shallow lake source and to assess the impact of shooting in a lake ecosystem. In addition, 3 seismic wave tests were conducted to investigate wave propagation in the shallow perma-frost layer. The pilot experiment demonstrated that high quality seismic data could be acquired in the geologically complex Brooks Range and that we could generate sufficient seismic energy at distances as large as 100 km using a distributed charge in a shallow lake (less than 3 meters depth). The only significant ecological effect of such a shot, in the absence of fish, is to stir up mud that remains in suspension for a period of a few weeks. The wave tests demonstrated that ground roll, a serious source of noise in reflection recording, propagates in the permafrost layer as a relatively compact, high-velocity wave group which can be eliminated with standard reflection processing without employing special recording arrays. A report of the data collected during the pilot experiment has been compiled and is available along with the data from IRIS. An environmental impact report was prepared and filed with the U.S. Bureau of Land Management.

In the years following the 1984 planning meeting for the Brooks Range experiment, IRIS launched the rapid development of the Ref Tek instrument base for academic seismological research. Additionally, in 1989 IRIS and the USGS provided funds for support and modification of 195 Seismic Group Recorders (SGR) which AMOCO donated to Stanford University. Modification of the SGR's included conversion of the turn-on from radio control to internal clock control; thereby making them suitable for use in the rugged terrain of the Brooks Range. Anticipating the possibility that more instruments would be available in 1990, we logged every location in the Brooks Range, Koyukak basin, and North Slope where a shotpoint (drill-hole or lake) could be located more than 1000 feet from the oil-pipeline. We also established curves relating particle velocity to shot size and distance for our blasts to demonstrate to pipeline officials (Alyesca Pipeline Service Company) that our blasts would not damage any of their equipment (Kohler and Fuis, 1989, 1992).

After receiving permission from state and federal agencies and pipeline officials to proceed, the Brooks Range experiment commenced in May, 1990. An advance team arrived before spring breakup in the Arctic to supervise shot hole drilling. Three parties of surveyors staked and flagged 3200 seismic stations in June and the 45 member seismic crew arrived on July 4 and 5. Data was recorded for 5 deployments from July 12 through July 26. Two cleanup crews remained in the Arctic until August 10.

We designed the experiment so that all shots within the Brooks Range were recorded at smaller ranges (0 - 10 km or more) by instruments with higher-frequency response (Ref Teks and SGR's). For larger ranges of Brooks Range shots and shot points beyond the Brooks Range, data were recorded by instruments with a lower-frequency response (SCR's and PRS1's). A 315 kilometer-long seismic profile was recorded during 5 deployments (Figure 5). Of this length, 200 km was recorded by higher-frequency instruments and is suitable for producing a low-fold, common-midpoint (CMP) stacked section. Instruments were deployed along the edge of the Dalton Highway except for a 45-km-long dogleg in the road between shotpoints 141 and 150. A helicopter was used to deploy instruments cross country along the latter segment of the transect. The first deployment extended from the Arctic Circle through the Koyukuk Basin to the edge of the Brooks Range. Eight in-line shots and three off-end shots were fired into the deployment (Figures 1, 3, 5a). The second deployment extended from the end of deployment 1 half way through the Brooks Range. Seven in-line shots and four off-end shots were fired into the deployment (Figures 1, 3, 5b). The third deployment extended from the end of deployment 2 through the Brooks Range. Nine in-line shots and six off-end shots were fired into the deployment (Figures 1, 3, 5c). Deployment 4 is the northernmost transect. At it's southern end, deployment 4 overlapped the northern end of deployment 3, and it extended

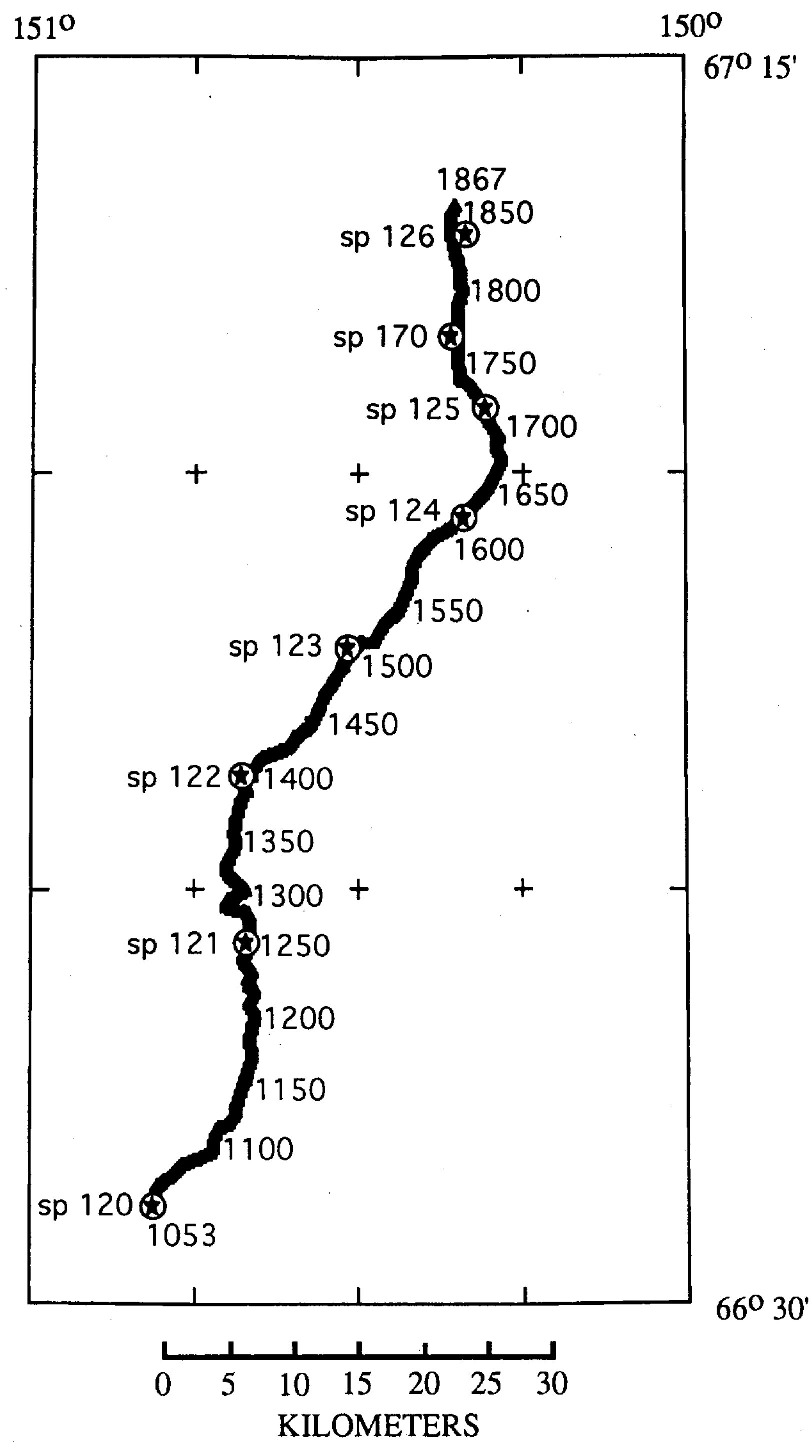

Figure 5a. Deployment 1 location map. Shotpoint location numbers (e.g. sp 120) and selected instrument location numbers (e.g. 1053) are given.

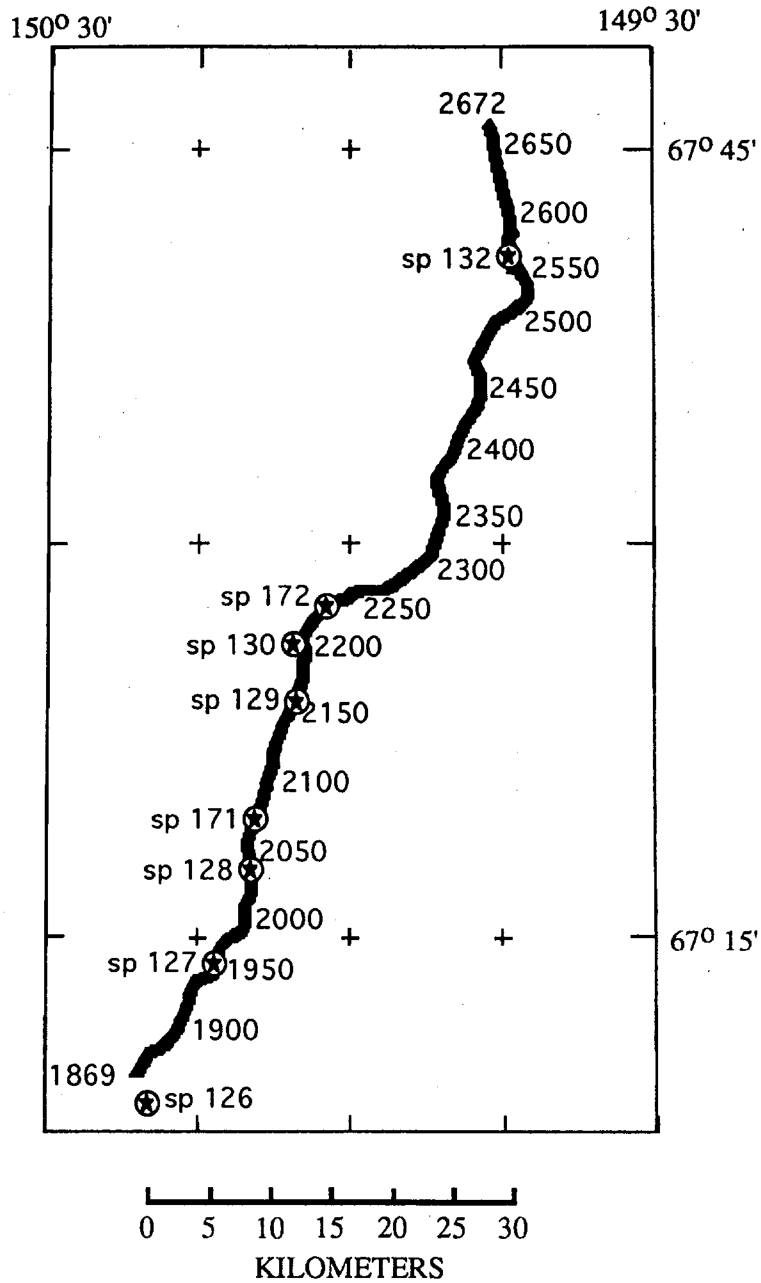

Figure 5b. Deployment 2 location map.

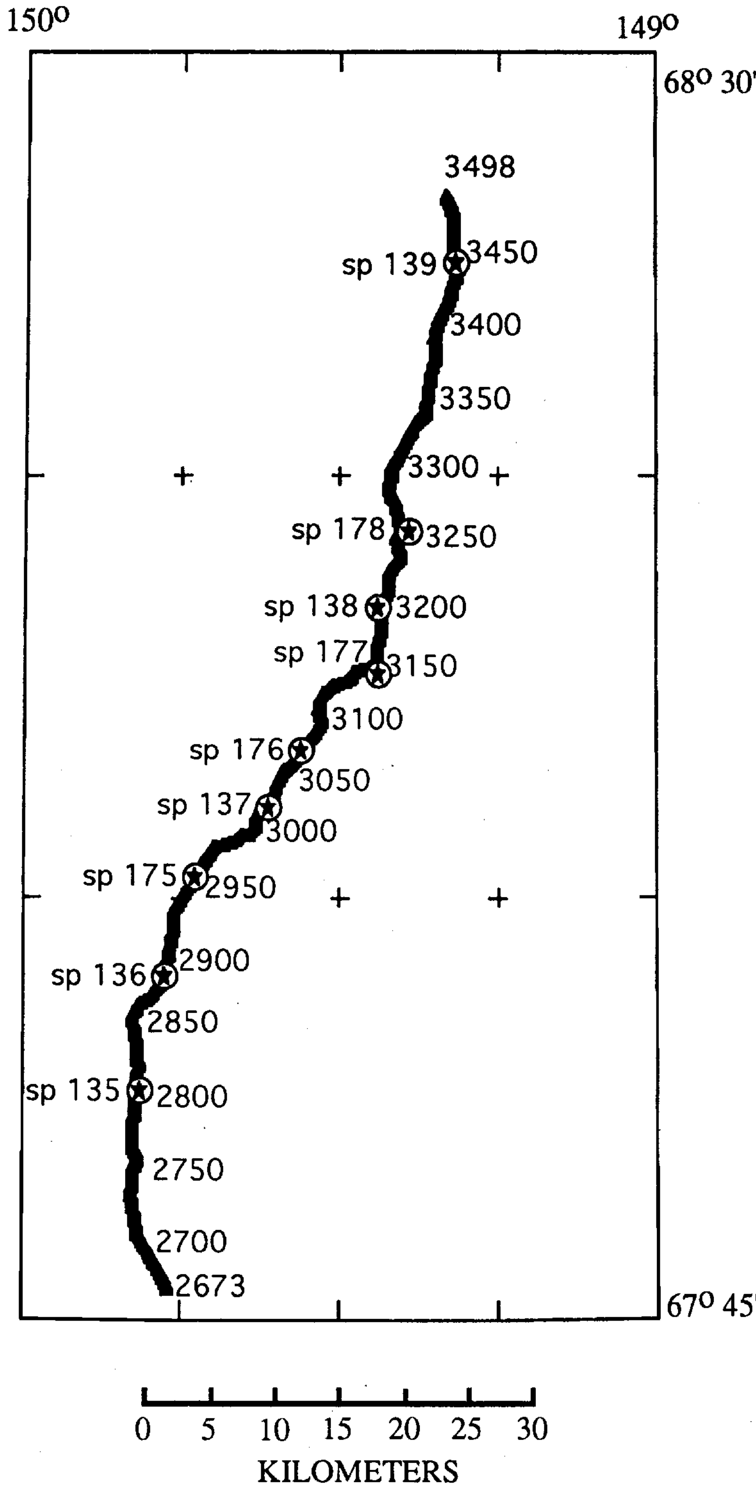

Figure 5c. Deployment 3 location map.

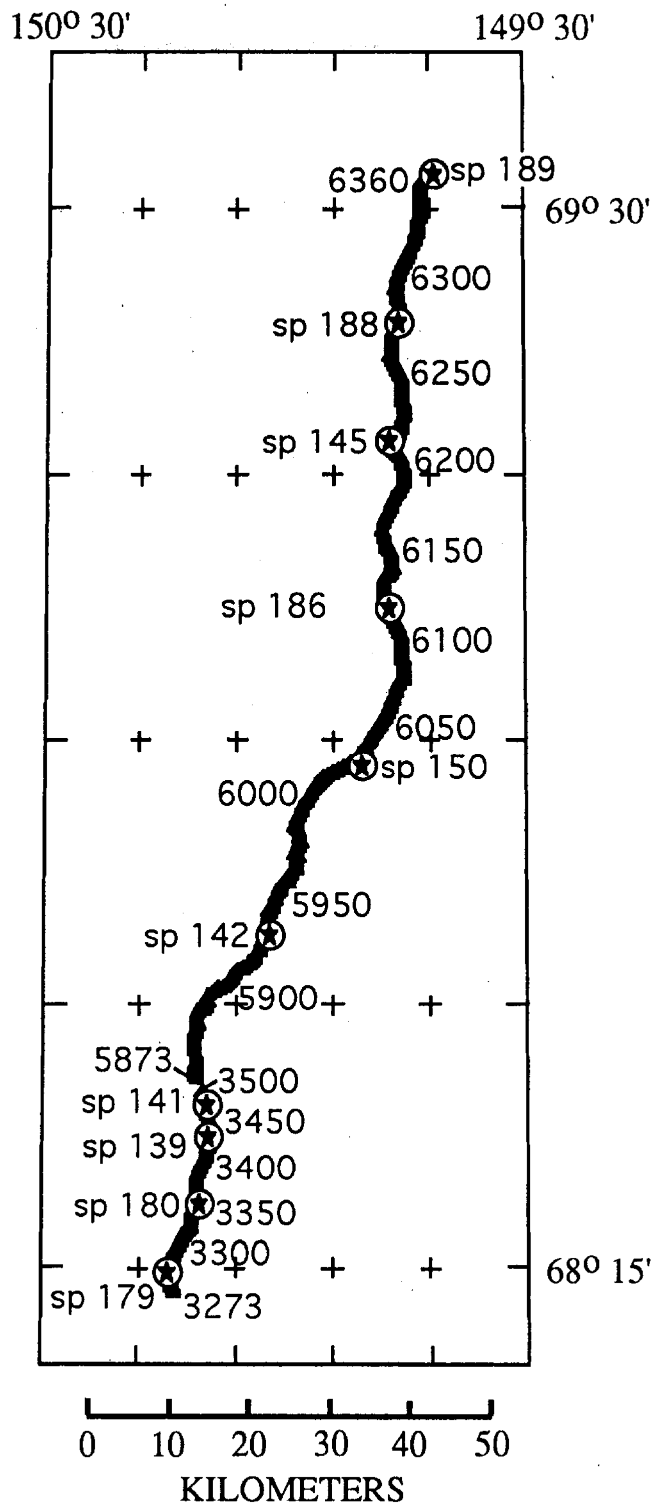

Figure 5d. Deployment 4 location map.

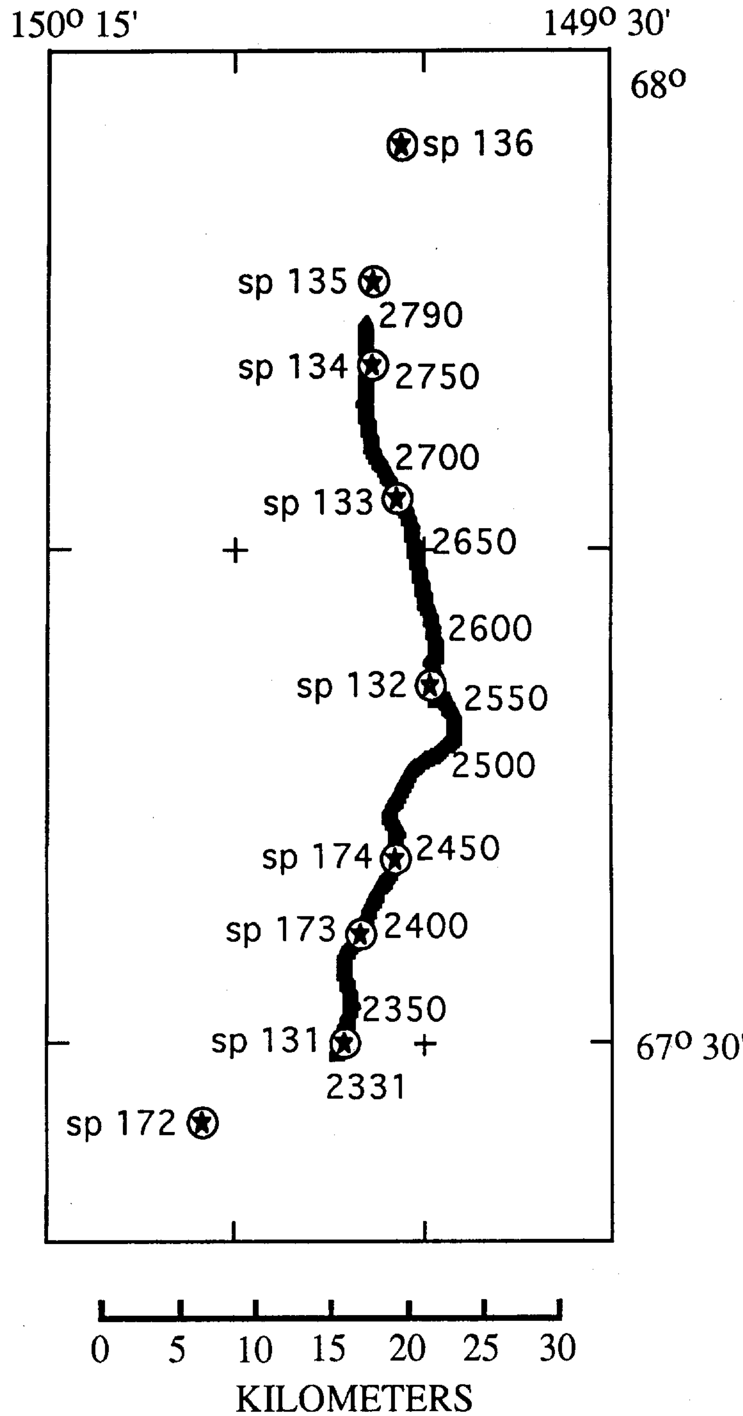

Figure 5e. Deployment 5 location map.

through the Brooks Range onto the North Slope. Ten in-line shots and four off-end shots were fired into the deployment (Figures 1, 3, 5d). Deployment 5 was laid out such that it overlapped both deployments 2 and 3; it filled in a gap in high-frequency coverage. Seven in-line shots and two off-end shots were fired into the deployment (Figures 1, 3, 5e).

Seismic stations and shotpoints were located using two Global Positioning Satellite navigation systems (GPS; the Trimble Navigation Pathfinder). These locations are estimated to be accurate to within ±10 meters horizontally and ±30 meters vertically. Seismic sources were produced by explosions in drilled holes and shallow lakes. Drill-hole shotpoints consisted of a 20-cm-diameter drill hole filled with an ammonium-nitrate-based blasting agent, boosters, and detonating cord. Shallow lake shotpoints consisted of a distributed charge at the bottom of the lake with detonating cord extending to shore. The amount of explosive and the depth to the top of the charge for each shotpoint are listed in table 2. At shot time, a signal from a USGS master reference clock triggered the shooting system to fire an electric blasting cap, which sequentially caused the detonating cord, boosters, and blasting agent to detonate. The shot origin times are determined by the master clocks, assuming that the explosives detonated at the exact time of the cap break. Generally, master clocks drift less than 1 millisecond per week. However, during this experiment some master clocks had large errors. Theses errors were corrected during data processing and are described below (see Data processing section). The corrected shot times are listed in Table 2.

SEISMIC RECORDERS

Four different instruments were used to collect data during this experiment - USGS Seismic Cassette Recorders (SCR), GSC PRS1s, Stanford Seismic Group Recorders (SGR III), and PASSCAL Ref Tek 72A-02s. A general description of each is given here. For more detailed descriptions see Murphy (1988) regarding the SCR's, Asudeh and others (1992) regarding the PRS1's, and the SGR II seismic group recorder field system technical manual and the Mark Products L-10 geophone specifications for the Stanford SGR III's.

The SCR's are a single-channel instrument consisting of a Mark Products L-4A 2-Hz vertical-component geophone, a set of three parallel amplifier boards with adjustable gain settings, a clock (temperature-compensated oscillator, TCXO), a VCO (voltage controlled oscillator), and a cassette recorder (Figure 6). The use of three parallel amplifier boards with gains set so that the dynamic ranges of the

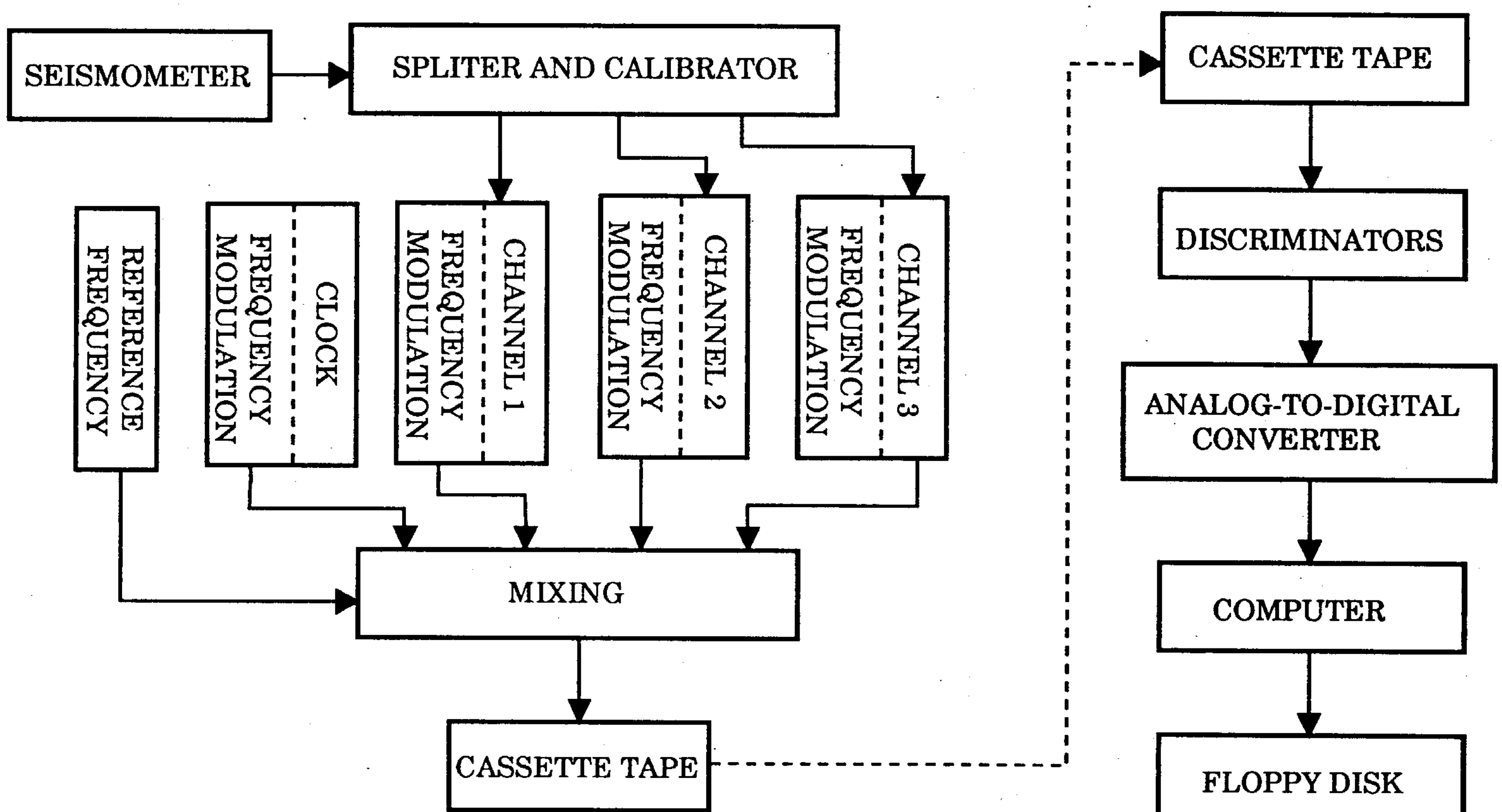

Figure 6. Schematic diagram of the Seismic Cassette Recorder (SCR) data acquisition and processing system

amplifiers overlap, affords a variable total dynamic range. All three data channels and the time code signal (IRIG E) are frequency modulated. The three data carrier frequencies, the clock carrier frequency, and a tape-speed compensation carrier frequency are summed and recorded on cassette tape. During the digitizing process, the cassette tapes are played back and the signals are demultiplexed and demodulated. To prevent accidental shifting of the data-carrier frequencies, the tape-speed compensation carrier frequency is demultiplexed and sent to a circuit board which continuously adjusts the speed of the tape deck such that the tape-speed compensation carrier frequency matches a locally generated reference frequency. A 12-bit analog-to-digital (A/D) converter converts the signals to digital data which are stored on floppy disks. The data are sampled at 200 samples per second. The complete system velocity response is roughly flat between 2 and 30 Hz (Figure 7a) and the approximate ground motion, $A_g(t)$, for this frequency range can be calculated:

$$A_g(t) = \frac{A(t)}{R_{GLE}\, R_{SA}\, R_{VCO}\, D_{DSC}\, D_{A/D}} = \frac{A(t)}{(409.6)\, R_{SA}}$$

where A(t) is the amplitude response and R_{GLE}, R_{SA}, R_{VCO}, D_{DSC}, and $D_{A/D}$ are the amplitude factors of the major components (Table 3). Phase characteristics are shown in Figure 7b. Prior to deployment, the clocks in each unit are synchronized to a USGS master clock which drifts approximately one millisecond per week and is checked periodically against satellite clocks. When the cassette recorders are retrieved, a clock drift is measured and these data are used to calculate chronometer corrections at shot time (assuming linear drifts). Most clocks drift less than 20 milliseconds during a 24 hour period.

TABLE 3

Component	Value
R_{GLE}	1 V/cm/sec
R_{SA}	dimensionless gain variable (V/V)
R_{VCO}	25 Hz/V
D_{DSC}	0.04 V/Hz
$D_{A/D}$	409.6 counts/V

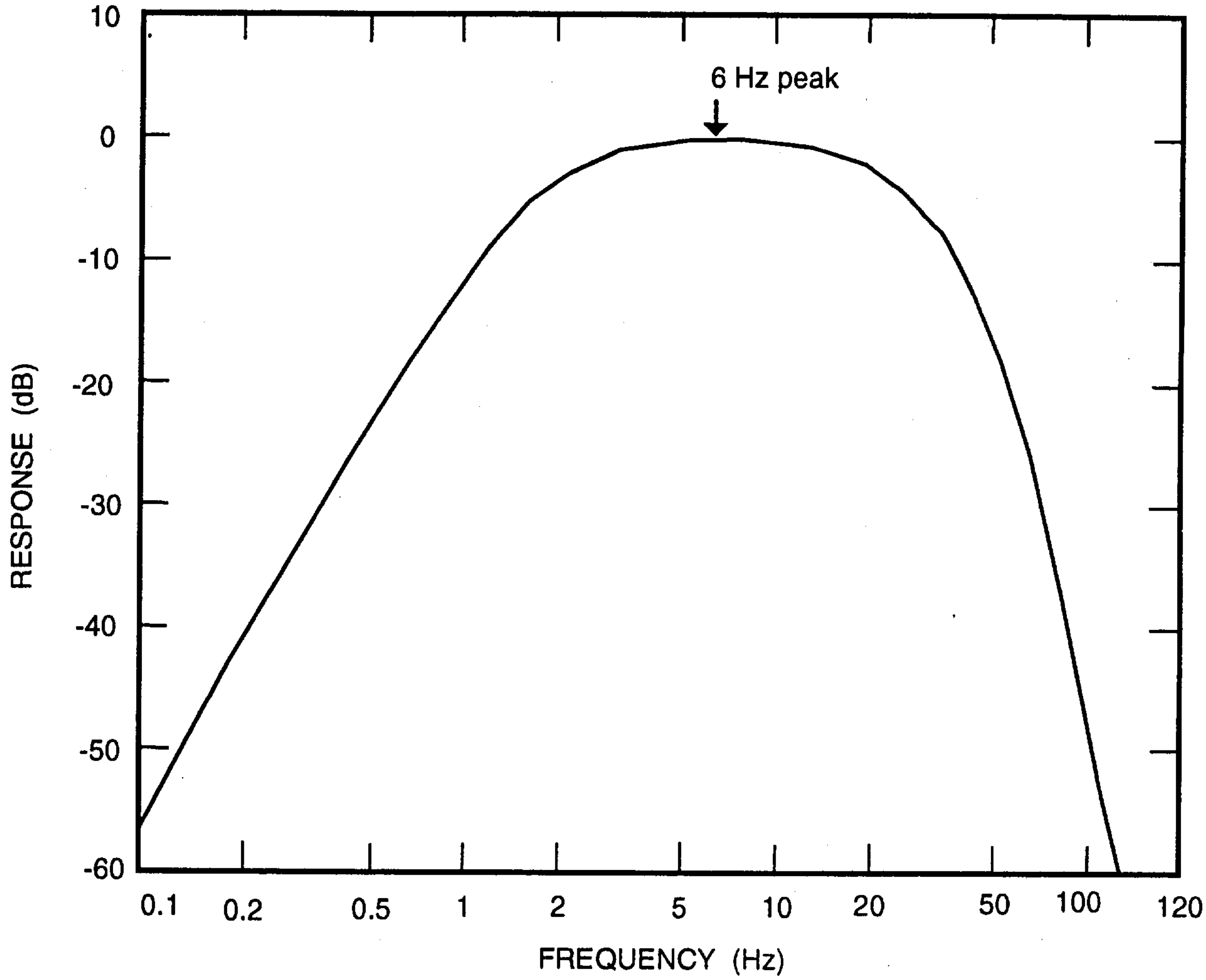

Figure 7a. Theoretical velocity response for the USGS seismic cassette recorder (SCR) and digitizing system with a Mark Products L-4A geophone (2-Hz). (From Dawson and Stauber, 1986)

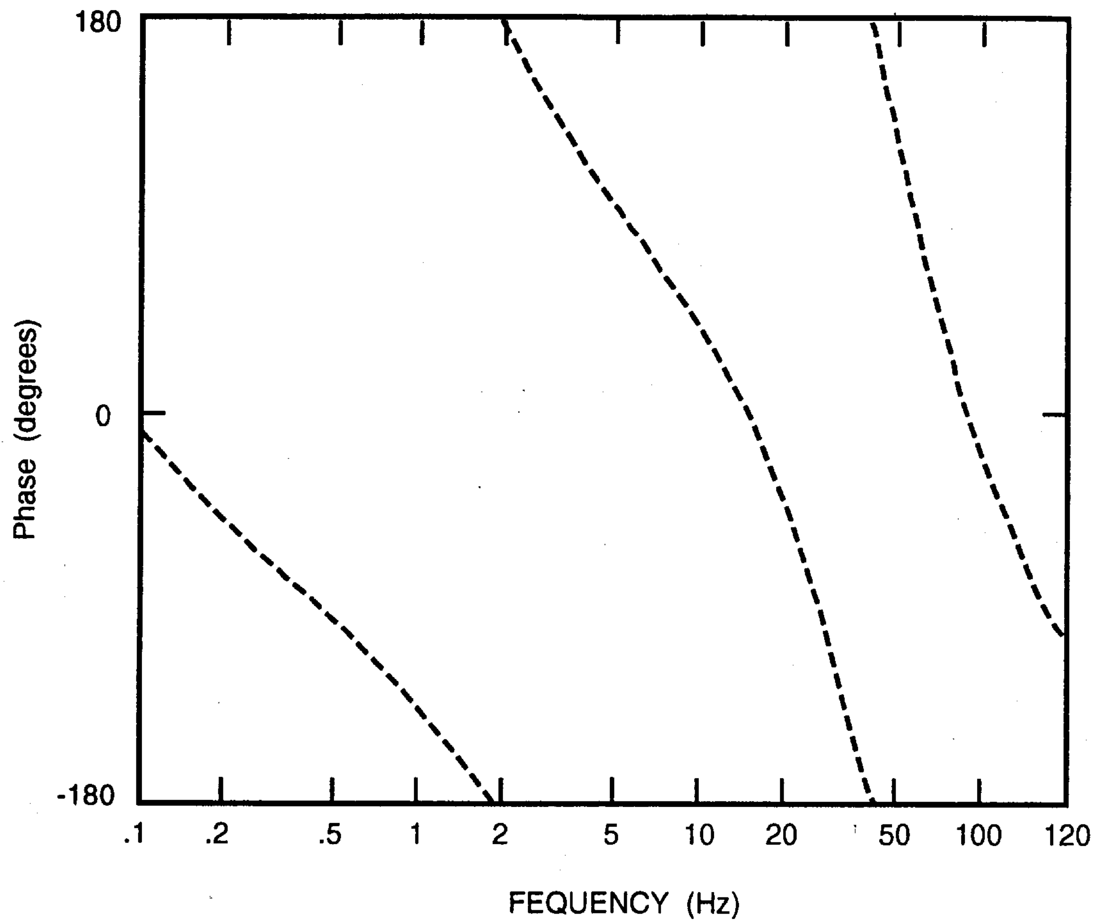

Figure 7b. Phase characteristics of the USGS seismic cassette recorder (SCR) and digitizing system. (From Dawson and Stauber, 1986)

The PRS1's are also single-channel instruments that use a Marks Products L-4A 2-Hz vertical-component geophone. Automatic gain-ranging from 1 to 1024 in binary steps allows a total dynamic range for these instruments of 132 dB. Seismic data are sampled at 120 samples per second by a 12-bit A/D board and stored in memory (DRAM) until the data are uploaded to a PC. Phase and amplitude response curves for the overall system are shown in Figures 8a and 8b, respectively. The amplitude response peaks about 5 Hz. Timing is provided for each unit by a temperature-compensated oscillator (TCXO) that is synchronized to GMT via satellite during the programming (or downloading) process. After retrieval of the instruments, the clock drift is measured for each instrument and clock corrections are made assuming linear drift rates. Most clocks drift less than 20 milliseconds during a 24 hour period. The PRS1 was designed by the Geological Survey of Canada and built by EDA Instruments Ltd.

The SGR III is a single channel, digital seismic recorder with a theoretical dynamic range of 156 dB. Data are sampled at 500 samples per second by a 12-bit A/D board with gain ranging from 0-90 dB in 6 dB steps. The Stanford SGR's have been modified to turn on at preset times instead of using the standard radio turn on. Timing is provided by a temperature-compensated internal oscillator (TXCO) that is synchronized to a USGS master clock prior to deployment. Like the SCR's and the PRS1's, most SGR clocks drift less than 20 milliseconds during a 24 hour period. The digital data and the clock drift at the time of instrument retrieval are recorded on cartridge tape. The drift rates (assumed linear) are used to calculate chronometer corrections at shot time. For this experiment, the SGR III pre-amplifier was set to 50 mV, the low-cut filter was "out", and the 60-Hz notch filter was "in". Figure 9a shows the phase characteristics associated with these filter settings. Each SGR III was connected to a single string of 6 modified Mark Products L-10B vertical component geophones (8 Hz) connected in series. The total system response is shown in Figure 9b. The SGR III recorders were designed by Amoco Production Company, built by Globe Universal Sciences, Inc., and modified by the USGS.

The PASSCAL Ref Tek 72A-02 instruments are a six-channel digital seismic data acquisition systems with a 200 M Byte data disk and an OMEGA clock. The instruments have a variable-gain preamplifier which can be set between a gain of 1 and a gain of 8192. During this experiment most of the instruments had a gain of 256. Cables were extended to 6 sets of Mark Products L-10B vertical-component geophones, similar to ones used with the SGR III's described above. Thus, each Ref Tek recorded data from six separate locations (or stations). The total system response is shown in figure 10.

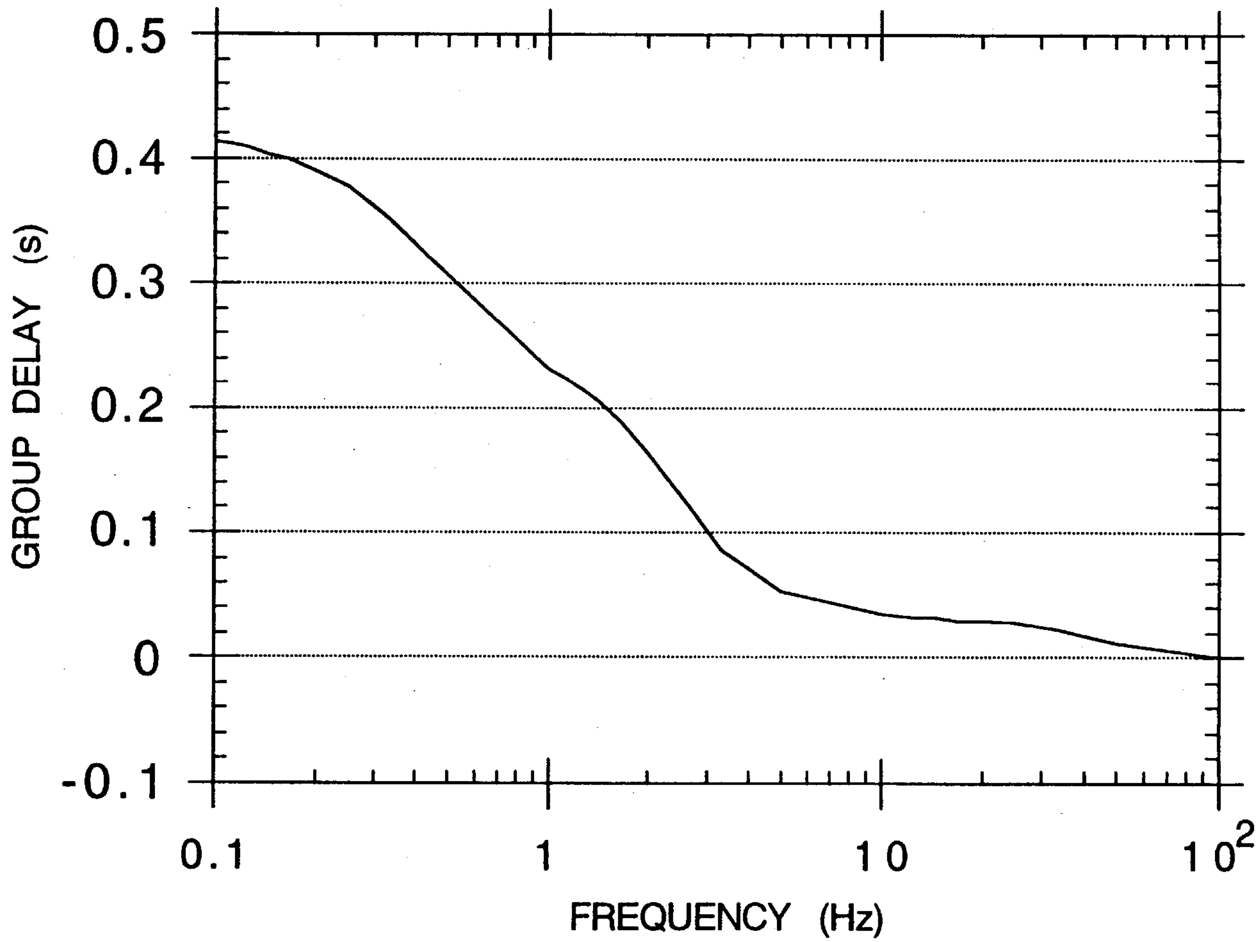

Figure 8a. The phase characteristics of the *PRS1*.

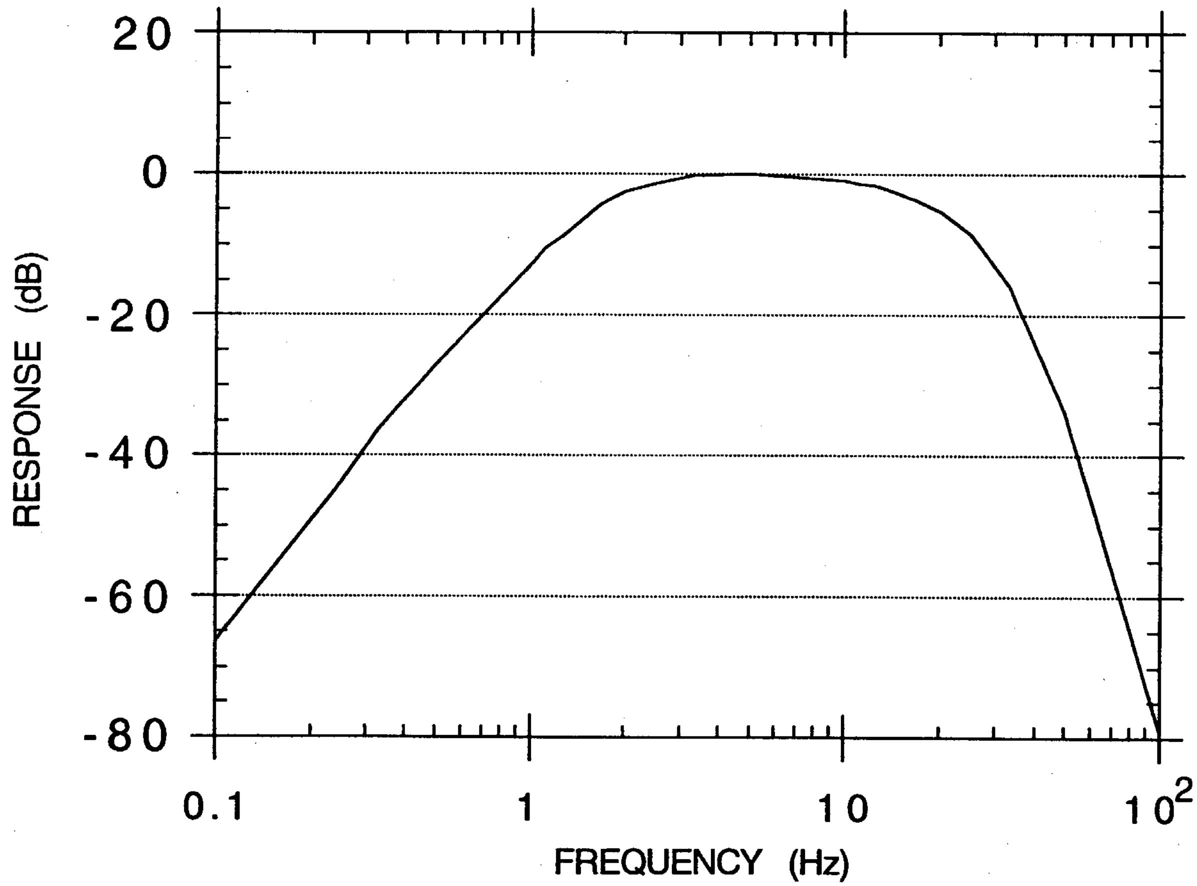

Figure 8b. The amplitude response for the PRS1 with the Mark Products L4-A geophone (2-Hz).

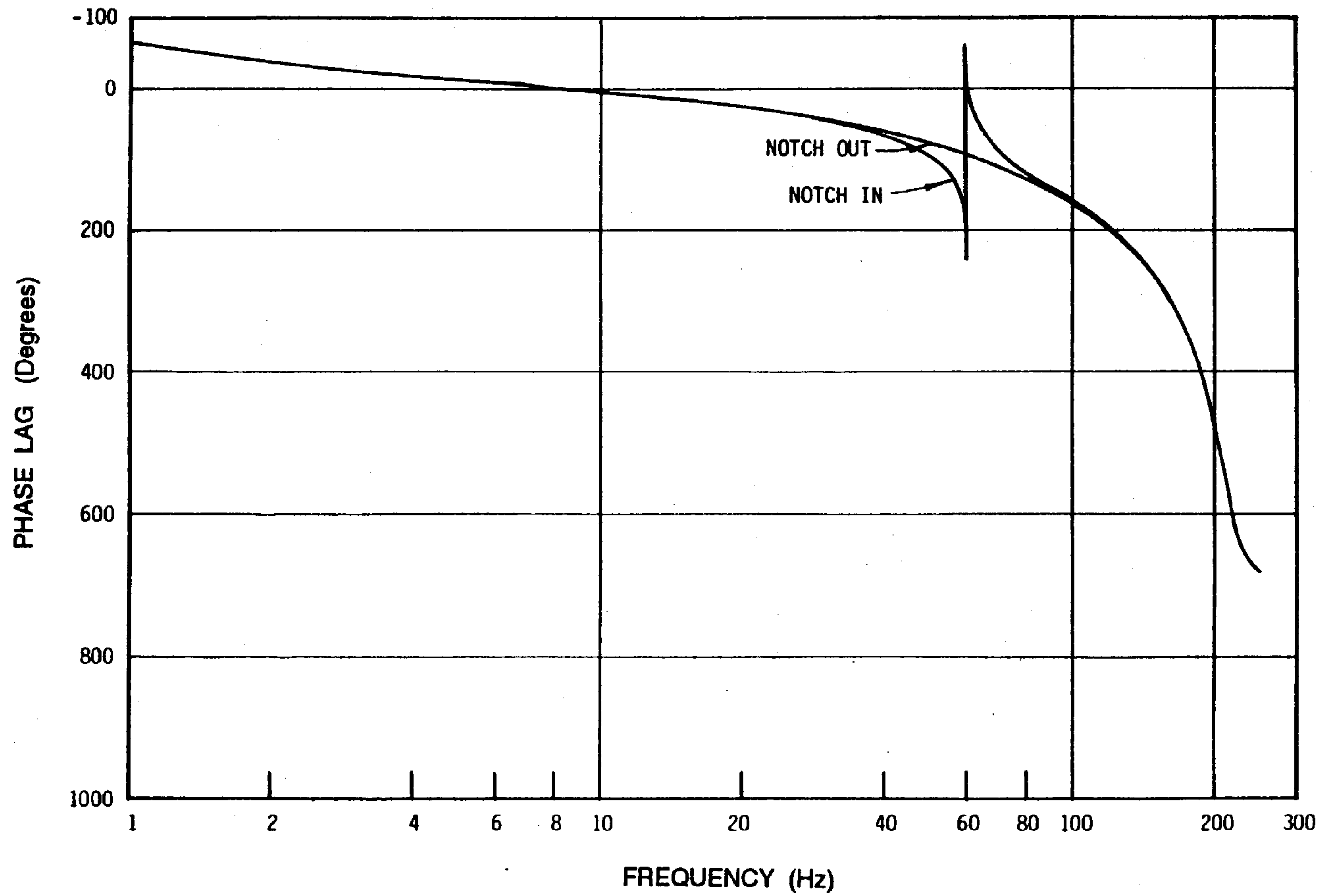

Figure 9a. The phase characteristics of the SGR III's with filters as described in the text (the geophone is not included here).

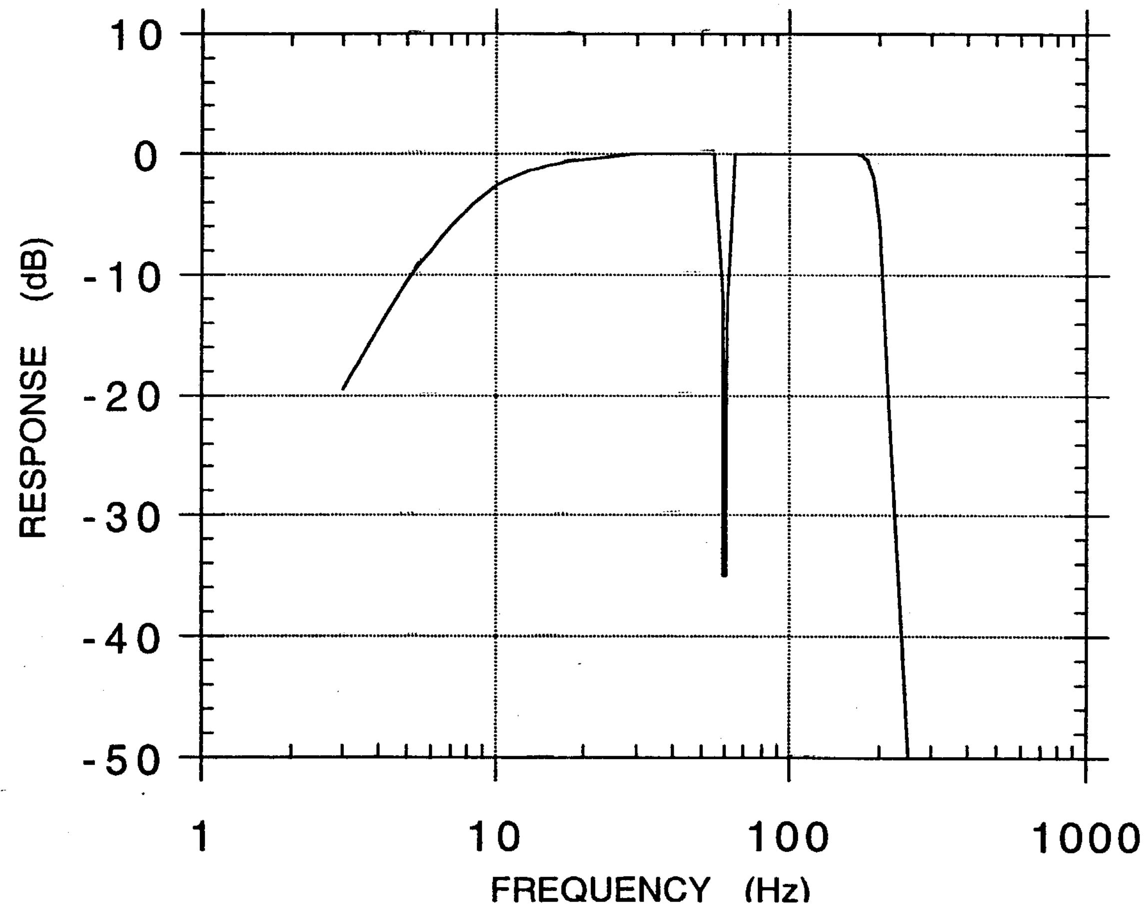

Figure 9b. The amplitude response for the SGR III with the modified Mark Products L10-B geophone string.

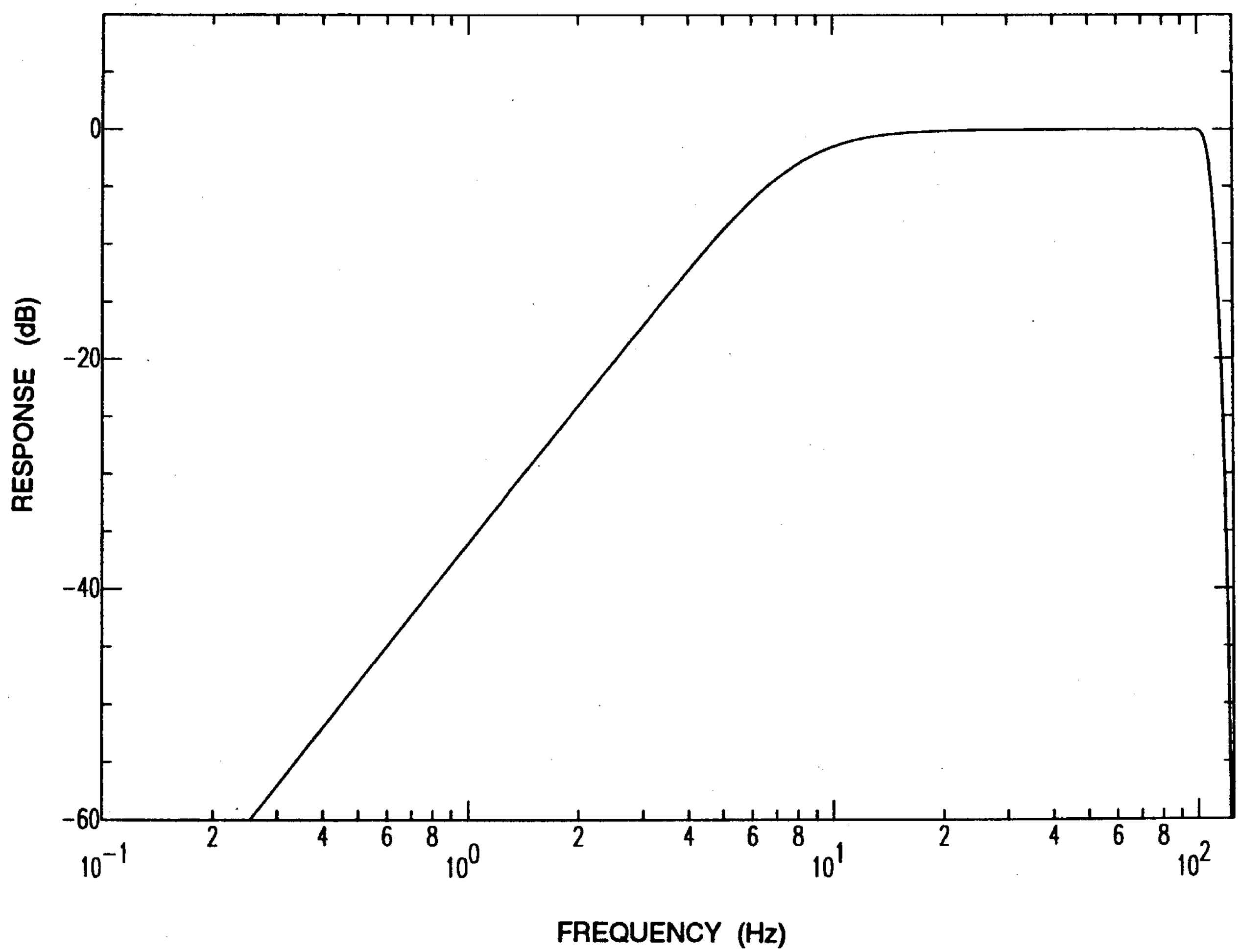

Figure 10. The amplitude response for the REF TEK 72A-02 seismic recorder with the Mark Products L10-B geophone string.

DATA PROCESSING

The mix of instruments posed several unique recording problems. The SCR and PRS1 instruments have nearly matched instrument responses designed for lower-frequency refraction recording (2-30 Hz), whereas the SGR and Ref Tek recorders are matched and were equipped with industry geophones designed for higher-frequency reflection recording (≥ 10 Hz). Although all four playback systems produce SEGY data tapes, the header files and sample rates are different for each system. Record sections and normal-moveout (NMO) corrected shot gathers were produced in the field within 48 hours of shooting because each seismic instrument system had its own data playback facility. However, merging the data required extensive processing.

Processing of the data was undertaken at Rice University on a SUN SPARC 4/390 computer using the Cogniseis DISCO processing system. Geometry for recording sites was defined for each of the five deployments (Figures 3 and 5) and shotpoints were defined by distance to the nearest recording site. No geometry was defined for shots 62 and 63. Processing proceeded deployment by deployment in 3 stages (Figure 11). In the first stage, major trace header variables were established for each instrument type including shot and receiver parameters. Timing corrections associated with instrument recording and geometry corrections were applied in the first phase along with a reducing velocity of 8 km/sec. In the second stage, data belonging to each of the different instrument types were merged and sorted into shot order. Additional trace header variables were assigned and all shots were plotted and tables for the trace headers were compiled. Finally, in stage III, the shot ordered data were written in SEGY format to tape.

Stage I

Each of the different instrument systems produced raw SEGY formatted data tapes with different predefined trace headers. Certain key variables, namely the field file identification, FFID, trace sequence number, SEQNO, and the receiver station location, XSTA, were used to define a consistent set of major trace headers; SHOT (bytes 9-12), SP (bytes 17-20), and CHAN (bytes 13-16). To identify the different instrument types, a BOXTYPE (bytes 211-212) trace header was defined; 1= SCR, 2 = SGR, 3 = PRS1, and 4 = Ref Tek.

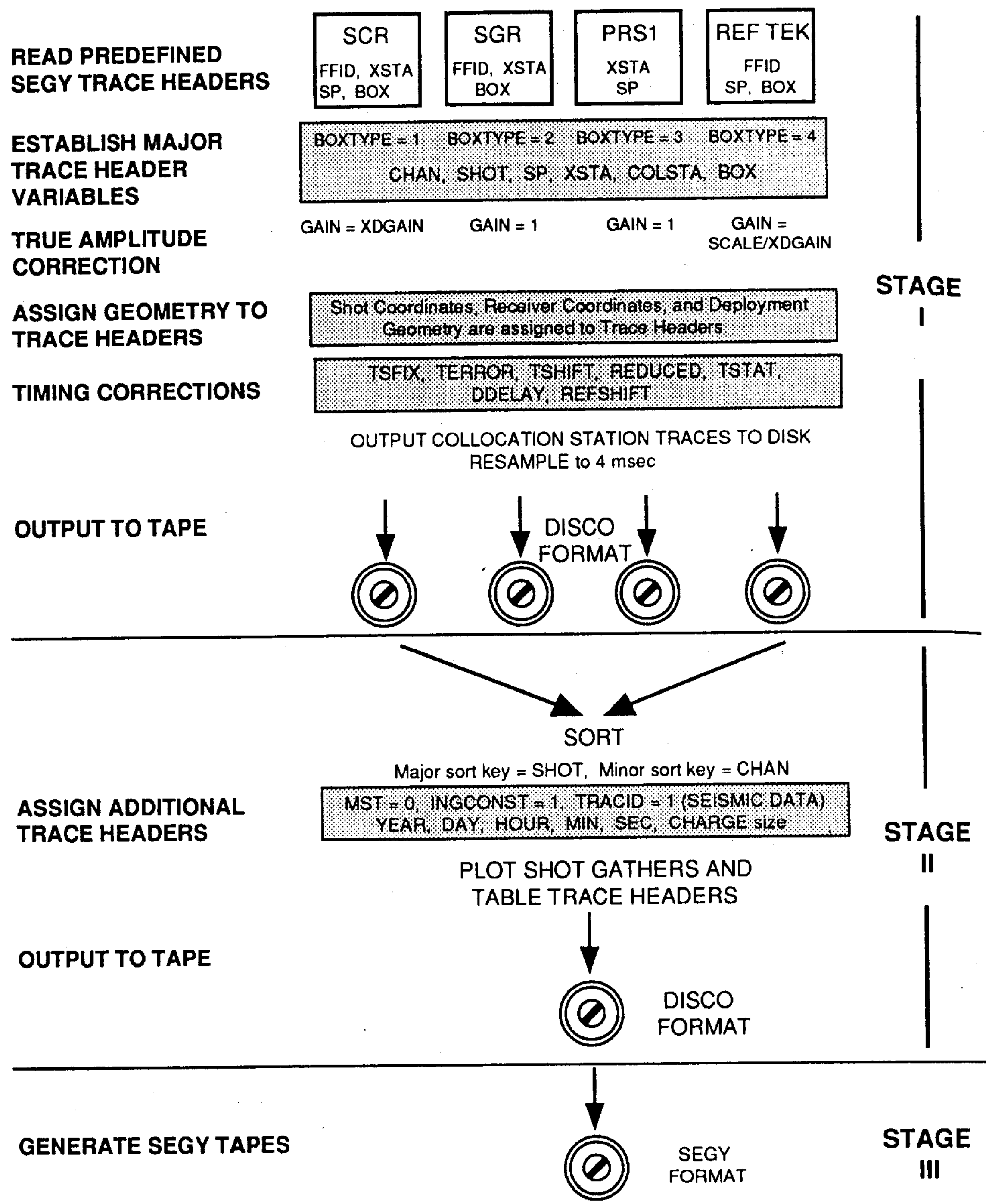

Figure 11. Schematic diagram showing the steps used to process the Brooks Range data.

During each deployment, one site was chosen to collocate all instrument types. The trace header COLSTA (bytes 235-236) was defined to indicate which traces are from collocation sites. COLSTA is set to 1 for collocation sites; otherwise it is 0. Table 4 lists station locations used for collocation sites. Collocation traces were used to check timing corrections and trace polarity. The amplitude of these traces can be used to obtain absolute amplitude corrections.

TABLE 4

Deployment	Collocation Station	Box type
1	1679	2,3,4
2	2100	1,2,3,4
3	3055	1,3,4
4	3480	3,4
5	2515	2,4

Amplitude corrections or scaling ratios of one instrument type to another have been calculated in two ways. The first (Table 5, A), a more approximate method, compared maximum and average amplitudes for collocated box-types 1, 2, and 4 for only deployment 2. In a second more thorough evaluation (Table 5,B), collocation amplitudes for all Brooks Range deployments were calculated by averaging both positive and negative amplitudes over a time window. A 'mean' or average scale factor for each box type was then calculated. These two estimates provide scale factors within a factor of 2 of each other (Table 5)

TABLE 5

		Scaling Factor	
Box Type	Instrument	A	B
1	SCR	1.0 /	1.0
2	SGR	4.5×10^6 /	6.79×10^6
3	PRS1	-- /	0.641
4	Ref Tek	7.5×10^7 /	9.73×10^7

The timing corrections applied to the Brooks Range data include: a correction due to shot errors, instrument drift corrections, and a reduction time correction. To ensure that the original data can be recovered or that the timing errors can be recomputed, the major timing variables are placed in the extended SEGY trace header space (user defined space). The following is a definition of those headers:

TSFIX	digitizing start time in msec. Bytes 203-204.
DRIFT	instrument drift in msec. Bytes 205-206.
TERROR	shot time correction in msec (due to master clock error). Bytes 207-208.
MST	MST is set equal to 0. Bytes 181-184 Timing correction so that digitized traces start on the second. For SGR data, this correction is done in the transcribing process by adding MST to the DRIFT term. In the SCR and PRS1 data, the correction is done in the digitizing process.
TSHIFT	Shifts the beginning of the trace to shot time. Bytes 217-220. TSHIFT is defined for each instrument type as follows: SCR XOFFSET/8.0* + TSFIX + TERROR - DRIFT PRS1 XOFFSET/8.0* + TSFIX + TERROR - DRIFT SGR TSFIX + TERROR + DRIFT Ref Tek TSFIX + TERROR + DRIFT * - reduction time applied to data in the field. Bytes 221-224.
REDUCED	reduction time applied to the data (- OFFSET/8.0 (km/s)).
TSTAT	Sum of all time shifts applied to the original data. Bytes 225-228. (TSHIFT + REDUCED).
DDELAY	Bytes 229-232. If DDELAY is removed the trace is returned to the state that we received it. DDELAY is defined for each instrument type as follows: SCR TSTAT - MST*/1000 PRS1 TSTAT - MST*/1000 SGR TSTAT + 0 Ref Tek TSTAT - MST* * - MST from original field tapes.
REFSHIFT	Empirical static shift applied to the Ref Tek's which experienced large clock drifts. This was calculated using cross correlation's on adjacent SGR traces. Bytes 237-238.

Based on analysis of first arrival time picks, it is likely that an additional -0.12 sec shift for shot 15 and a -0.1 sec shift for shot 29 is required to satisfy reciprocity constraints. These shifts (travel-time advances) are approximate. To correct for a missed shot window on the first deployment, traces from shot 63 (sp 126) were merged with shot 10 (sp 126). Data from shot 62 (sp 127) did not fit the defined geometry and therefore, are not presented here. At this stage, the data were resampled to 4 msec and temporary tapes were written for each instrument system.

Stage II

During the second stage, data from the temporary tapes for each instrument system were merged and sorted into shot ensembles and the data were plotted. In addition, trace headers were tabled and checked. At this stage, trace headers related to the date and time of shots (see extended SEGY trace header space of table 6) and shot charge size (CHARGE; bytes 187-188) were added, TRACEID (bytes 29-30) was set to 1 (seismic data), MST (bytes 181-184) was set to 0, and the instrument gain constant, INGCONT (bytes 185-186), was set to 1.

Stage III

In the third and final stage of processing, SEGY-formated data was written to tape at 6250 bpi and trace header information was written to the EBCDIC reel header (Figure 12). The data were written as shot gathers in deployment order with a sample rate of 4 msec and a trace length of 60 seconds (see appendix B for actual data length). A description of the trace headers is given in Table 6.

Several headers were specially set to ensure compatibility with U.S. Geological Survey record-section plotting programs and software at the Canadian Geological Survey (Luetgert, 1988). Headers MST (bytes 181-184) and COR (bytes 185-186) were set to zero. In addition, the trace start time (bytes 157 through 166) was set to the shot time (bytes 189 through 202). The instrument gain correction (bytes 121-122) was set to one.

```
*************************************
* SEG-Y BINARY HEADER INFORMATION *
*************************************

MAXNTR.......          800
SAMPLE RATE..         4000   (MICROSECONDS)
LENGTH.......        15000   (SAMPLES)
DATA FORMAT..            1   (IBM FLPT)


**********************
* EBCDIC REEL HEADER *
**********************


C1    BROOKS RANGE EXPERIMENT 1990  : RICE UNIVERSITY PROCESSING
C2    GSC, SGR, PRS1 AND  SCR MERGED DATA FOR DEPLOYMENT 2.
C3
C4    SAMPLE RATE = 4 MS / 60 SECS DATA / 32 BYTE IBM FLOAT FORMAT
C5    DATA IS REDUCED (VRED = +8.0KM/SEC)
C6    DATA IS DRIFT CORRECTED, AND CORRECTED FOR ALL OTHER TIMING ERROR
C7            AND TIMING SHIFTS.
C8    HEADERS ARE DESCRIBED AS NAME (XXX,N) WHERE XXX IS THE BYTE LOCATION
C9                                            N    IS THE NUMBER OF BYTES
C10    SHOT      (  9,4) = SHOT SEQUENCE NUMBER
C11    CHAN      ( 13,4) = CHANNEL NUMBER
C12    ESPNUM    ( 17,4) = SHOTPOINT NUMBER, EQUIVALENT TO SP
C13    INGCONST(121,2) = TRUE AMPLITUDE FACTOR =1 INSTRUMENT GROUPS ARE TRUE
C14                      AMPLITUDE WRT THEMSELVES NOT WRT EACH OTHER
C15   MST       (181,4) = 0 MICROSECONDS OF TRACE START TIME
C16   COR       (185,2) = 0 MS TIMING CORRECTION (MST AND COR HEADERS USED TO
C17                         MAINTAIN COMPATABILITY WITH LUETGERT'S PROGRAMS)
C18   CHARGE    (187,2) = CHARGE SIZE IN LBS
C19   SYEAP     (189,2) = SHOT TIME:(YEAR,HOUR,DAY,MIN,SEC)EACH IN 2 BYTE HEADER
C20   SSMIC     (199,4) = SHOT TIME: MICROSECONDS
C21   TSFIX     (203,2) = MSEC TIME BEFORE SHOT = INITIAL DIGITIZING TIME
C22   DRIFT     (205,2) = MSEC INSTRUMENT DRIFT
C23   TERROR    (207,2) = MSEC CORRECTION TO SHOT TIME
C24   BOX       (209,2) = SERIAL NO. OF THE BOX;  PRS1 VALUE SHOULD HAVE 'A' PRE
C25   BOXTYPE   (211,2) = 1 FOR SCR / 2 FOR SGR / 3 FOR PRS1 / 4 FOR REFTEK
C26   REC-STAT(213,4) = RECEIVER STATION
C27   TSHIFT    (217,4) = TSFIX + TERROR - DRIFT + XOFFSET/8.0 (TSHIFT CORRECTS
C28                       TO SHOT TIME; -XOFFSET/8.0 IS FAKE REDUCTION APPLIED IN
C29   REDUCED (221,4) = -OFFSET/8.0 (OFFSET IS TRUE <R-S< OFFSET)
C30   TSTAT     (225,4) = TSHIFT + REDUCED (WHAT WE APPLIED TO DATA)
C31   DDELAY    (229,4) = TSHIFT + REDUCED - MST/1000.
C32                       (MST IS A MICROSECOND ERROR ASSOCIATED WITH TURNON TIME
C33                       OF SCR AND PRS1 INSTRUMENTS) IF DDELAY IS REMOVED THE
C34                       TRACE IS RETURNED TO THE STATE IN WHICH WE RECEIVED IT
C35   GAIN      (233,2) = GAIN THAT APPLIED TO TRACES TO PROVIDE TRUE AMP
C36   COLSTA    (235,2) = 1 COLLOCATION STATION : ONE TYPE OF EACH INSTRUMENT
C37                     = 0 OTHERWISE
C38   REFSHIFT (237,2) = EMPIRICAL STATIC SHIFT APPLIED TO REFTEKS(CLOCK DRIFT)
C39   CONTACT A.R. LEVANDER OR S.A. HENRYS FOR ADDITIONAL INFORMATION
C40   PROCESSED BY S.A. HENRYS, A.R. LEVANDER, AND W. LUTTER*END REEL HEADER*
```

Figure 12. EBCDIC reel header.

TABLE 6

ARCHIVE DATA TAPE FORMAT

Archive data tapes are written in standard SEG-Y 32-bit IBM floating point format (Barry et al., 1975). The tape recording density is 6250 bpi and each tape has the standard SEG-Y EBCDIC reel header. Minor modifications to the trace headers allow refraction data to be archived in this format. A list of the header fields used for this data is shown below.

Trace Identification Header (total of 240 bytes)

1-4	Cumulative sequence number within deployment
5-8	Trace number within reel
9-12	Shot
13-16	Channel (recorder location number)
17-20	Shot point location number
21-24	CDP
25-28	Trace sequence number within shot ensemble
29-30	Trace identification code (1 = seismic data)
31-32	Not used
33-34	Not used
35-36	Not used
37-40	Distance from source to receiver
41-44	Receiver group elevation (m)
45-48	Surface elevation of source (m)
49-52	Shot depth
53-56	Not used
57-60	Not used
61-64	Not used
65-68	Not used
69-70	Not used
71-72	Not used
73-76	Source X coordinate (meters east of Shot point 154)
77-80	Source Y coordinate (meters north of Shot point 154)
81-84	Group X coordinate (meters east of Shot point 154)
85-88	Group Y coordinate (meters north of Shot point 154)

TABLE 6 (continued)

89-90	Not used
91-92	Not used
93-94	Not used
95-96	Not used
97-98	Not used
99-100	Not used
101-102	Not used
103-104	Not used
105-106	Not used
107-108	Not used
109-110	Not used
111-112	Not used
113-114	Not used
115-116	No of samples in this trace
117-118	Sampling interval in microseconds
119-120	Not used
121-122	Gain constant
123-124	Not used
125-126	Not used
127-128	Not used
129-130	Not used
131-132	Not used
133-134	Not used
135-136	Not used
137-138	Not used
139-140	Not used
141-142	Not used
143-144	Not used
145-146	Not used
147-148	Not used
149-150	Not used
151-152	Not used
153-154	Not used
155-156	Not used
157-158	Year of trace start time
159-160	Day of trace start time
161-162	Hour of trace start time
163-164	Minute of trace start time

TABLE 6 (continued)

165-166	Second of trace start time
167-168	Not used
169-170	Not used
171-172	Not used
173-174	Not used
175-176	Not used
177-178	Not used
179-180	Not used
181-184	Microseconds of trace start time
185-186	Millisecond of timing correction
187-188	Amount of explosives (lbs)
189-190	Shot time - Year
191-192	Shot time - Day
193-194	Shot time - Hour
195-196	Shot time - Minute
197-198	Shot time - Second
199-202	Shot time - Microsecond
203-204	Initial digitizing time
205-206	Clock drift rate
207-208	Correction to shot time in microseconds
209-210	Instrument number
211-214	Instrument type (1= SCR, 2= SGR, 3= PRS1, 4 = Ref Tek)
213-216	Reciever location number
217-220	Corrects trace to shot time (see comments in EBCDIC reel header)
221-224	Reduction (- offset / 8.0)
225-228	correction applied to data (see comments in EBCDIC reel header)
229-232	error in turn on time of SCR and PRS1 (in microseconds)
233-234	Gain
235-236	Collocation site for each type instrument (1=yes, 2=no)
237-238	Static shift applied to Ref Teks (clock drift)

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APPENDIX A

RECORD SECTIONS

The record sections presented below were plotted as follows. Reducing velocity is 6 km/s. All traces are represented, but we have plotted only positive trace fills and not the trace itself. Traces are plotted from south (left) to north (right) as shown in Figure 13. For offset shots, we show 2 sections; one with an automatic-gain-control (AGC) window of 2 sec, to emphasize all arrivals, and one with an AGC window of 12 sec, to emphasize only the strongest arrivals. Changes in instrument type along the line account for the changes in appearance of arrivals. For example, PRS1's and SCR's emphasize longer-period arrivals (e.g. surface waves). The instrument type for each trace is indicated in the trace header field (bytes 211-214) of the SEGY data on the magnetic tapes (see Tables 4, and 6). Profile numbers are the deployment numbers.

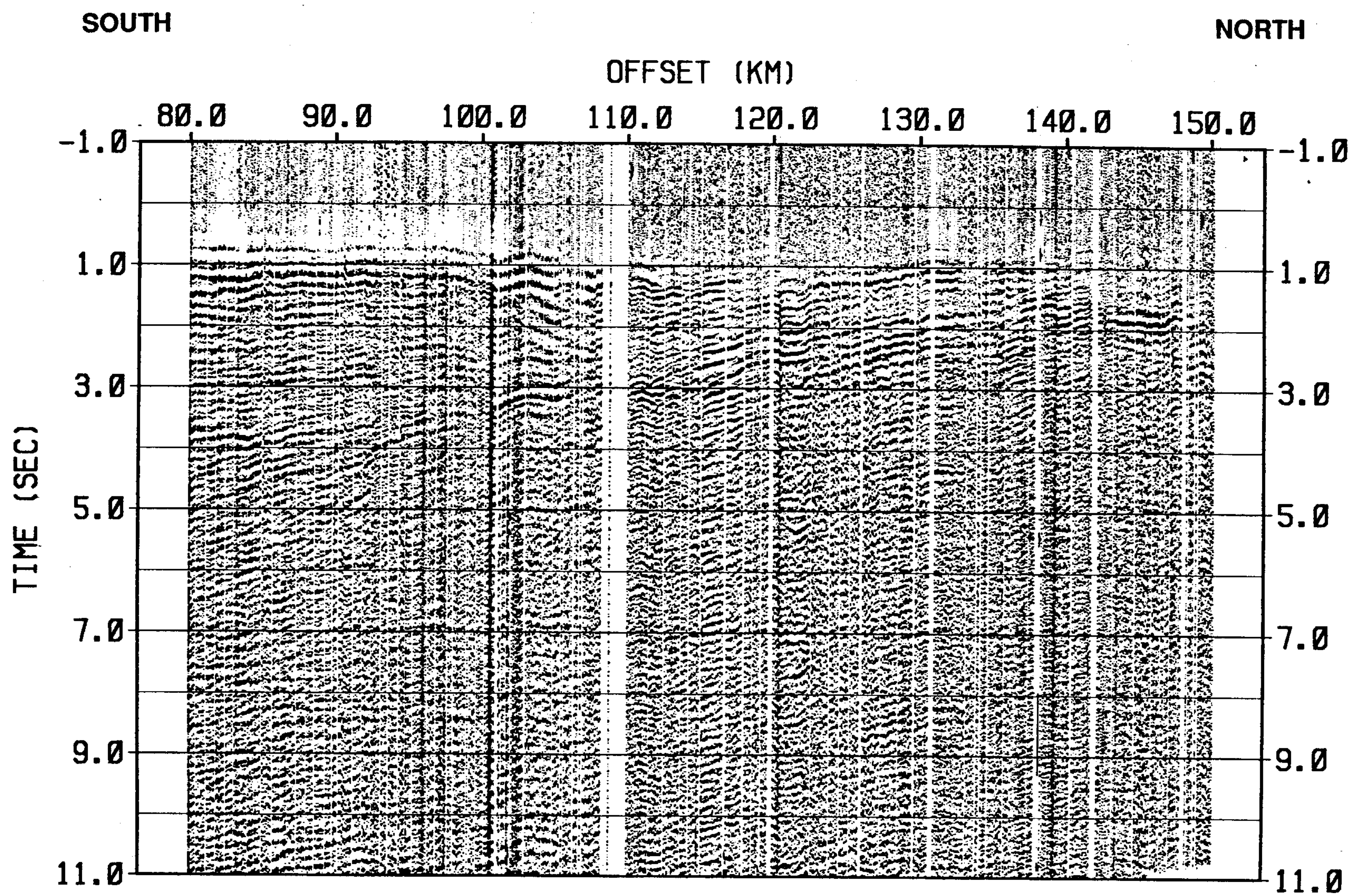

Figure 13 Profile 1

Shot 1 Shot Point 154 AGC = 2 sec

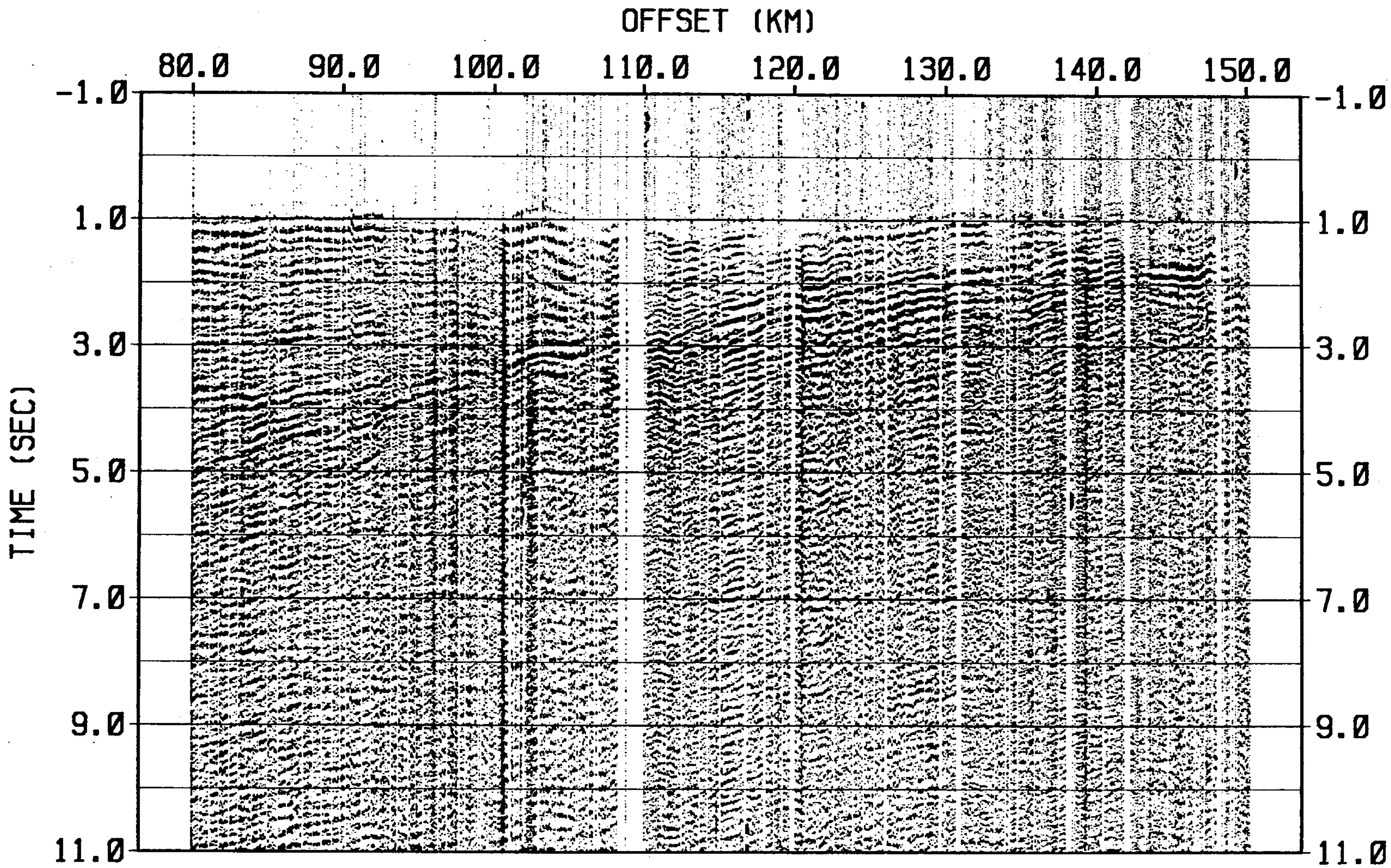

Figure 14 Profile 1

Shot 1 Shot Point 154 AGC = 12 sec

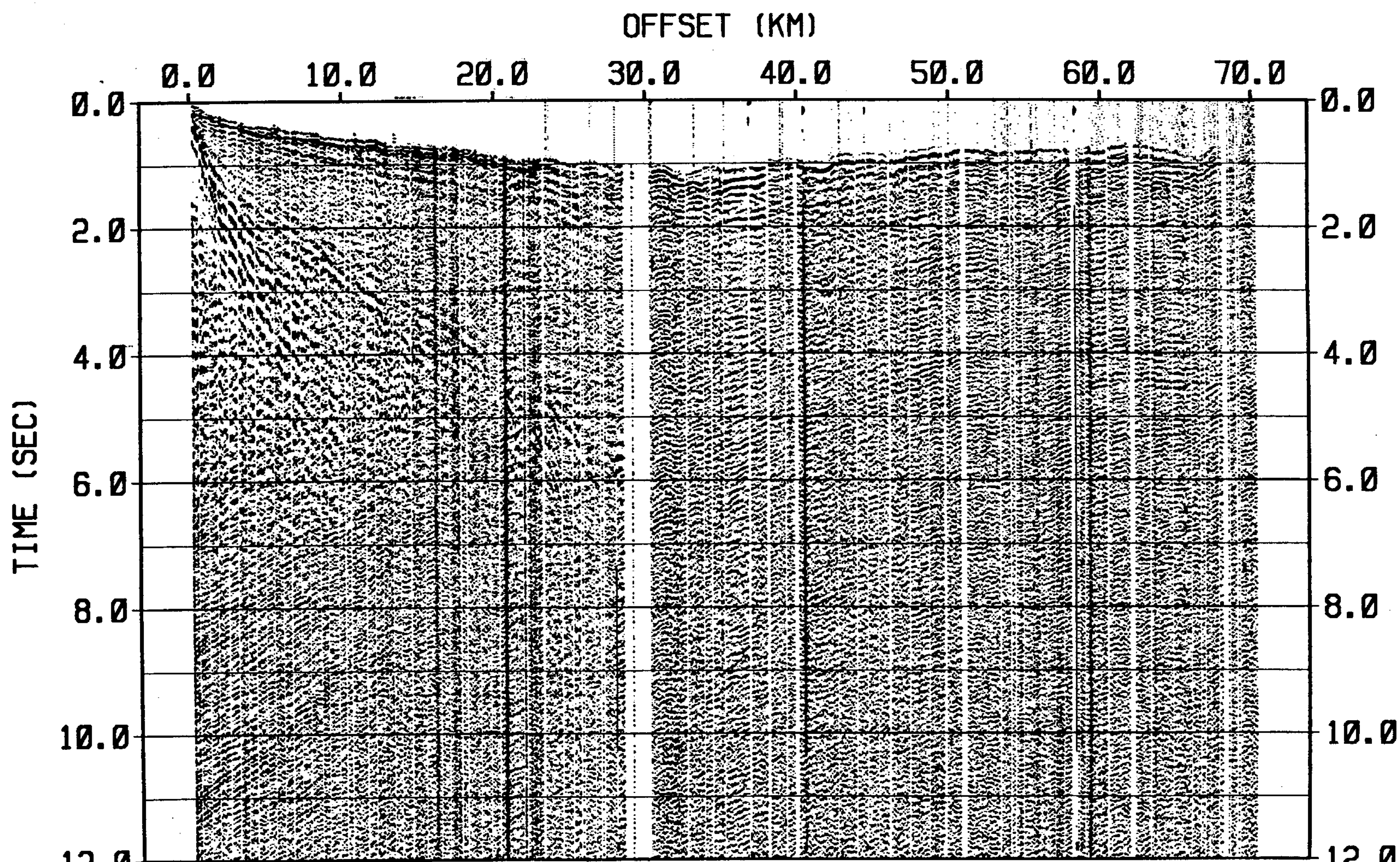

Figure 15 Profile 1

Shot 2 Shot Point 120 AGC = 2 sec

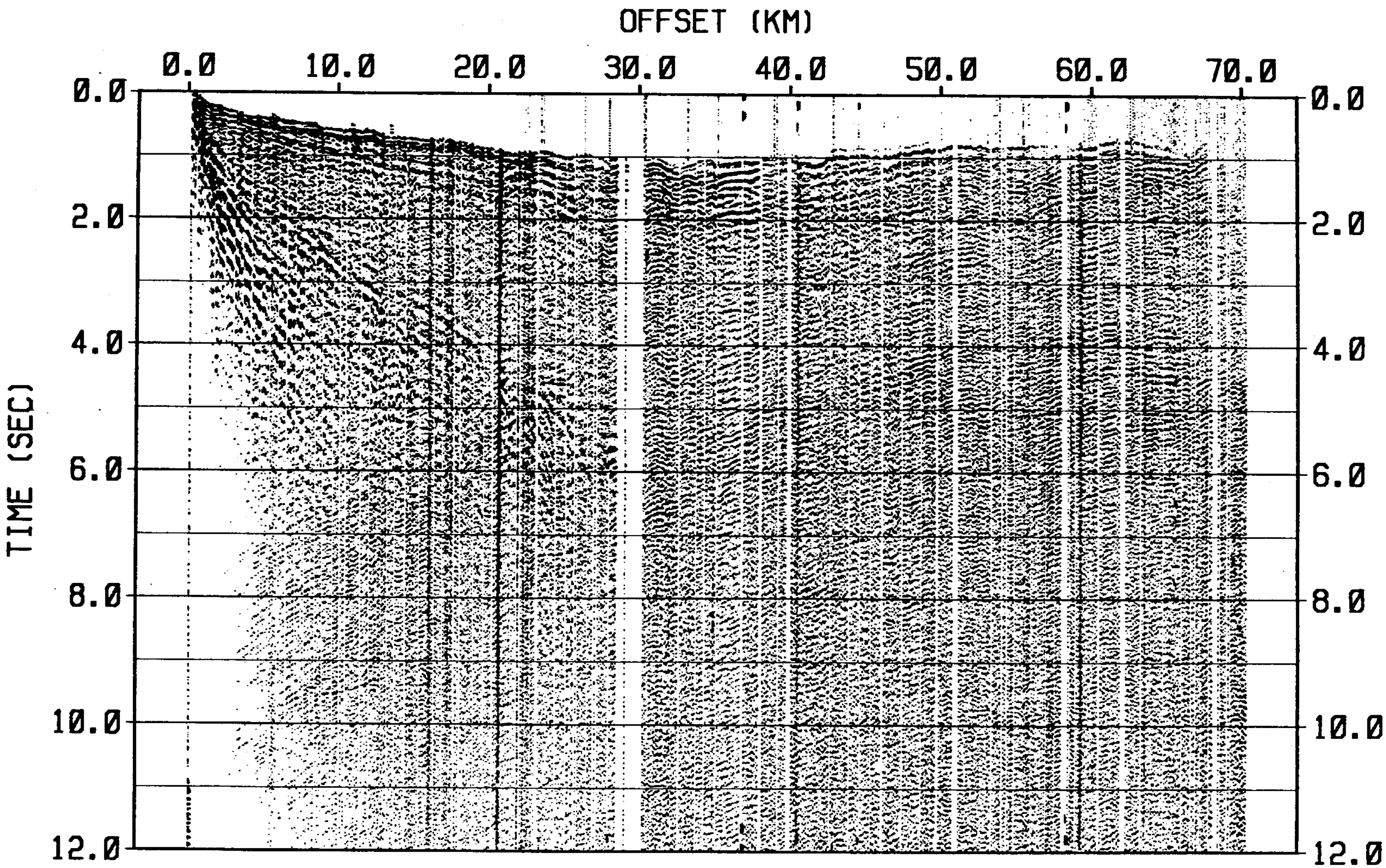

Figure 16 Profile 1

Shot 2 Shot Point 120 AGC = 12 sec

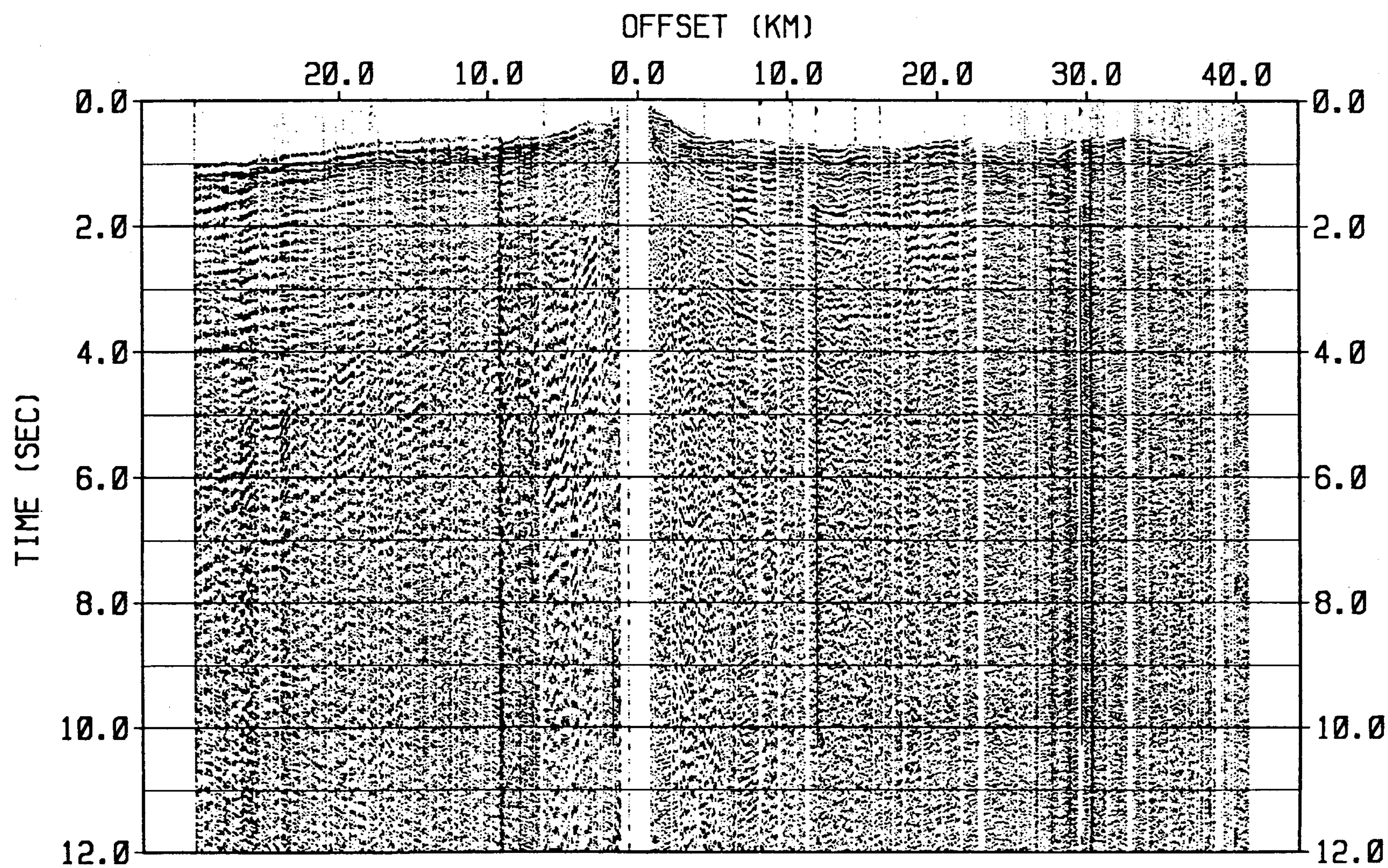

Figure 17 Profile 1

Shot 3 Shot Point 122 AGC = 2 sec

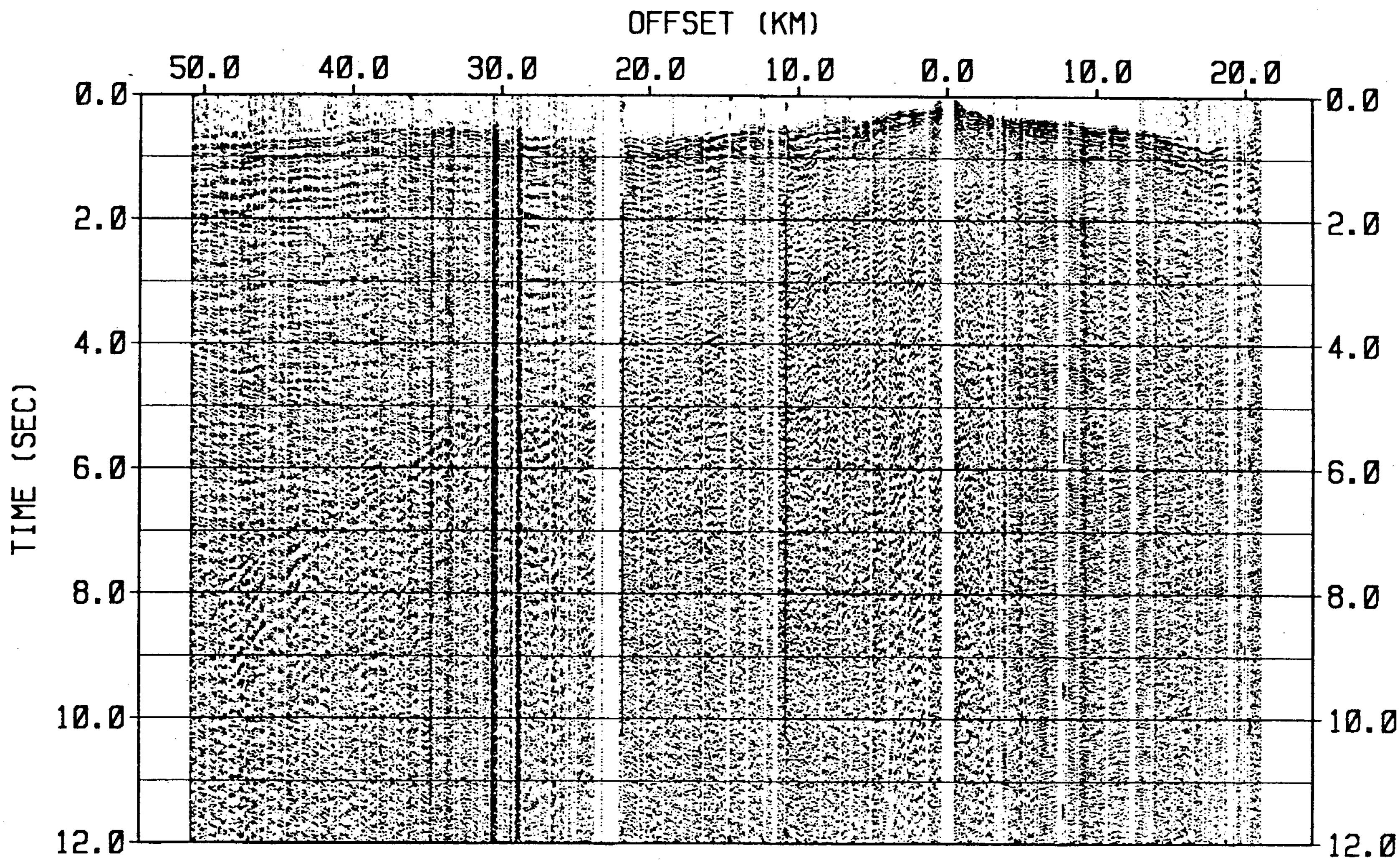

Figure 18 Profile 1

Shot 4 Shot Point 124 AGC = 2 sec

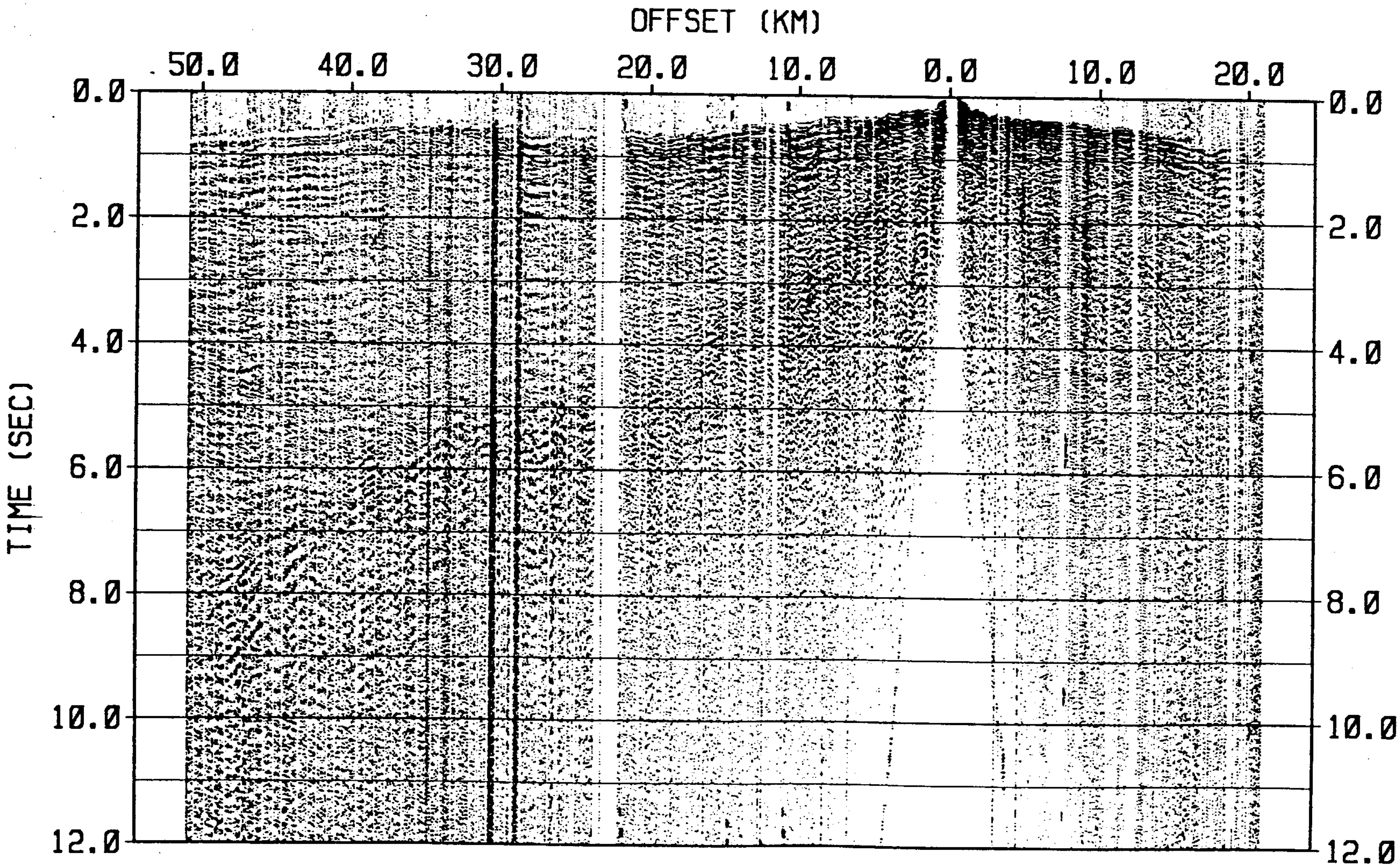

Figure 19 Profile 1

Shot 4 Shot Point 124 AGC = 12 sec

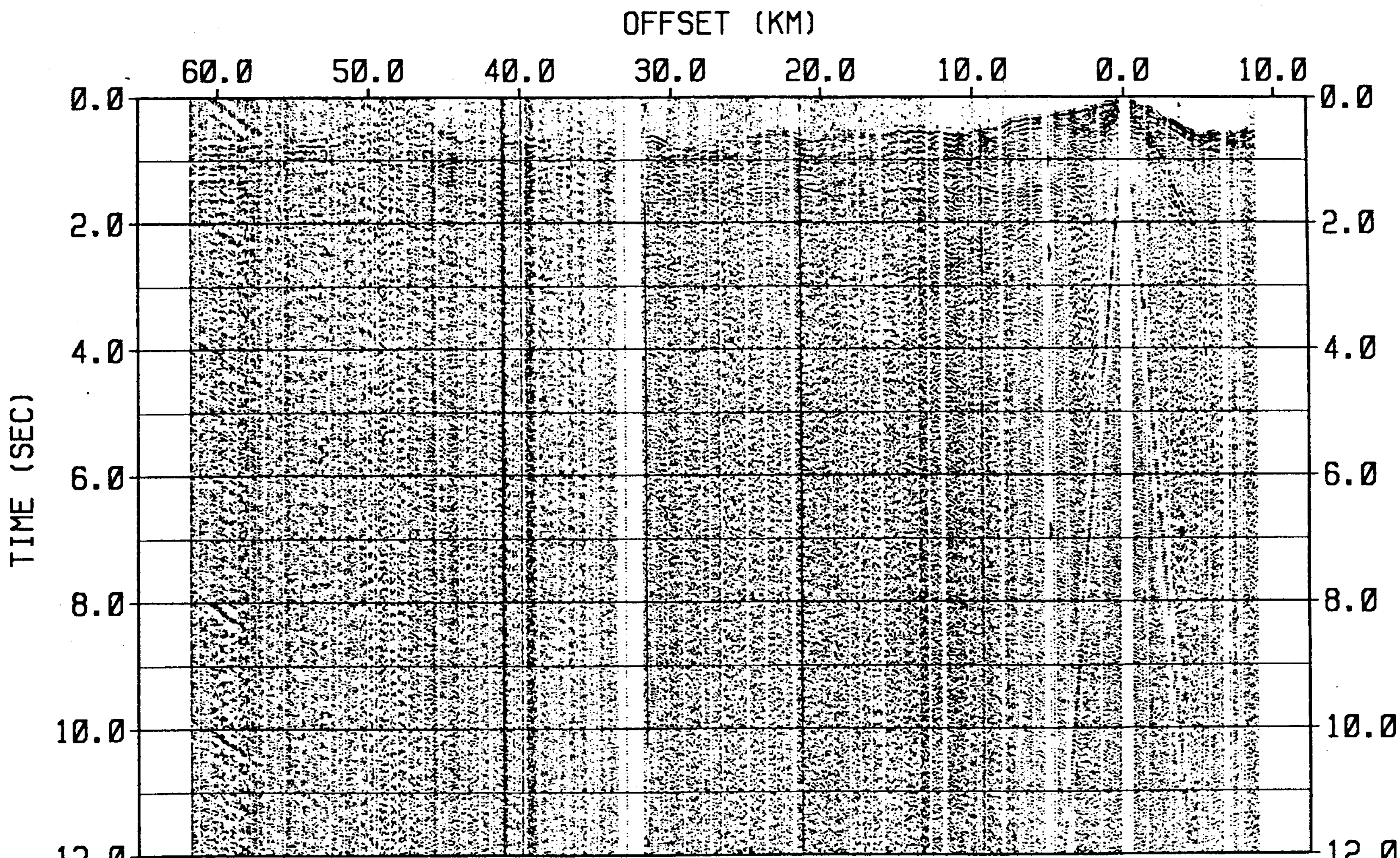

Figure 20 Profile 1

Shot 5 Shot Point 170 AGC = 2 sec

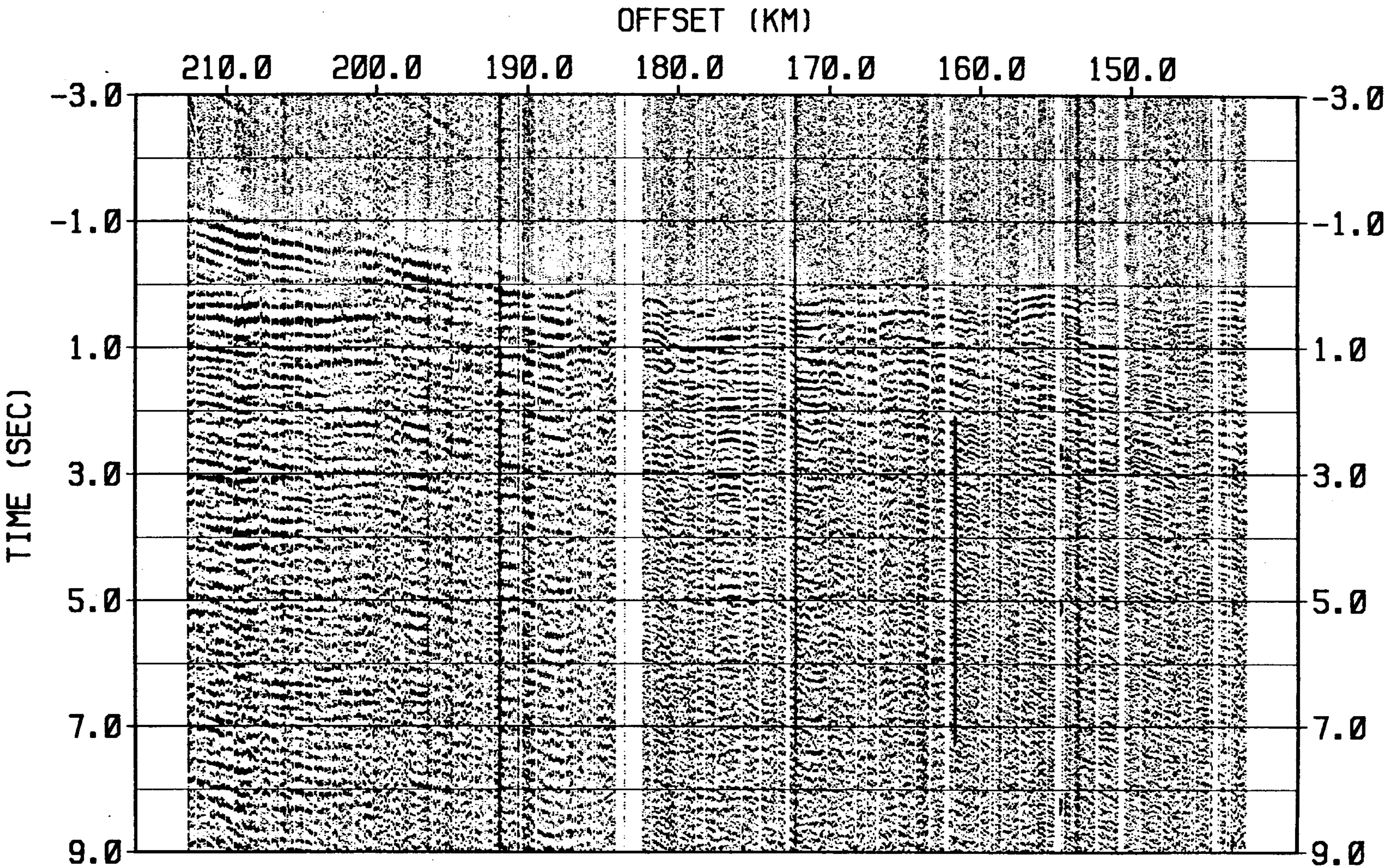

Figure 21 Profile 1

Shot 6 Shot Point 140 AGC = 2 sec

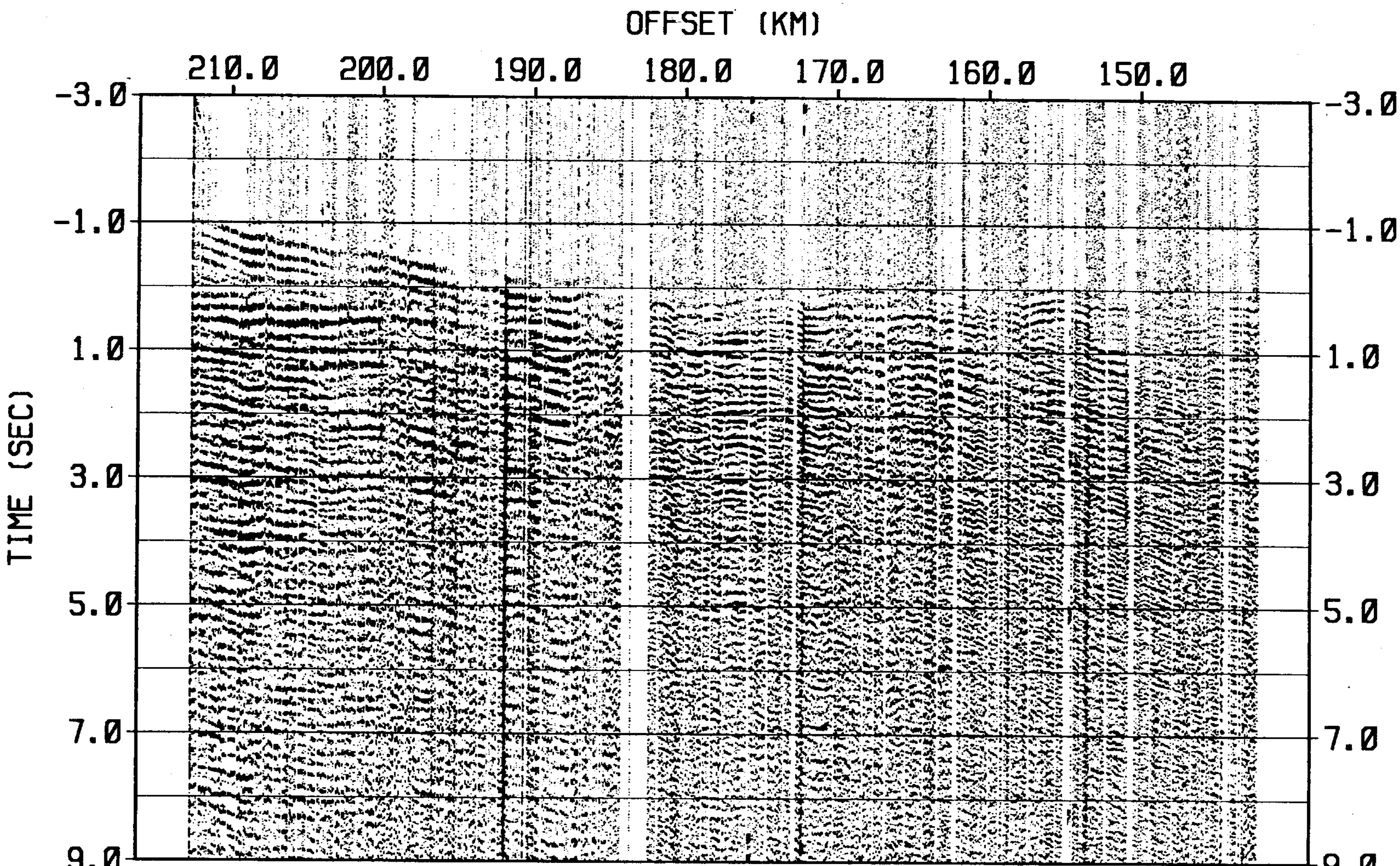

Figure 22 Profile 1

Shot 6 Shot Point 140 AGC = 12 sec

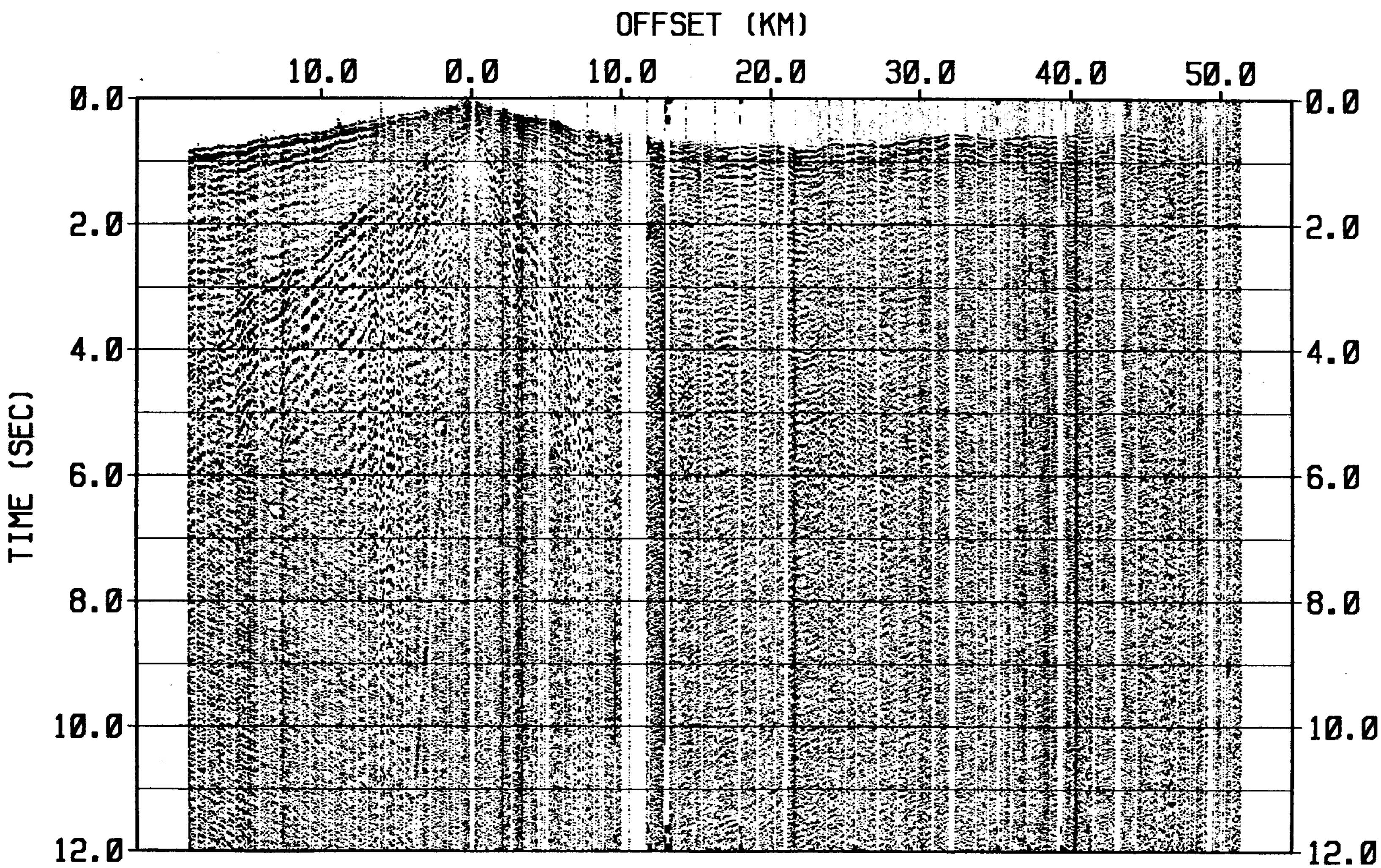

Figure 23 Profile 1

Shot 7 Shot Point 121 AGC = 2 sec

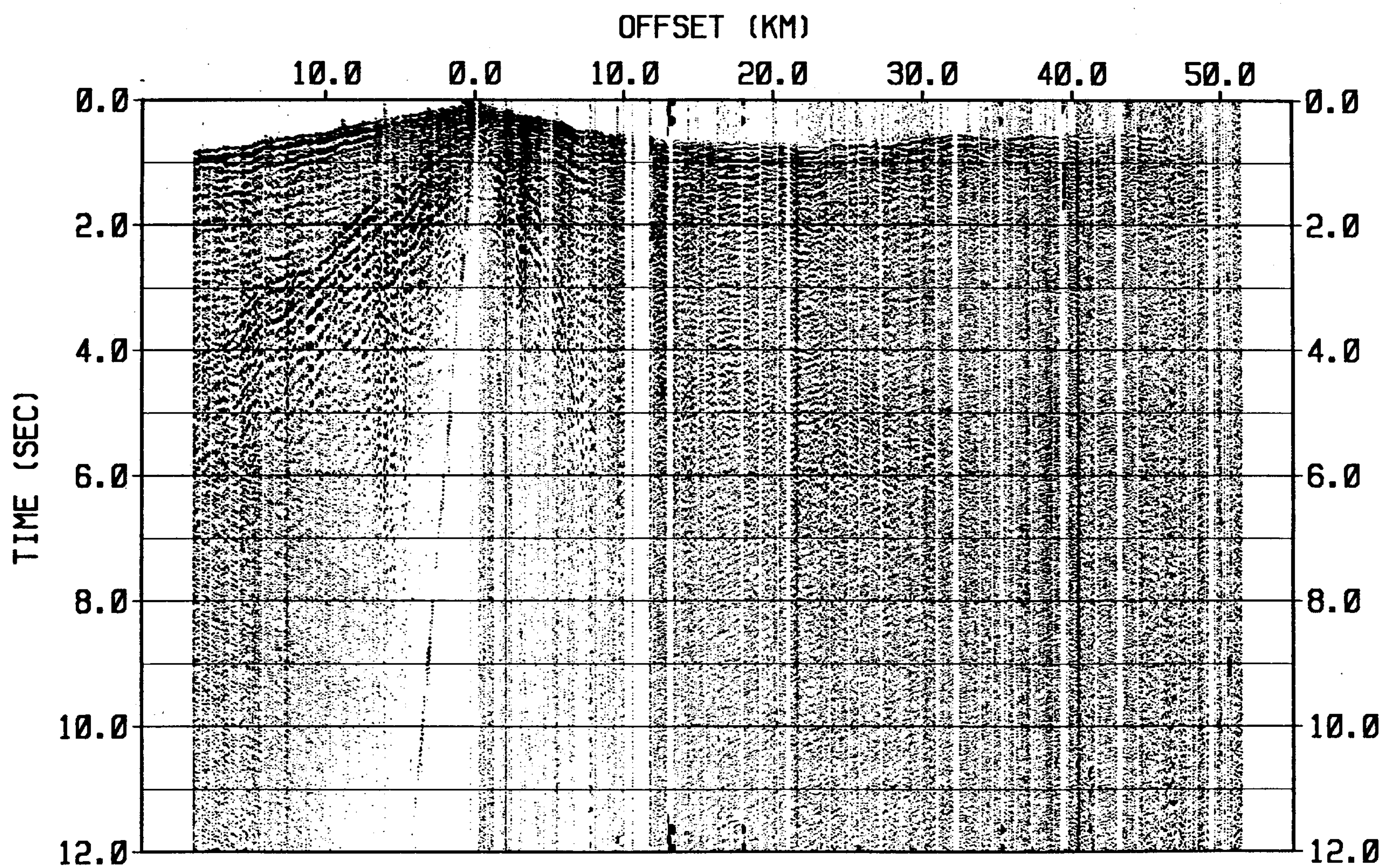

Figure 24 Profile 1

Shot 7 *Shot Point 121* *AGC = 12 sec*

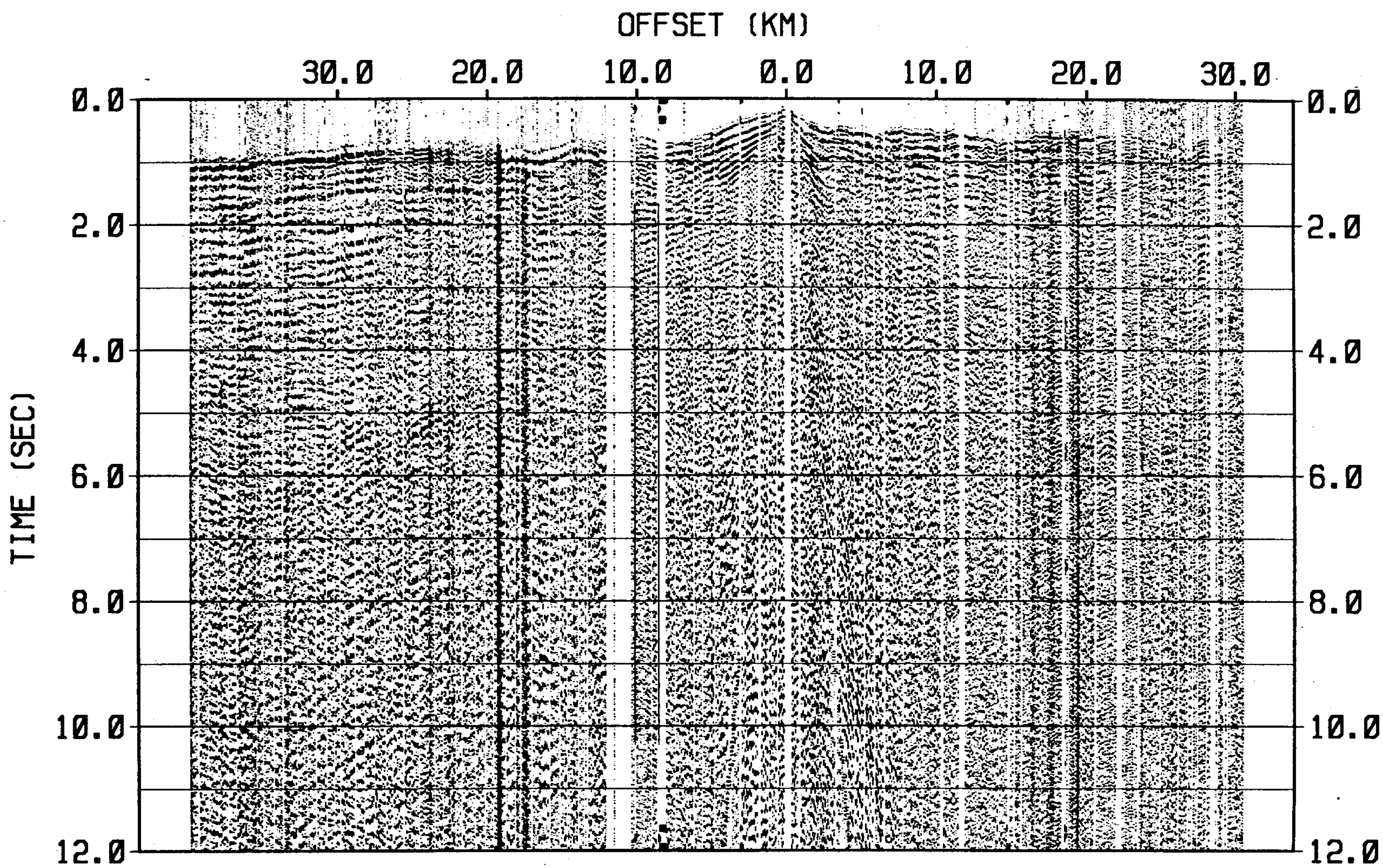

Figure 25 Profile 1

Shot 8 Shot Point 123 AGC = 2 sec

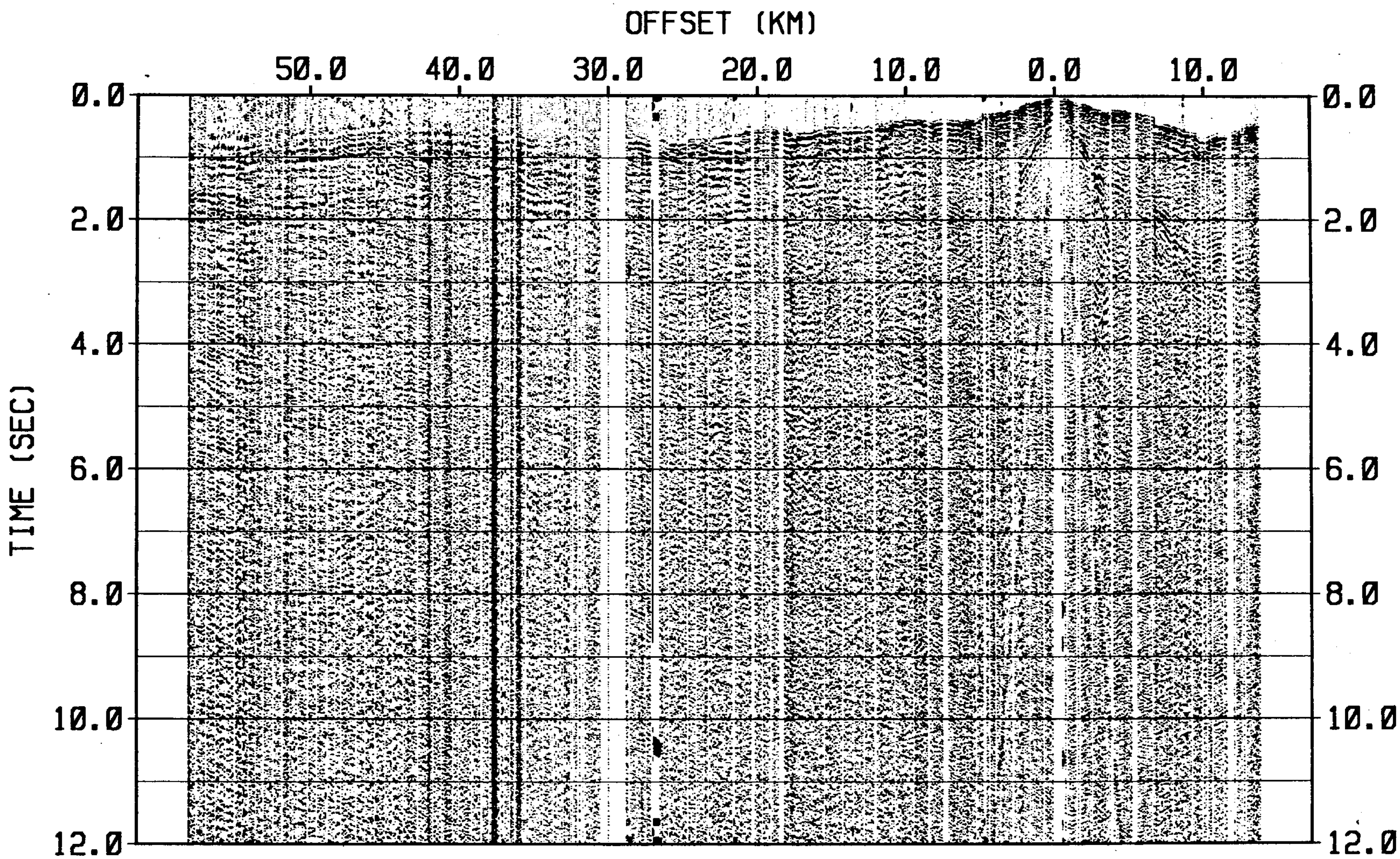

Figure 26 Profile 1

Shot 9 Shot Point 125 AGC = 2 sec

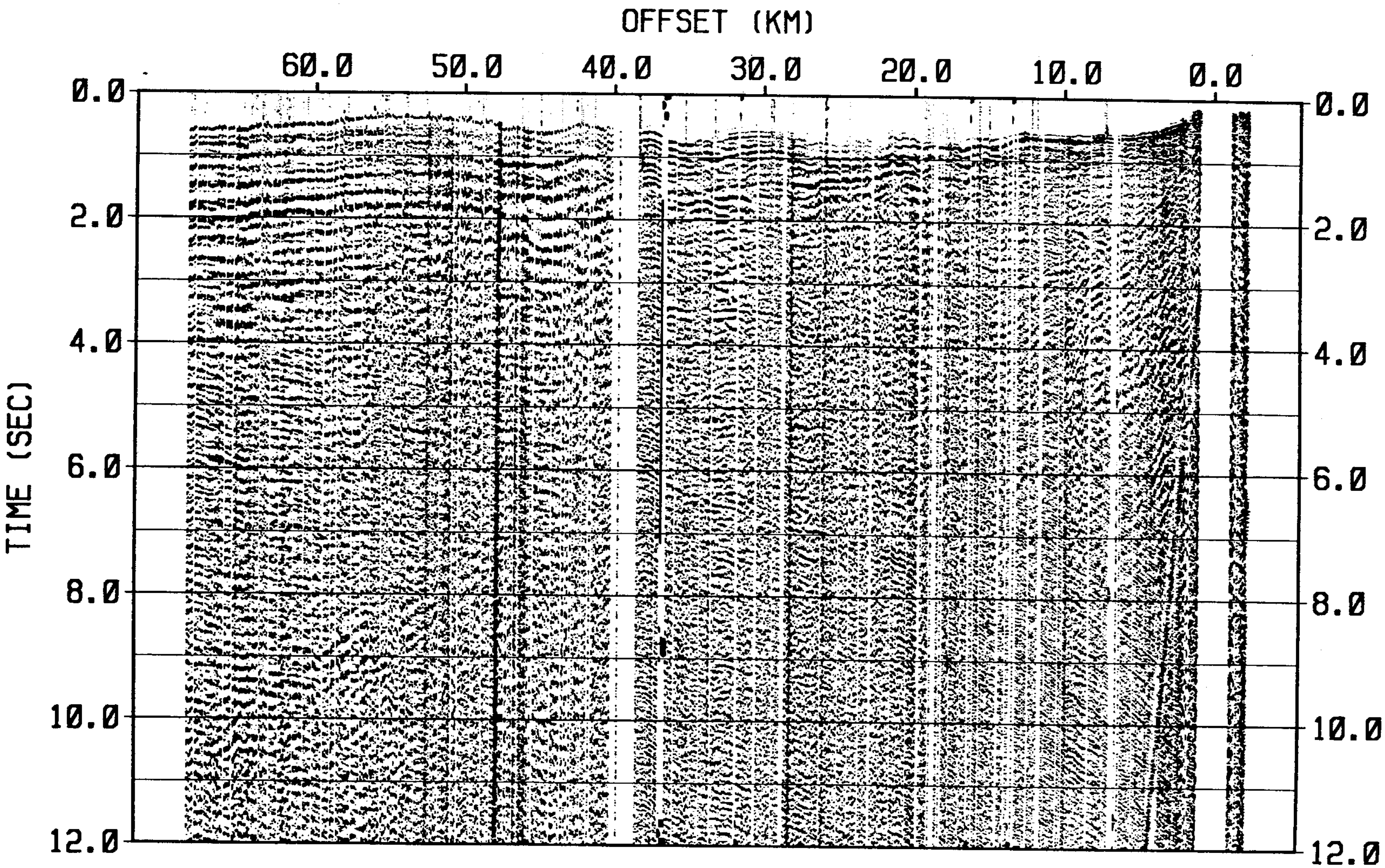

Figure 27 Profile 1

Shot 10 Shot Point 126 AGC = 2 sec

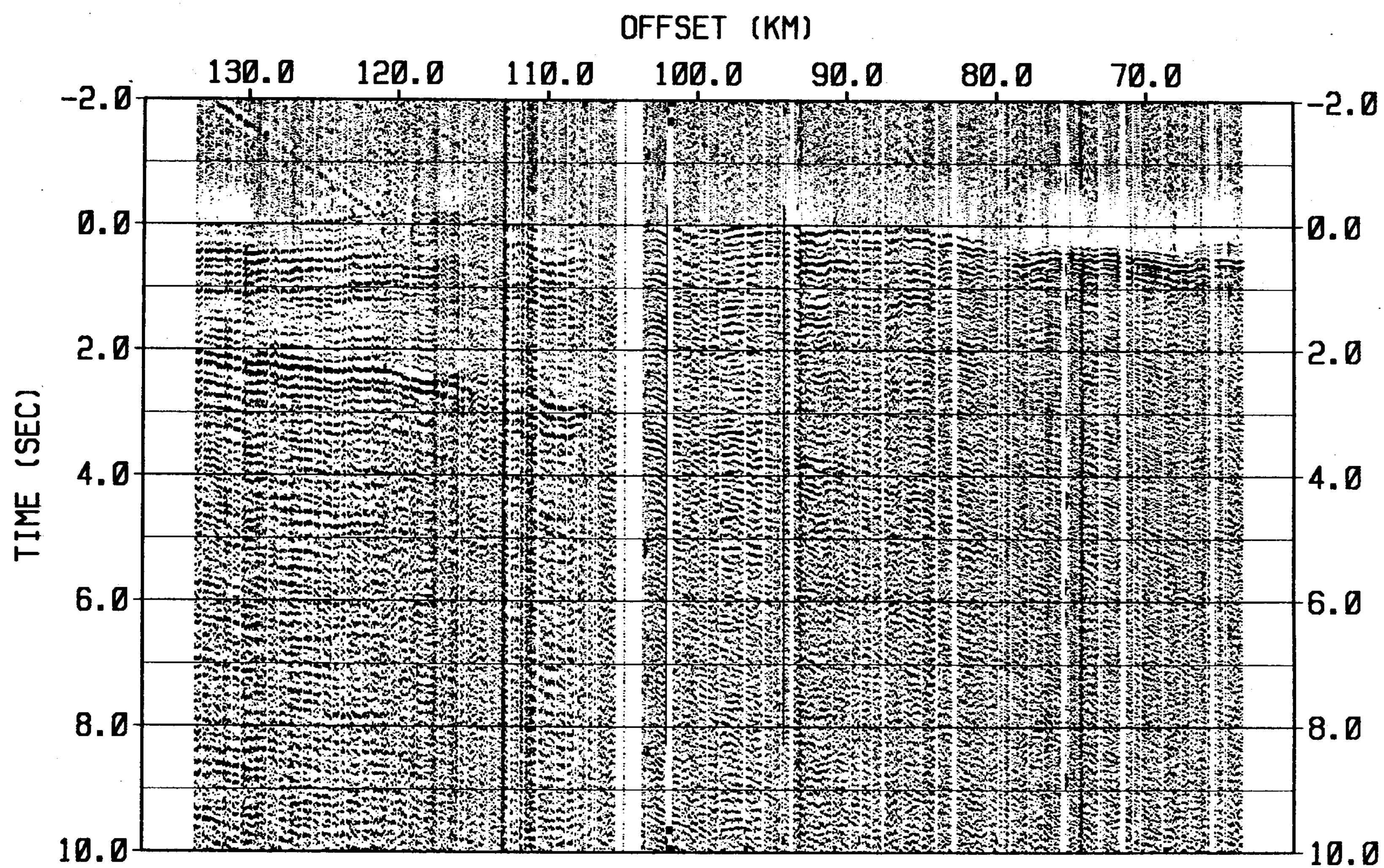

Figure 28 Profile 1

Shot 11 Shot Point 132 AGC = 2 sec

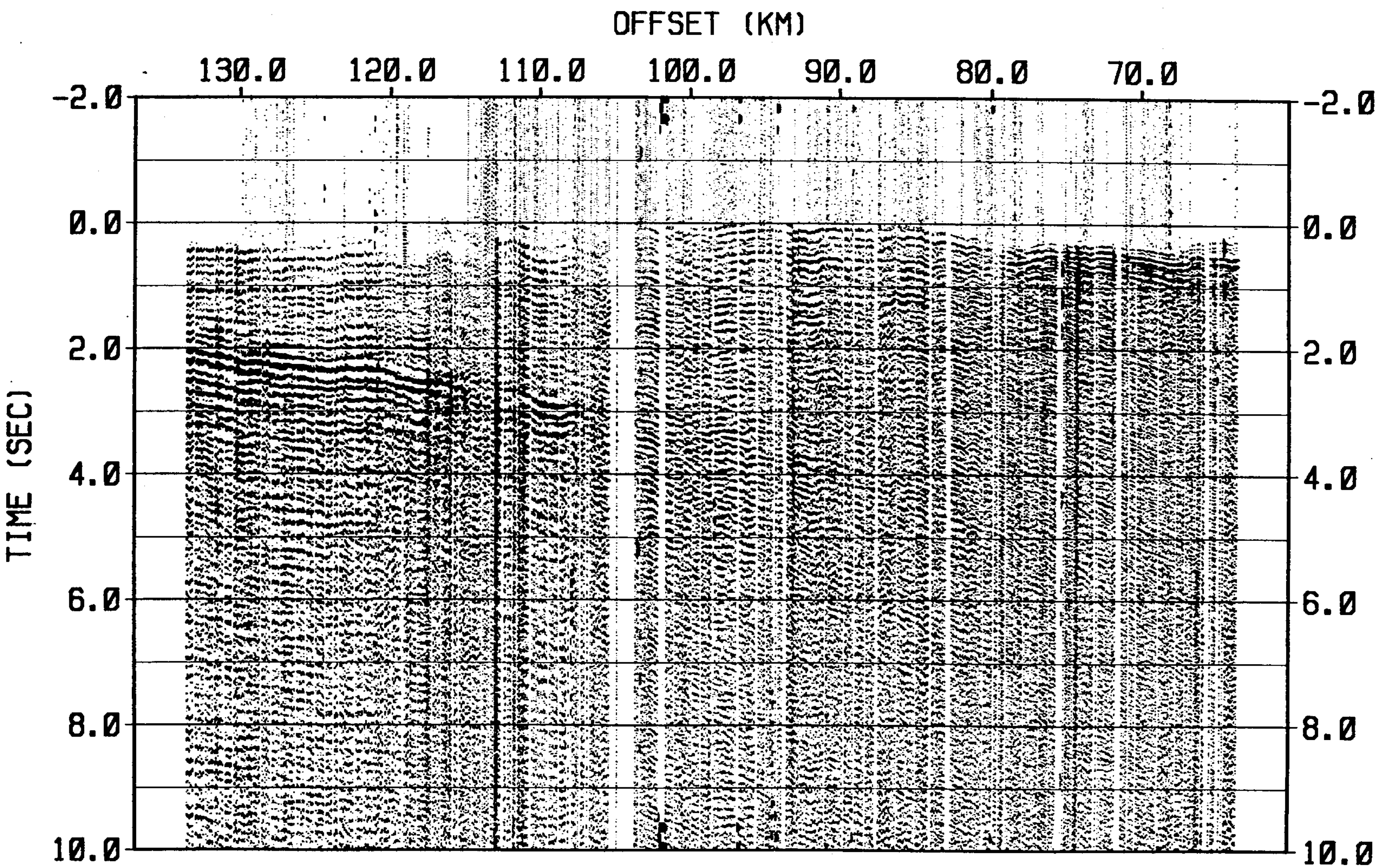

Figure 29 Profile 1

Shot 11 Shot Point 132 AGC = 12 sec

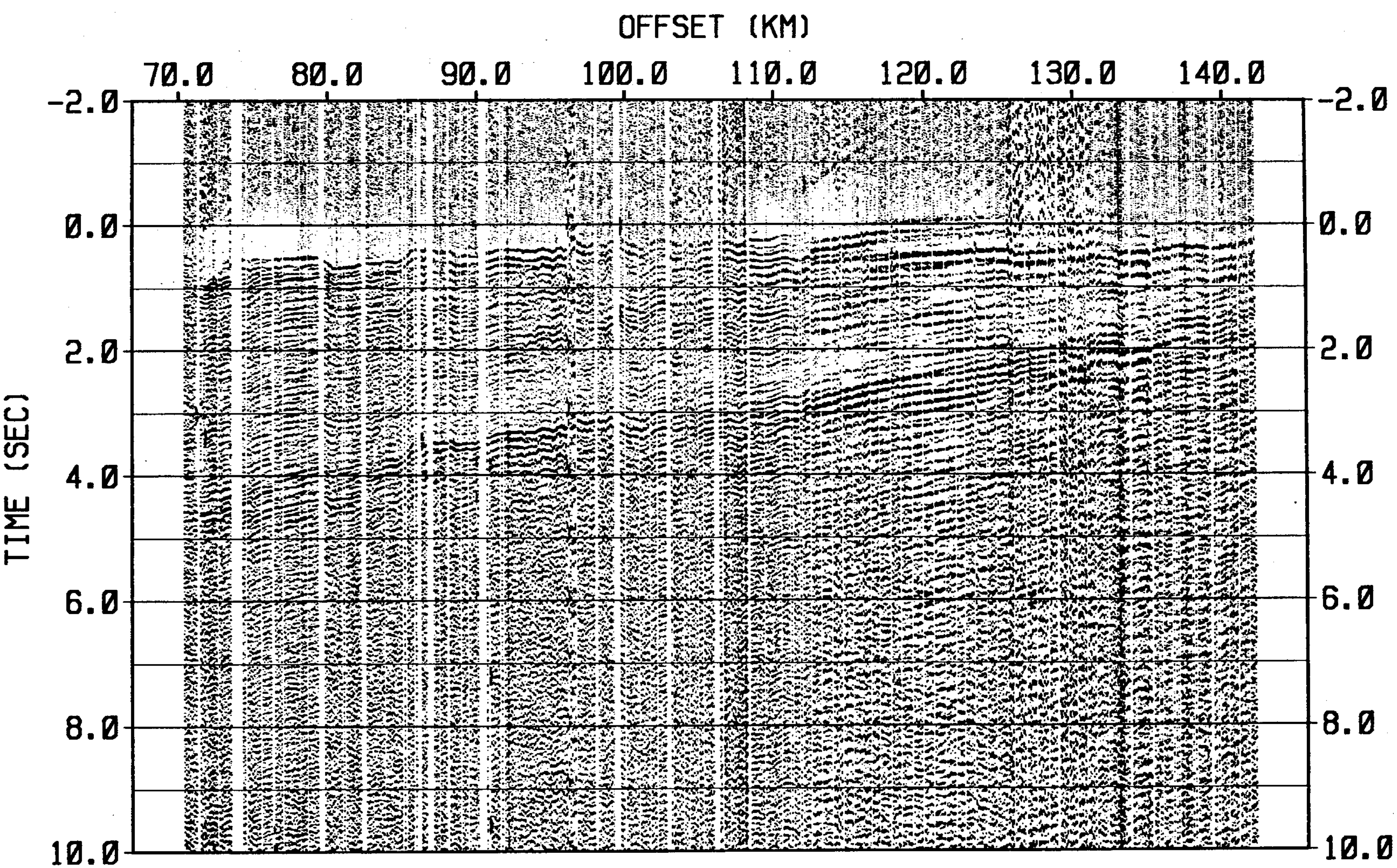

Figure 30 Profile 2

Shot 12 Shot Point 120 AGC = 2 sec

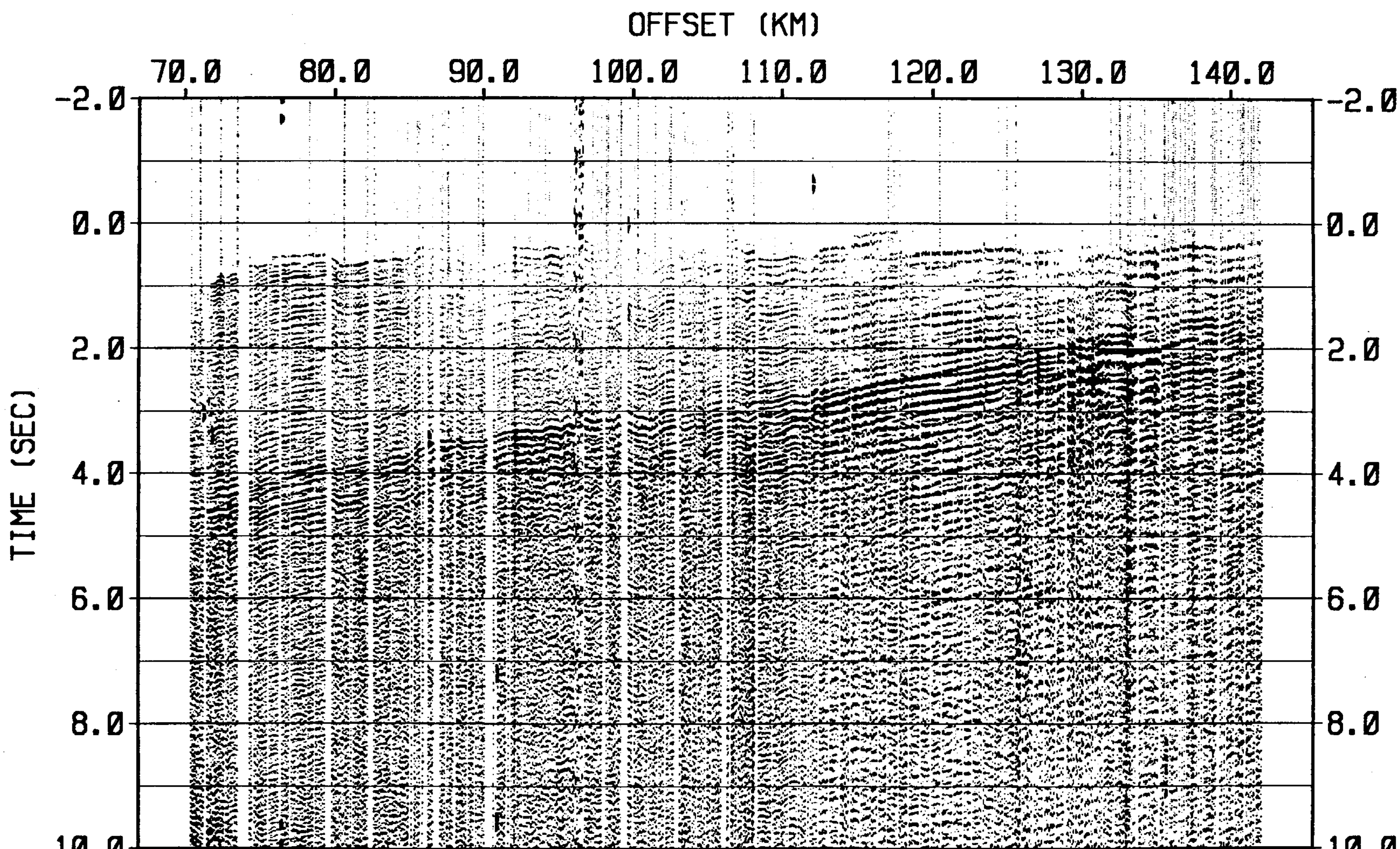

Figure 31 Profile 2

Shot 12 Shot Point 120 AGC = 12 sec

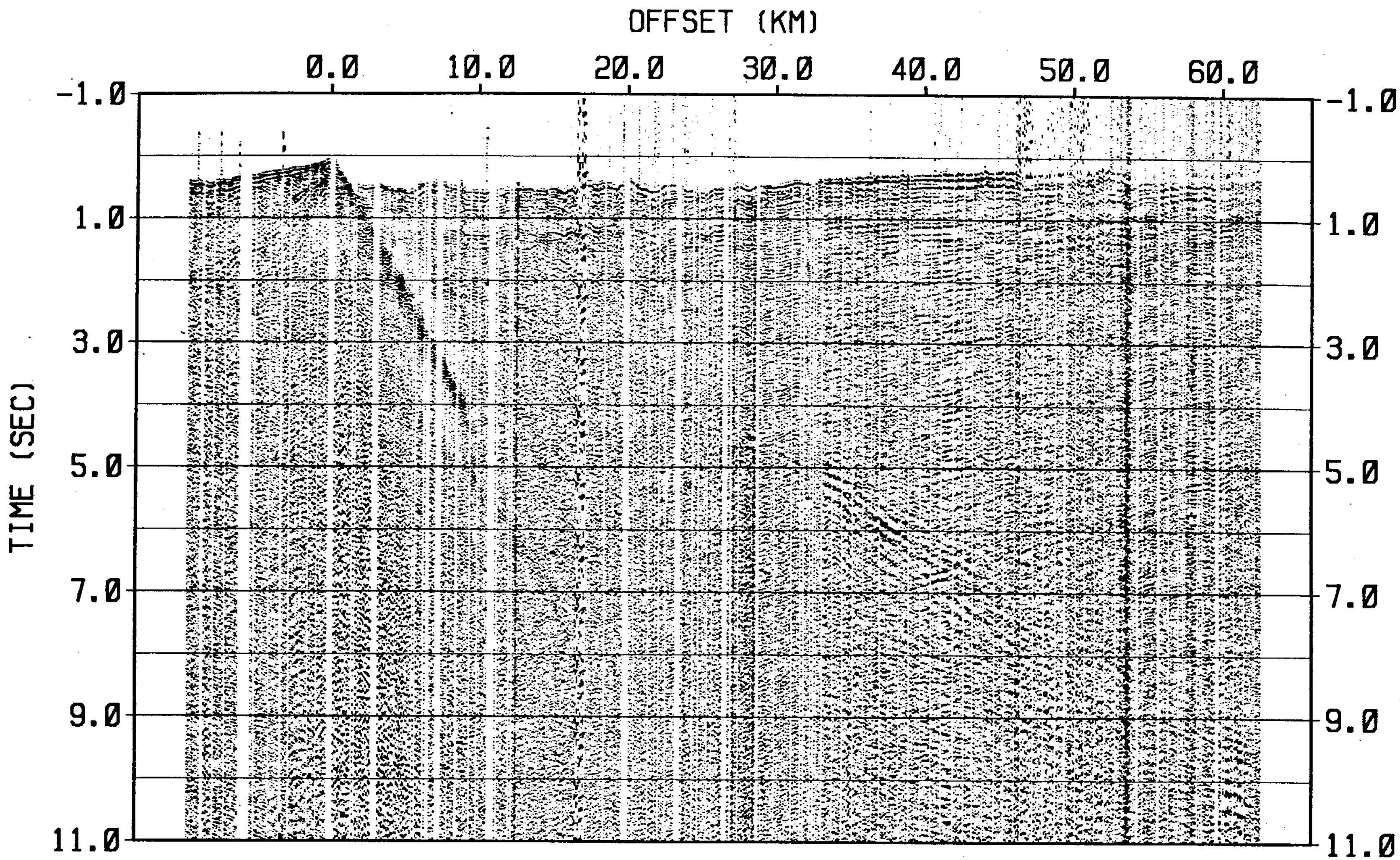

Figure 32 Profile 2

Shot 13 Shot Point 127 AGC = 2 sec

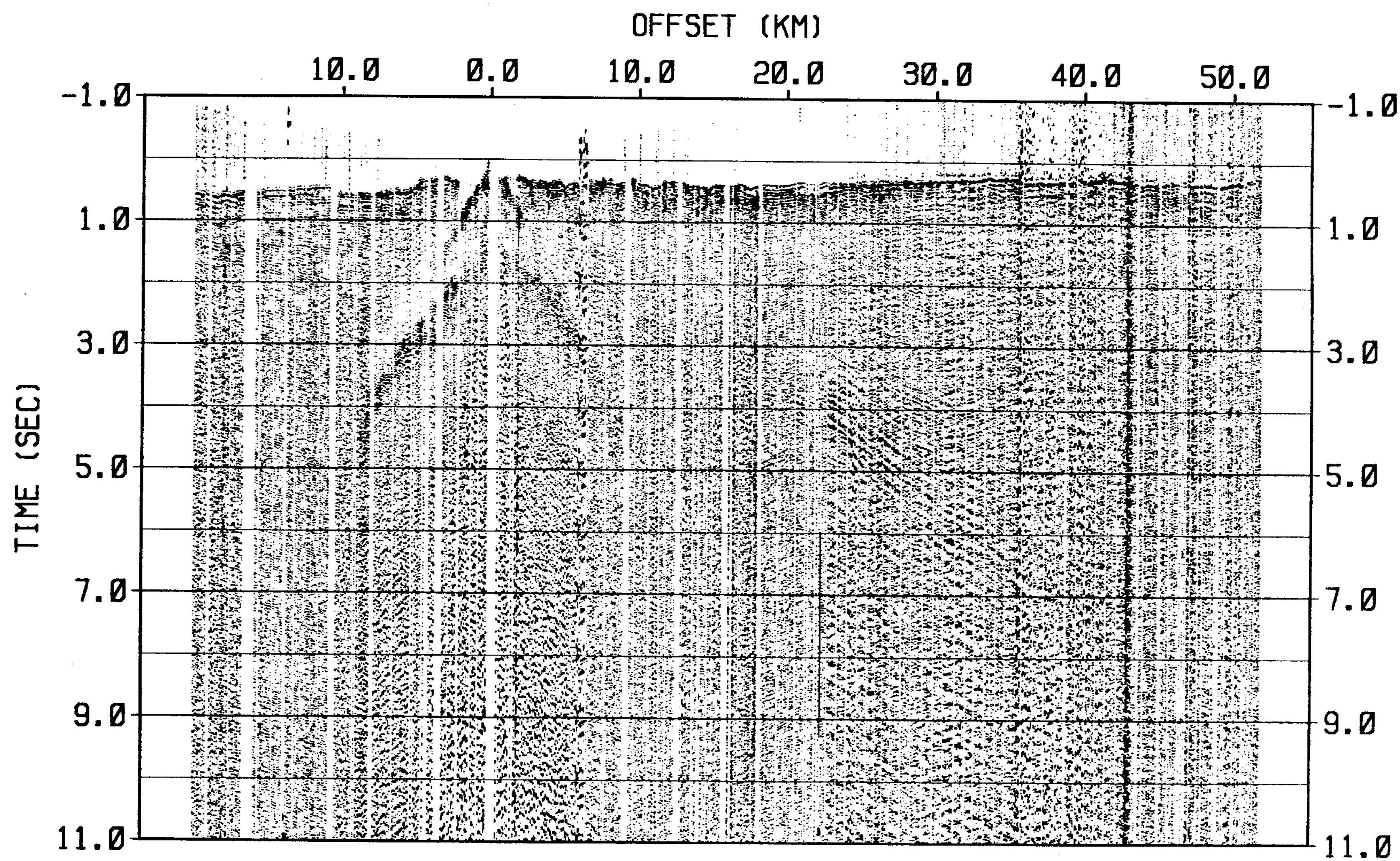

Figure 33 Profile 2

Shot 14 Shot Point 171 AGC = 2 sec

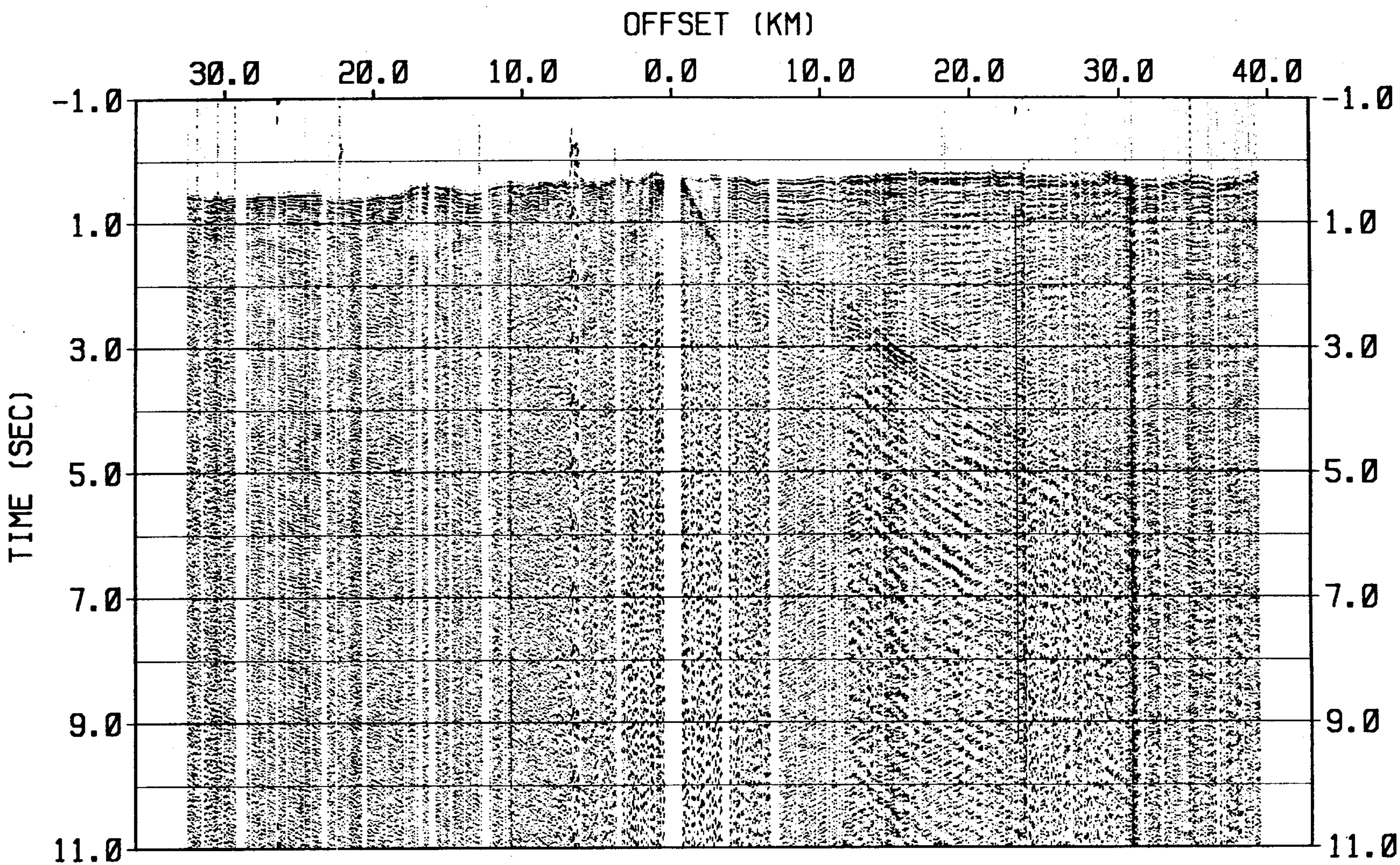

Figure 34 Profile 2

Shot 15 Shot Point 130 AGC = 2 sec

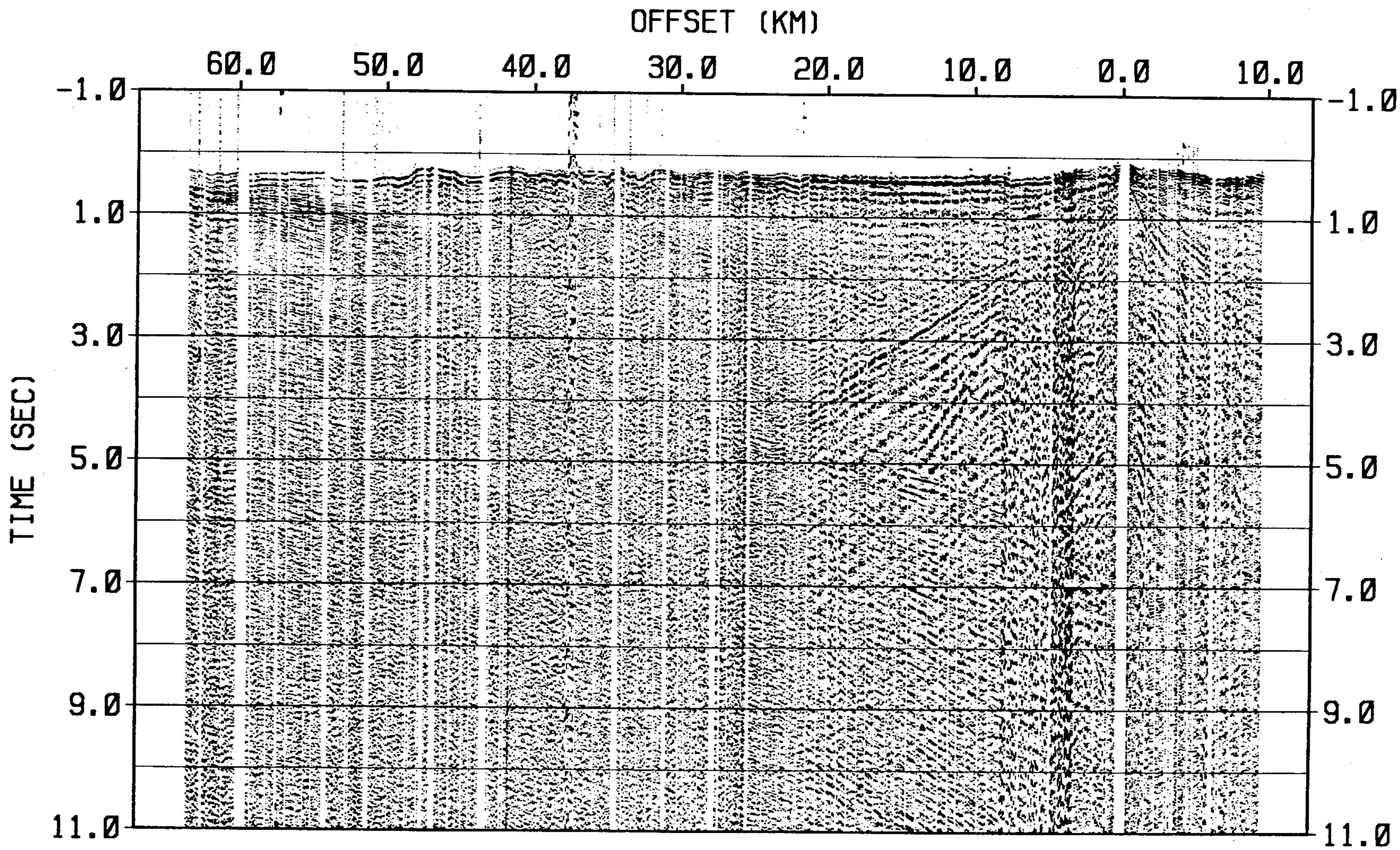

Figure 35 Profile 2

Shot 16 Shot Point 132 AGC = 2 sec

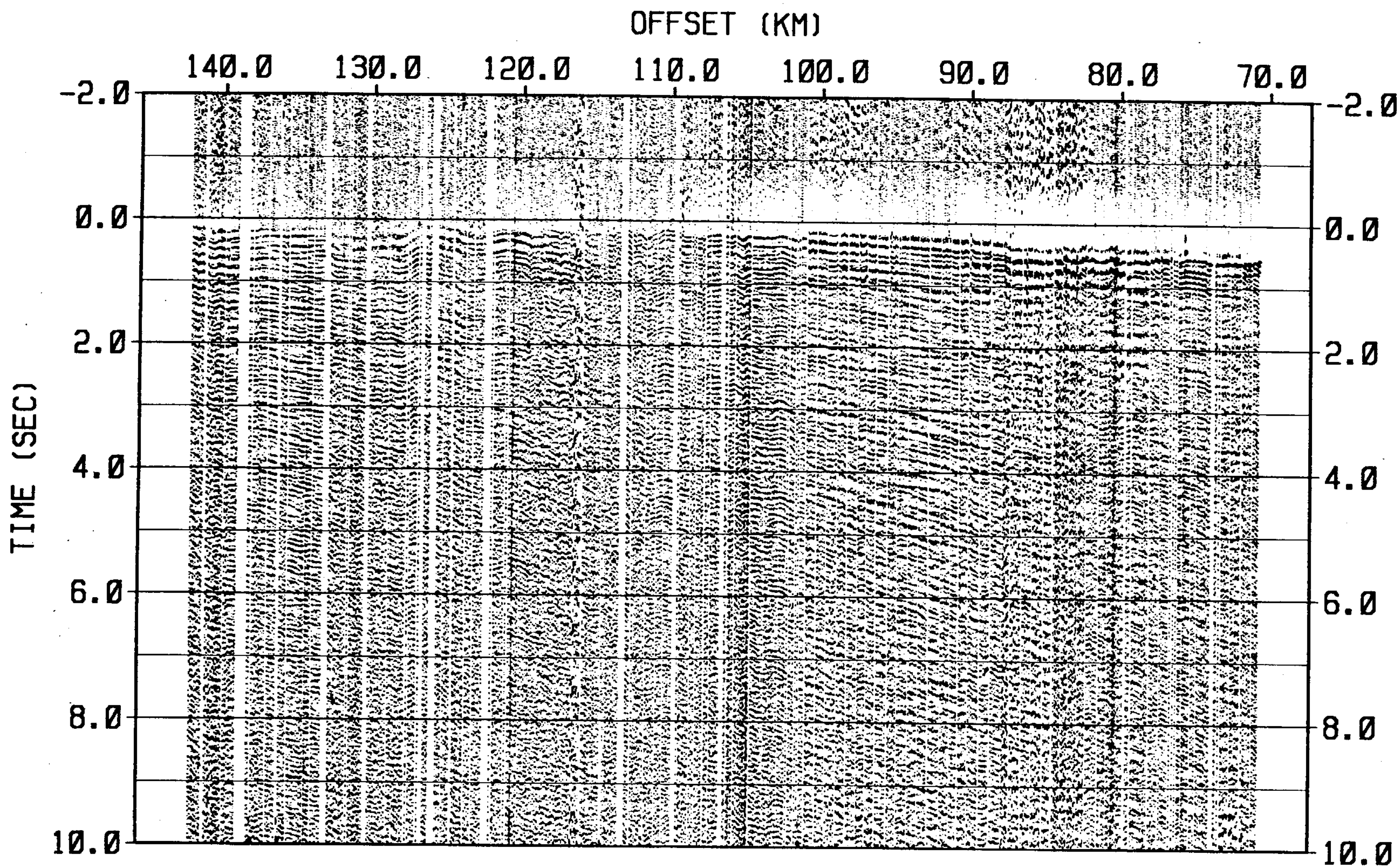

Figure 36 Profile 2

Shot 17 Shot Point 140 AGC = 2 sec

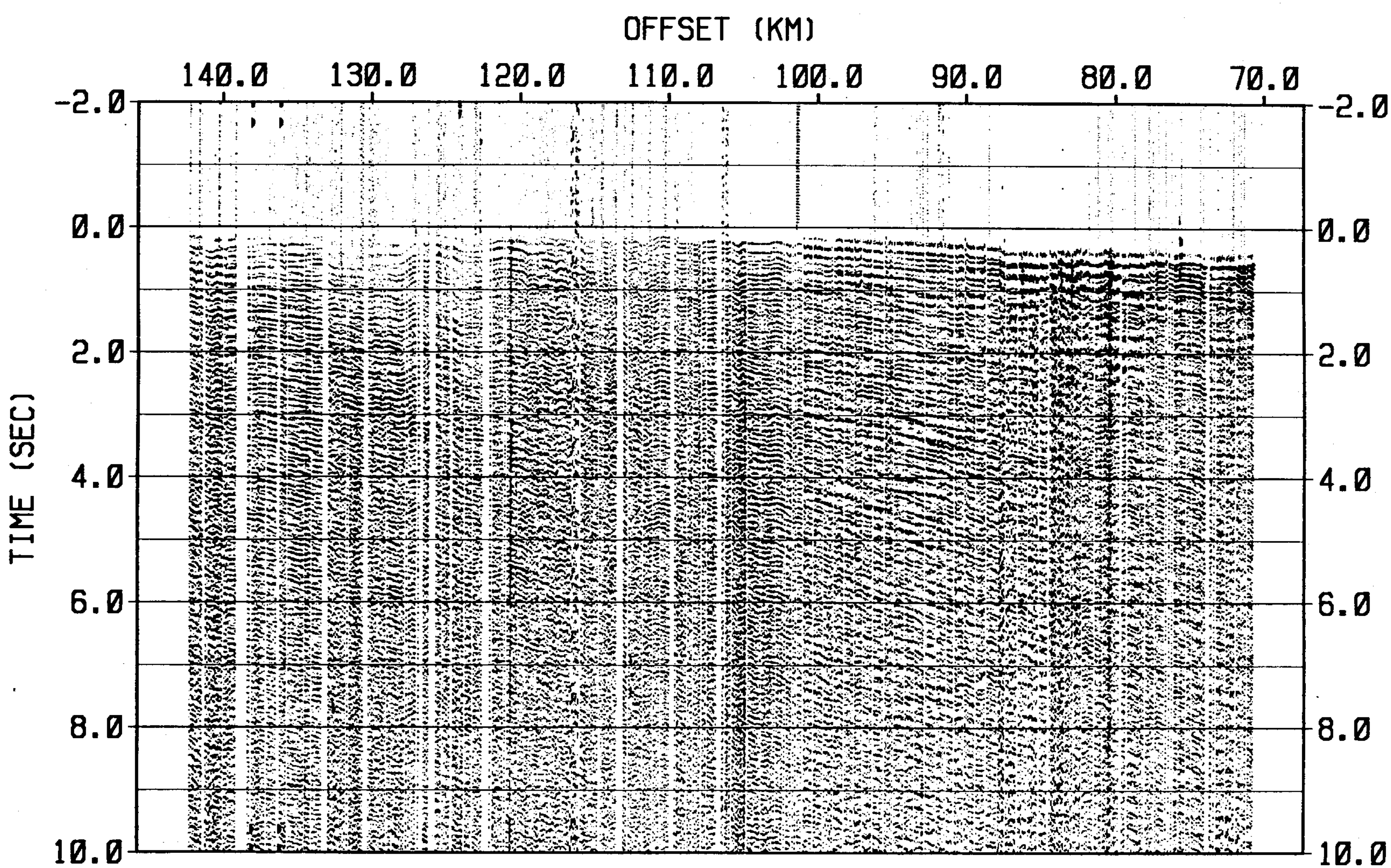

Figure 37 Profile 2

Shot 17 Shot Point 140 AGC = 12 sec

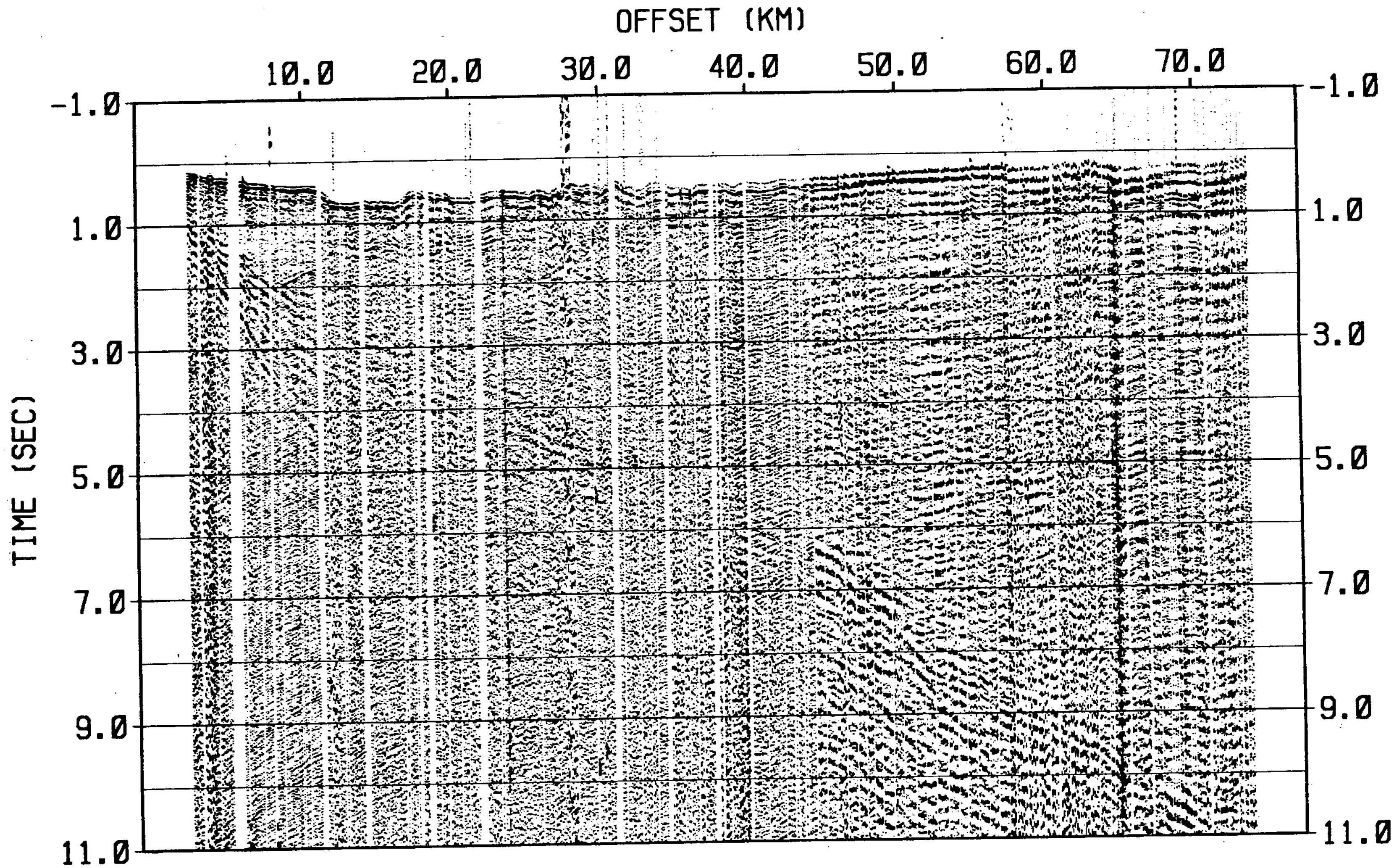

Figure 38 Profile 2

Shot 18 Shot Point 126 AGC = 2 sec

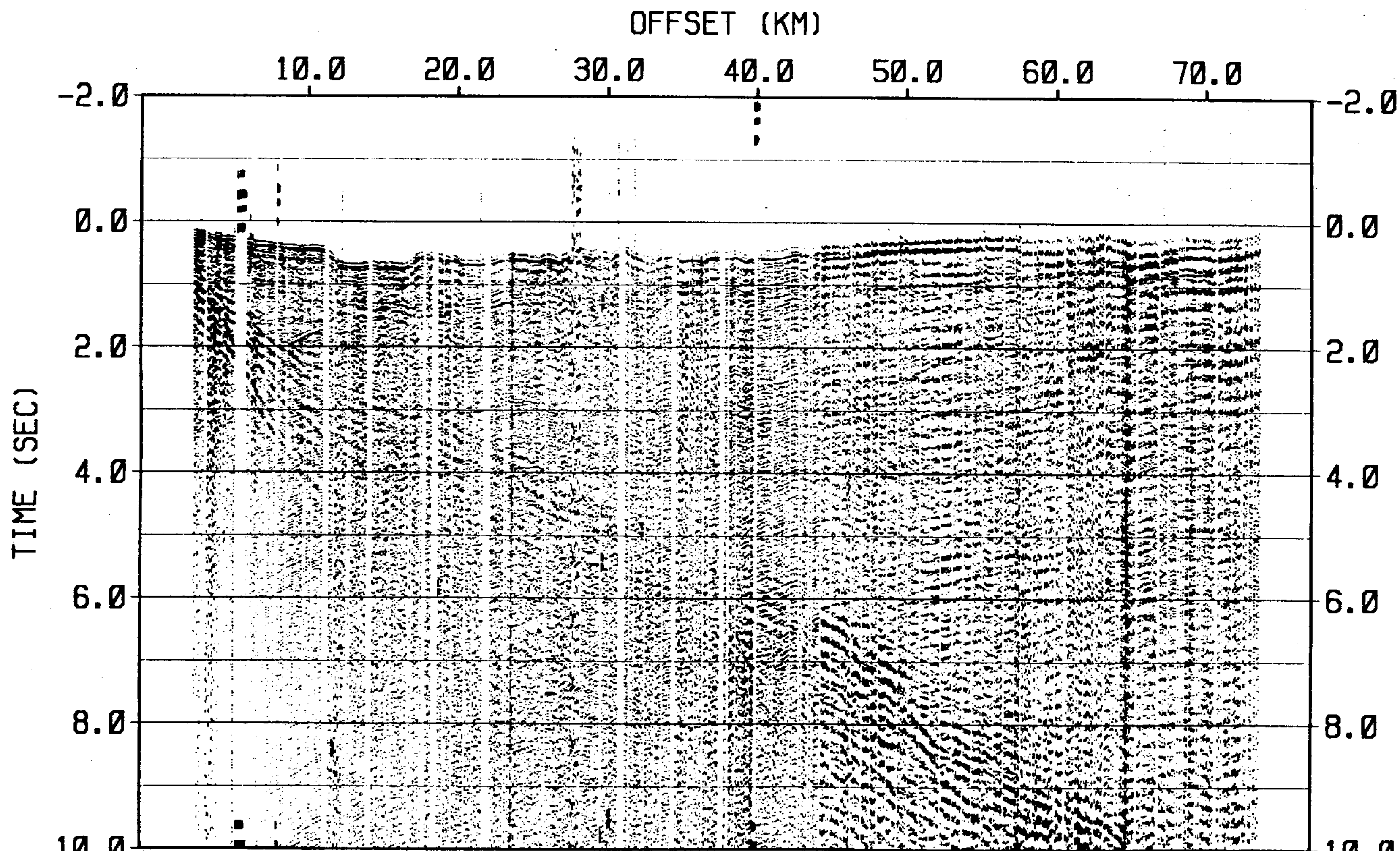

Figure 39 Profile 2

Shot 18 Shot Point 126 AGC = 12 sec

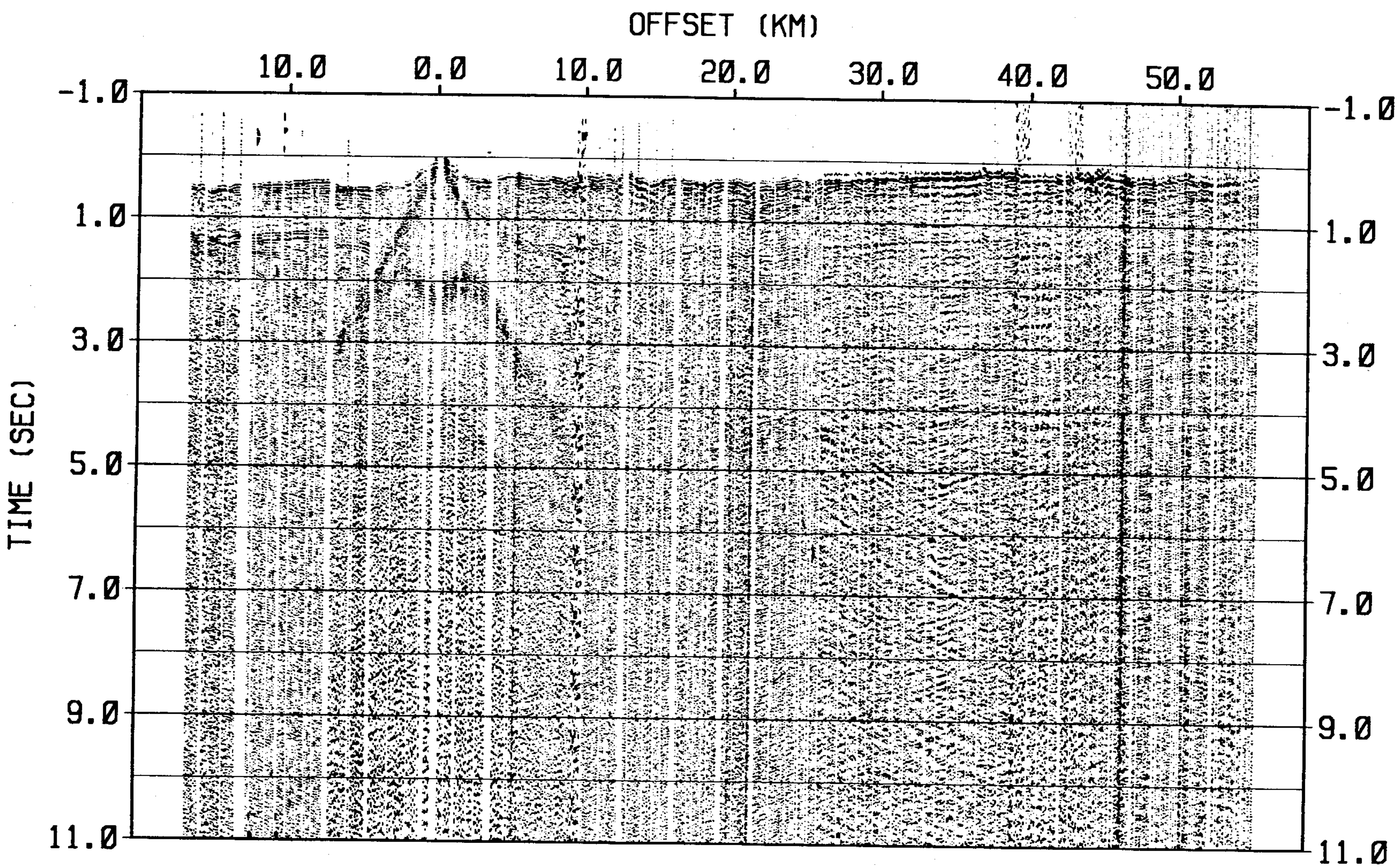

Figure 40 Profile 2

Shot 19 Shot Point 128 AGC = 2 sec

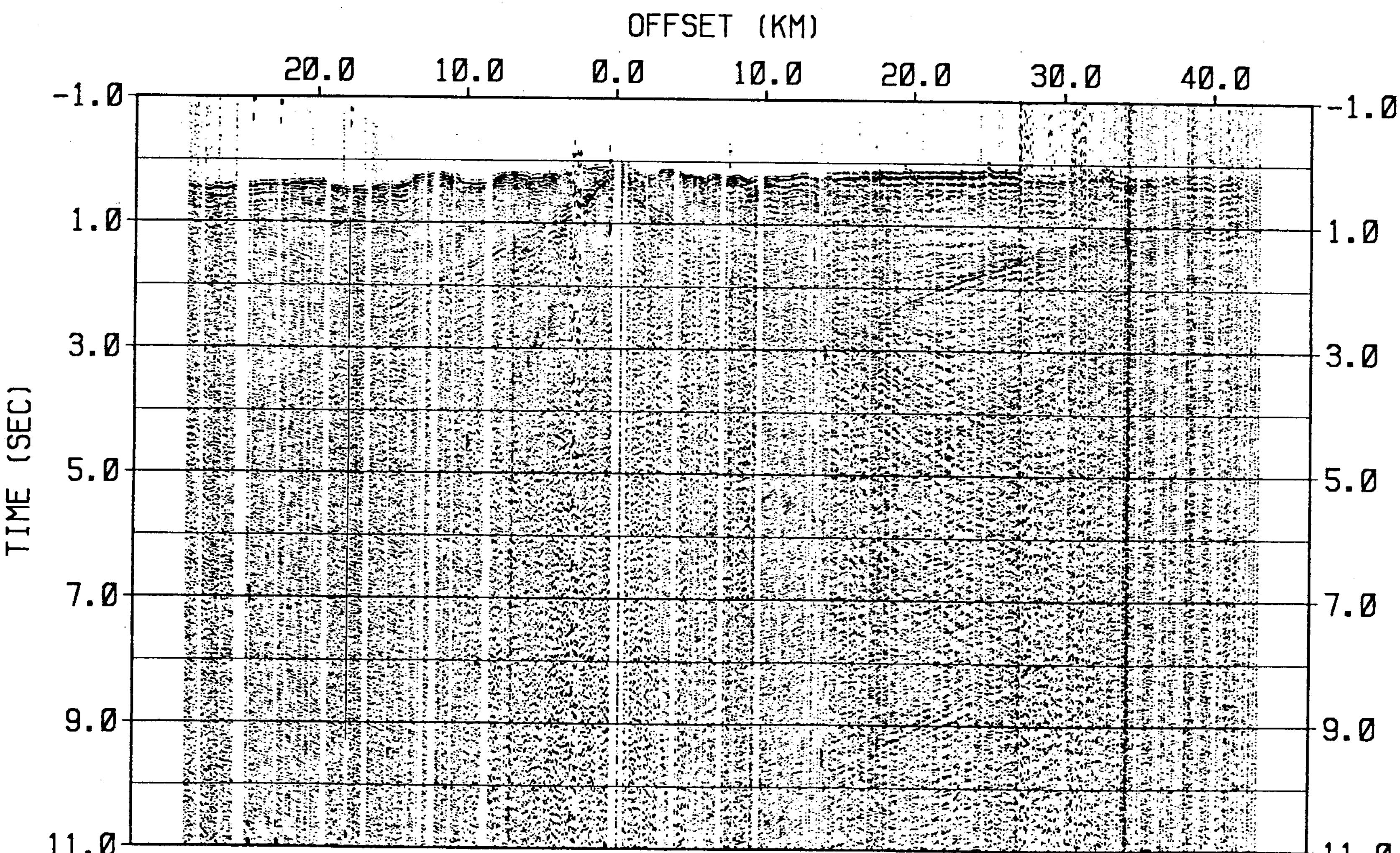

Figure 41 Profile 2

Shot 20 Shot Point 129 AGC = 2 sec

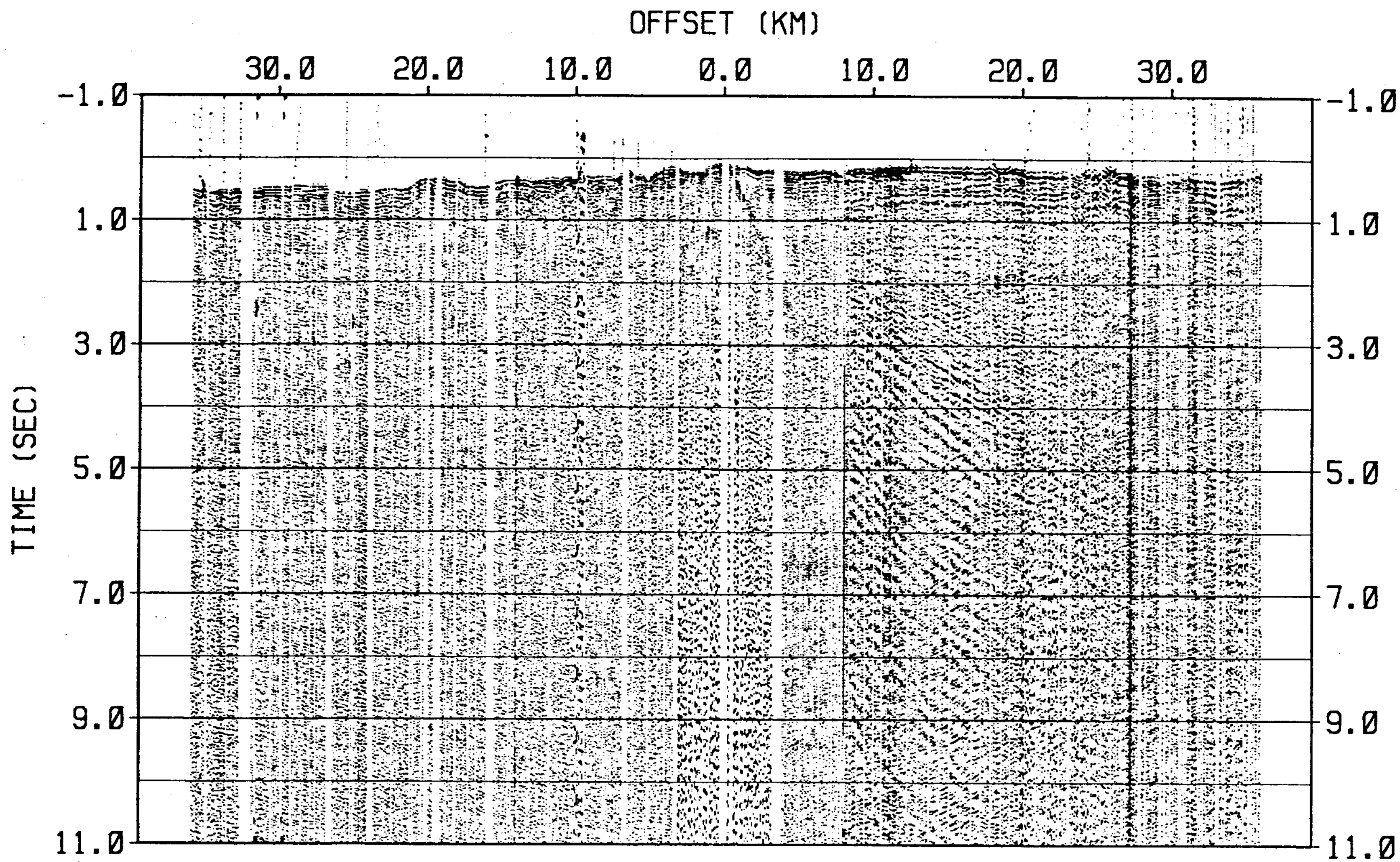

Figure 42 Profile 2

Shot 21 Shot Point 172 AGC = 2 sec

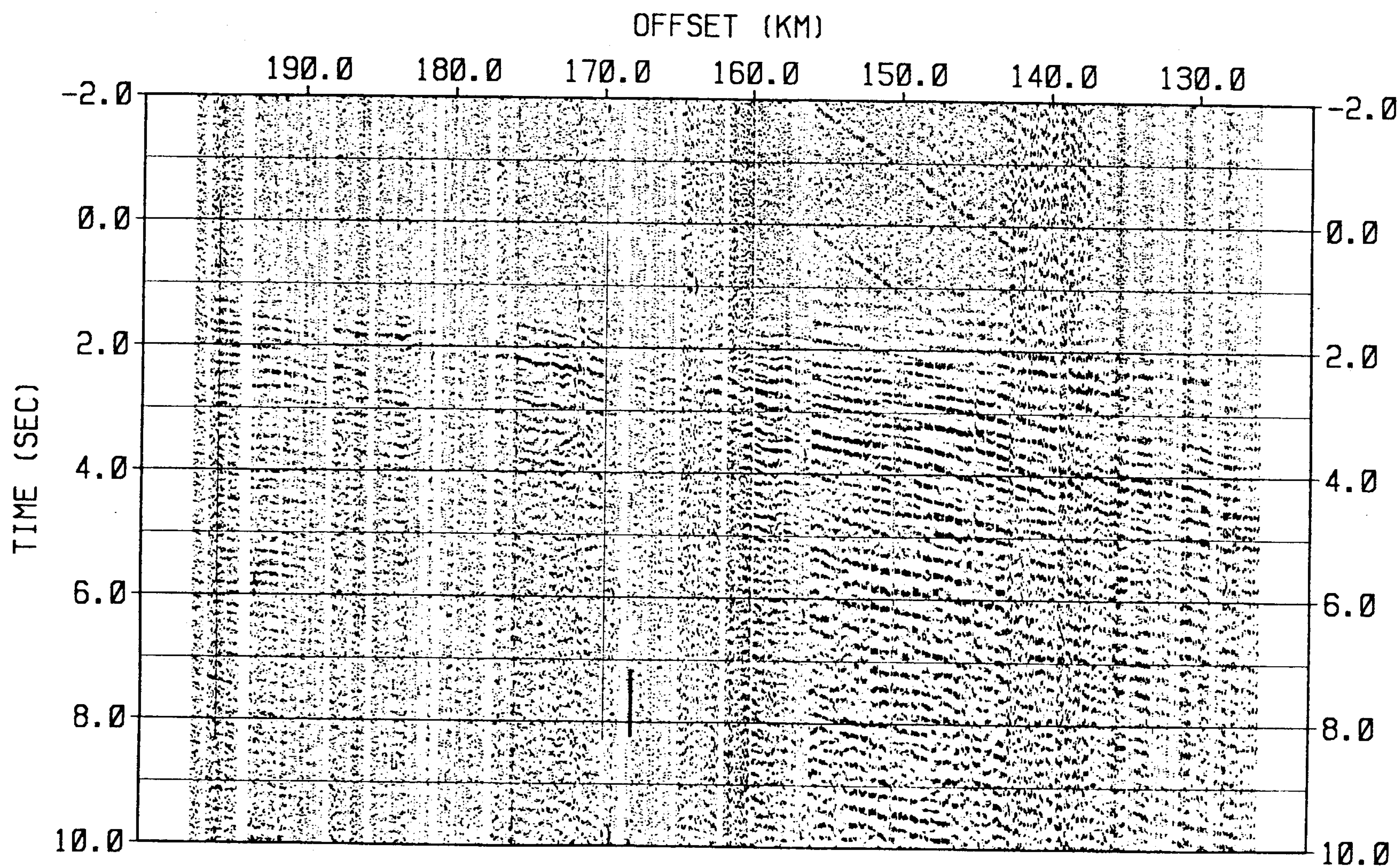

Figure 43 Profile 2

Shot 22 Shot Point 143 AGC = 2 sec

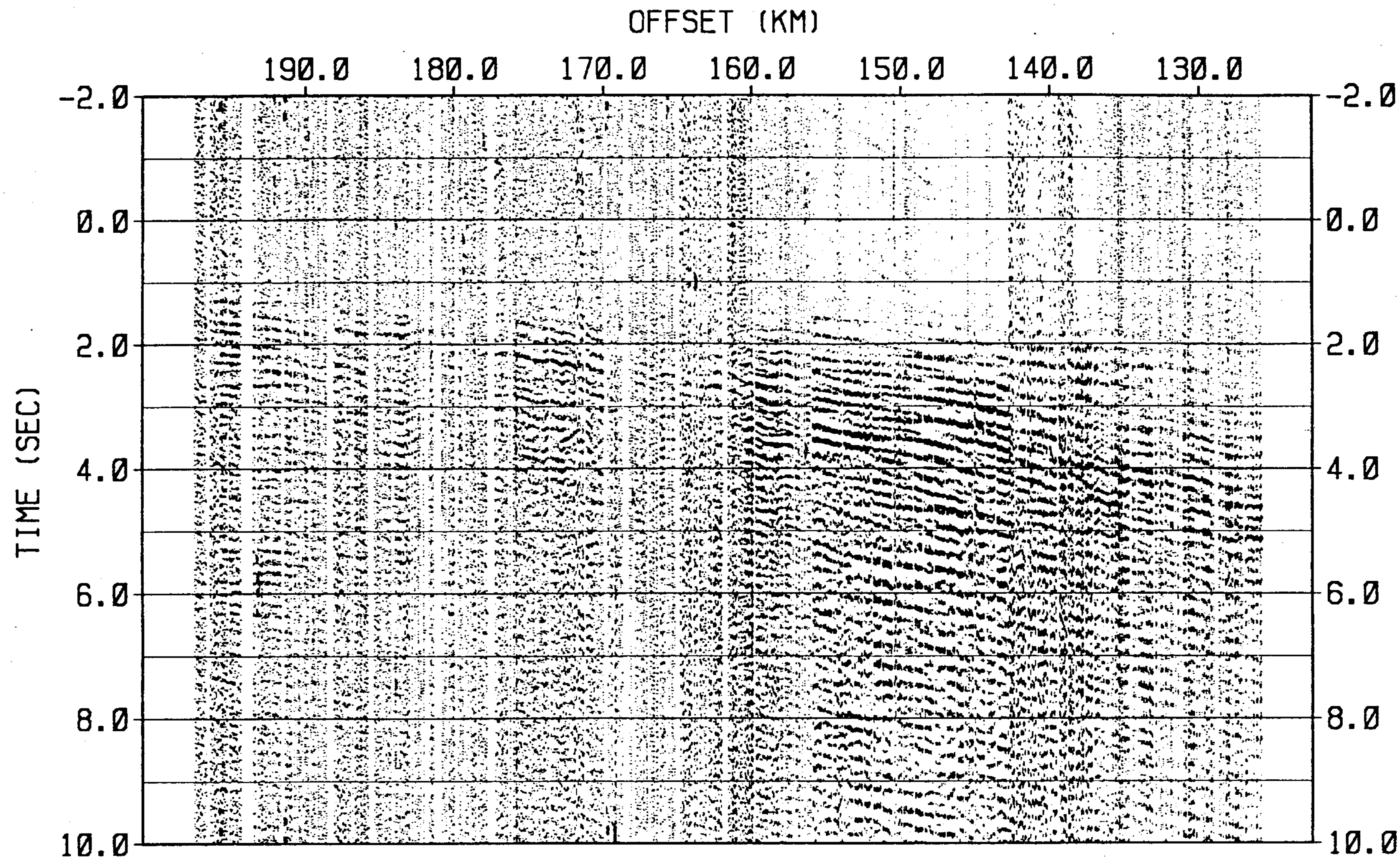

Figure 44 Profile 2

Shot 22 Shot Point 143 AGC = 12 sec

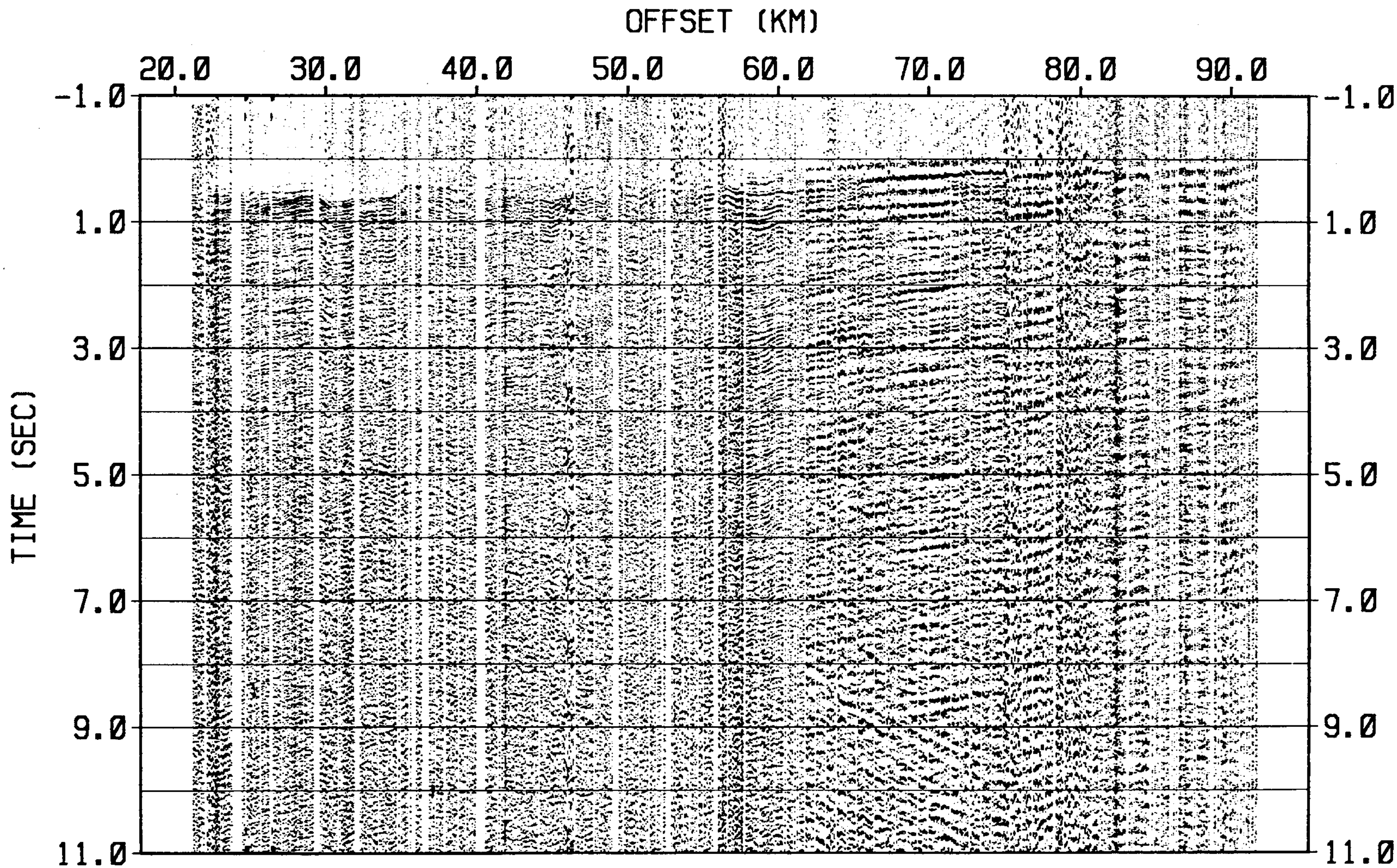

Figure 45 Profile 2

Shot 23 Shot Point 124 AGC = 2 sec

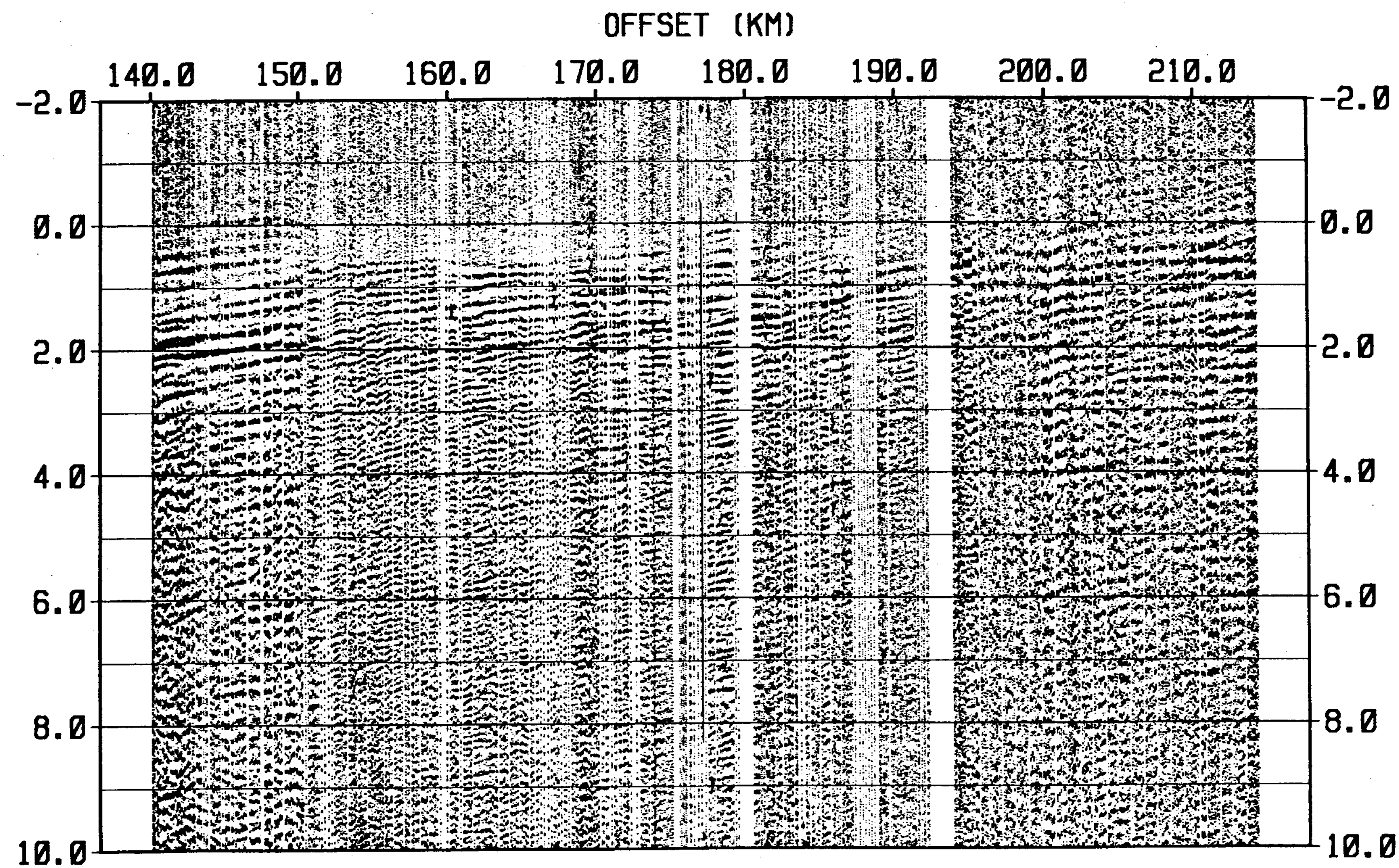

Figure 46 Profile 3

Shot 24 Shot Point 70 AGC = 2 sec

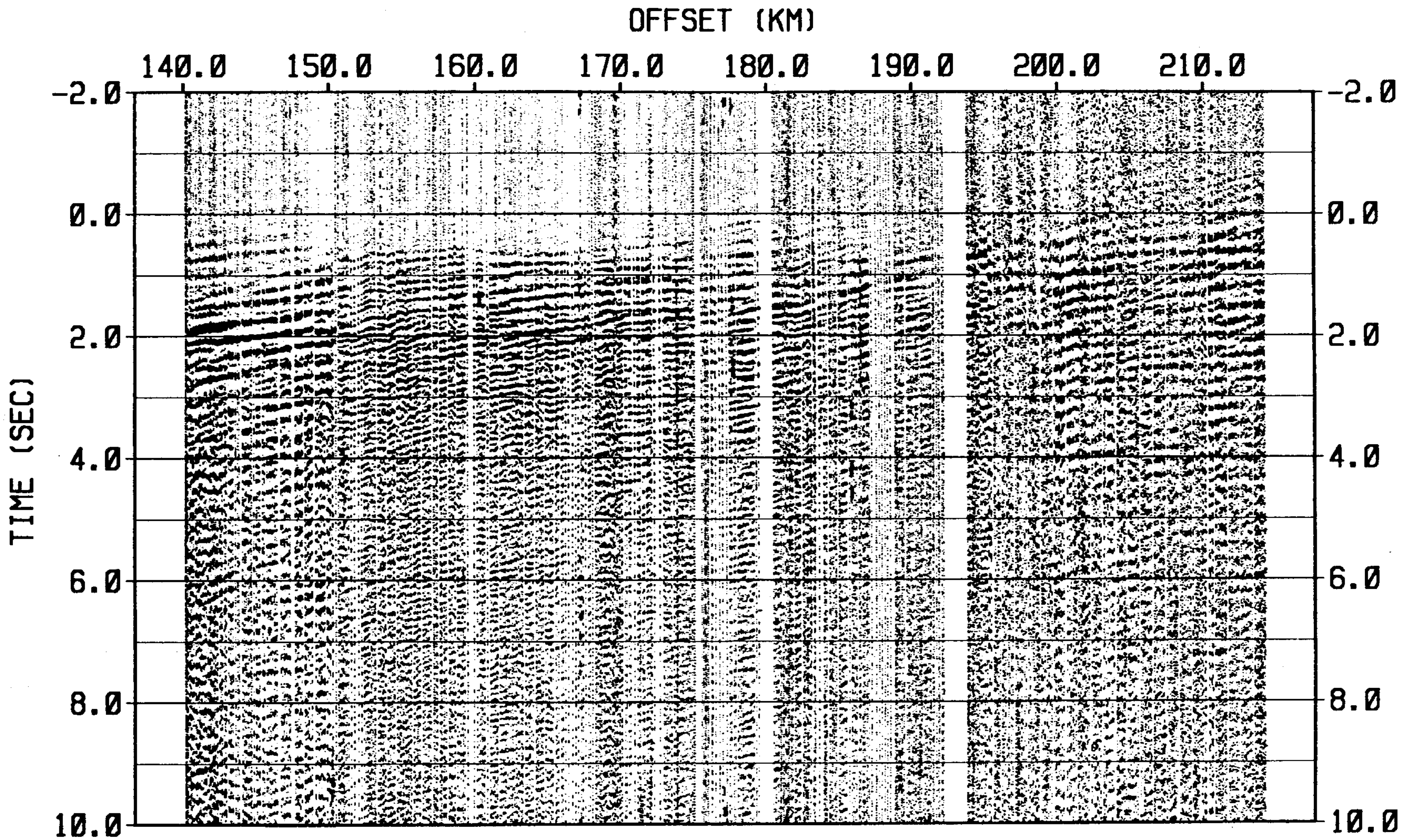

Figure 47 Profile 3

Shot 24 Shot Point 70 AGC = 12 sec

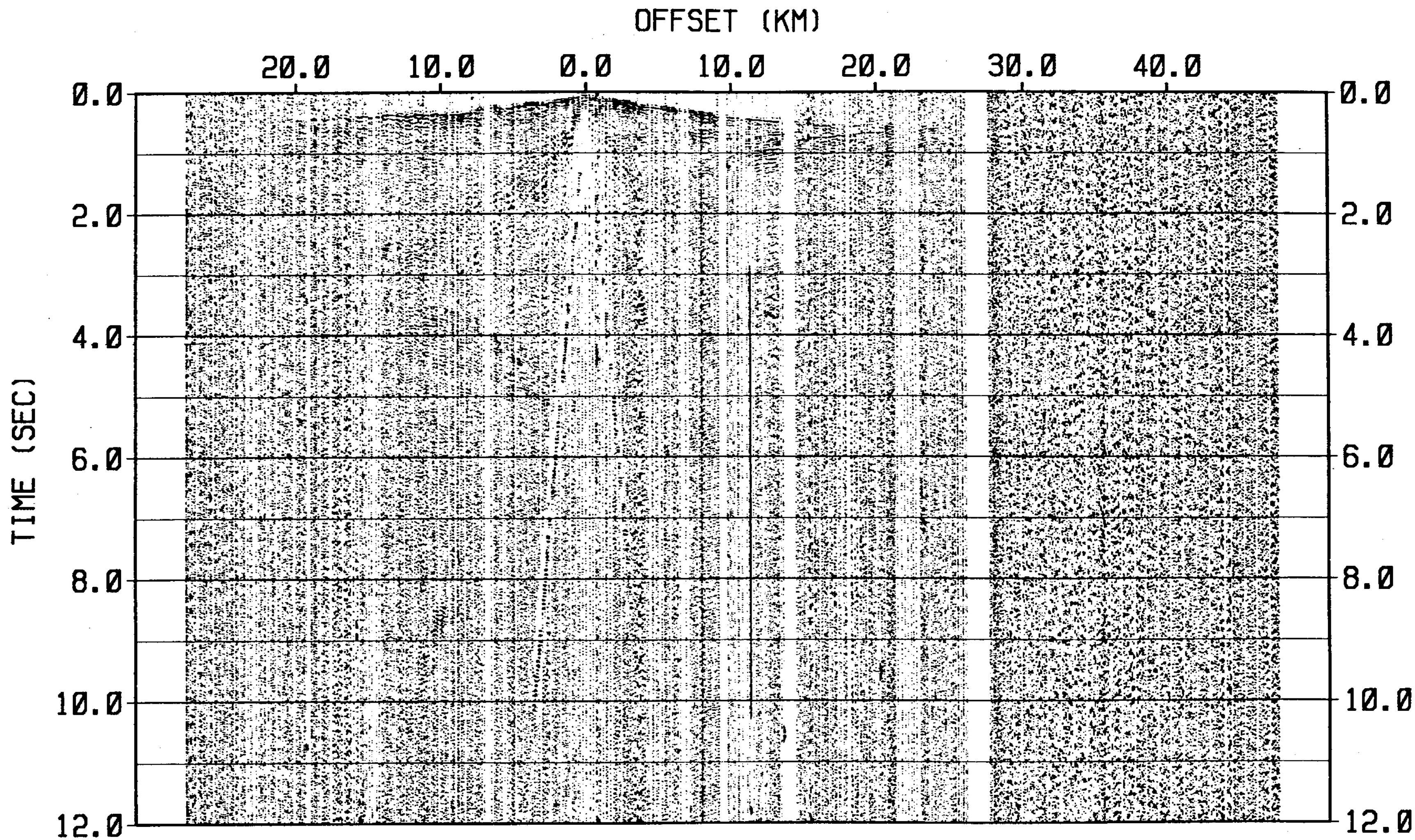

Figure 48 Profile 3

Shot 25 Shot Point 175 AGC = 2 sec

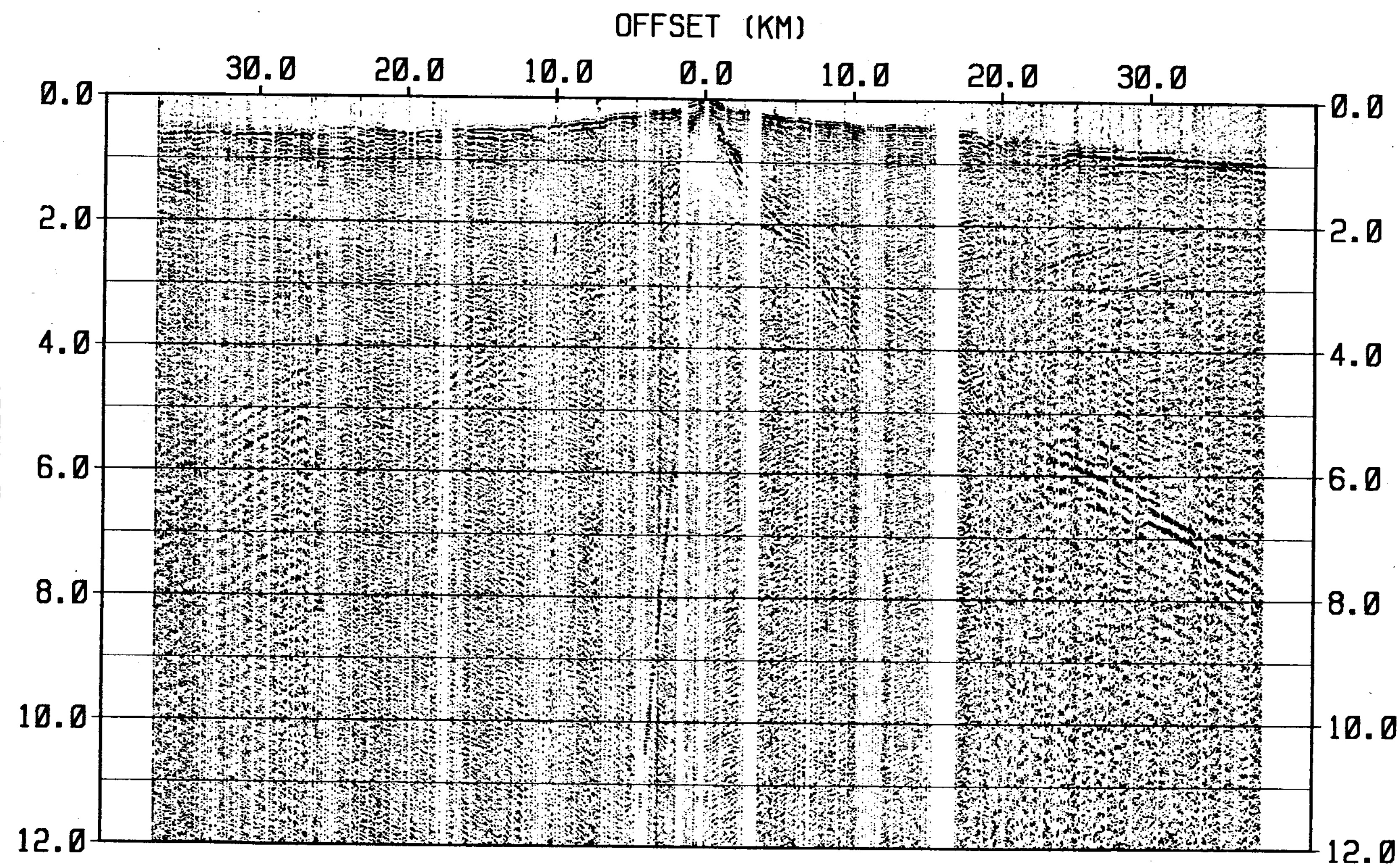

Figure 49 Profile 3

Shot 26 Shot Point 176 AGC = 2 sec

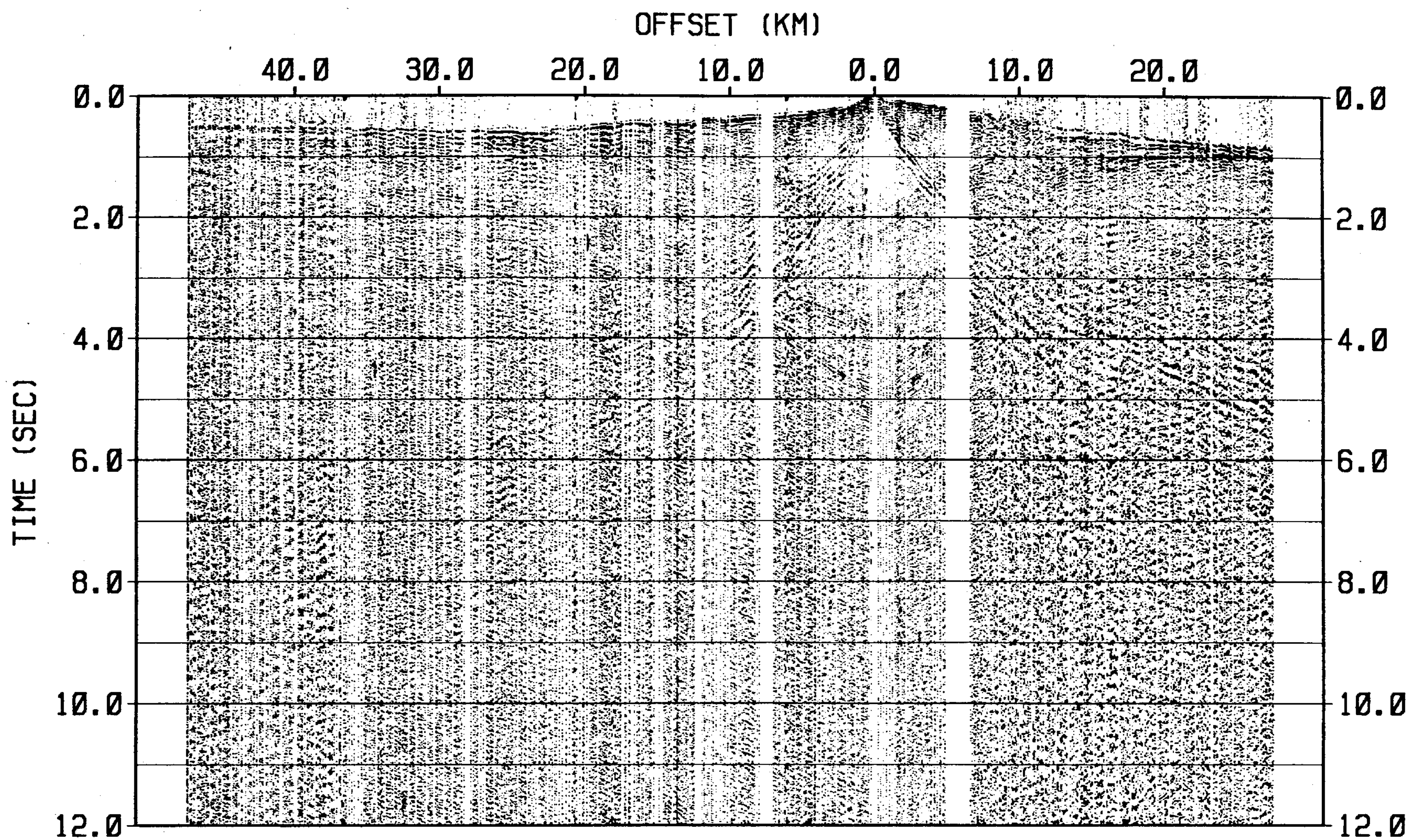

Figure 50 Profile 3

Shot 27 Shot Point 138 AGC = 2 sec

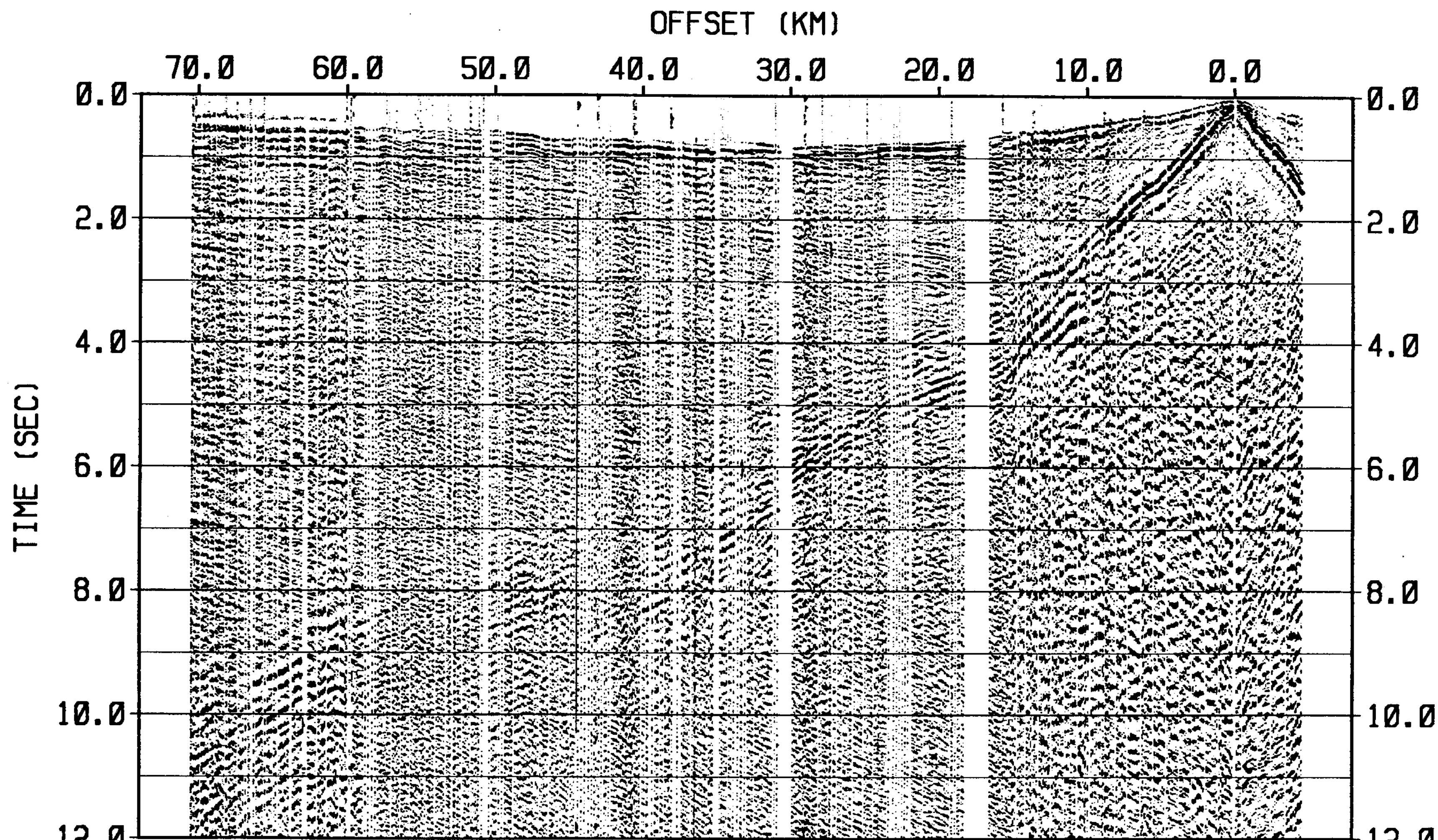

Figure 51 Profile 3

Shot 28 Shot Point 139 AGC = 2 sec

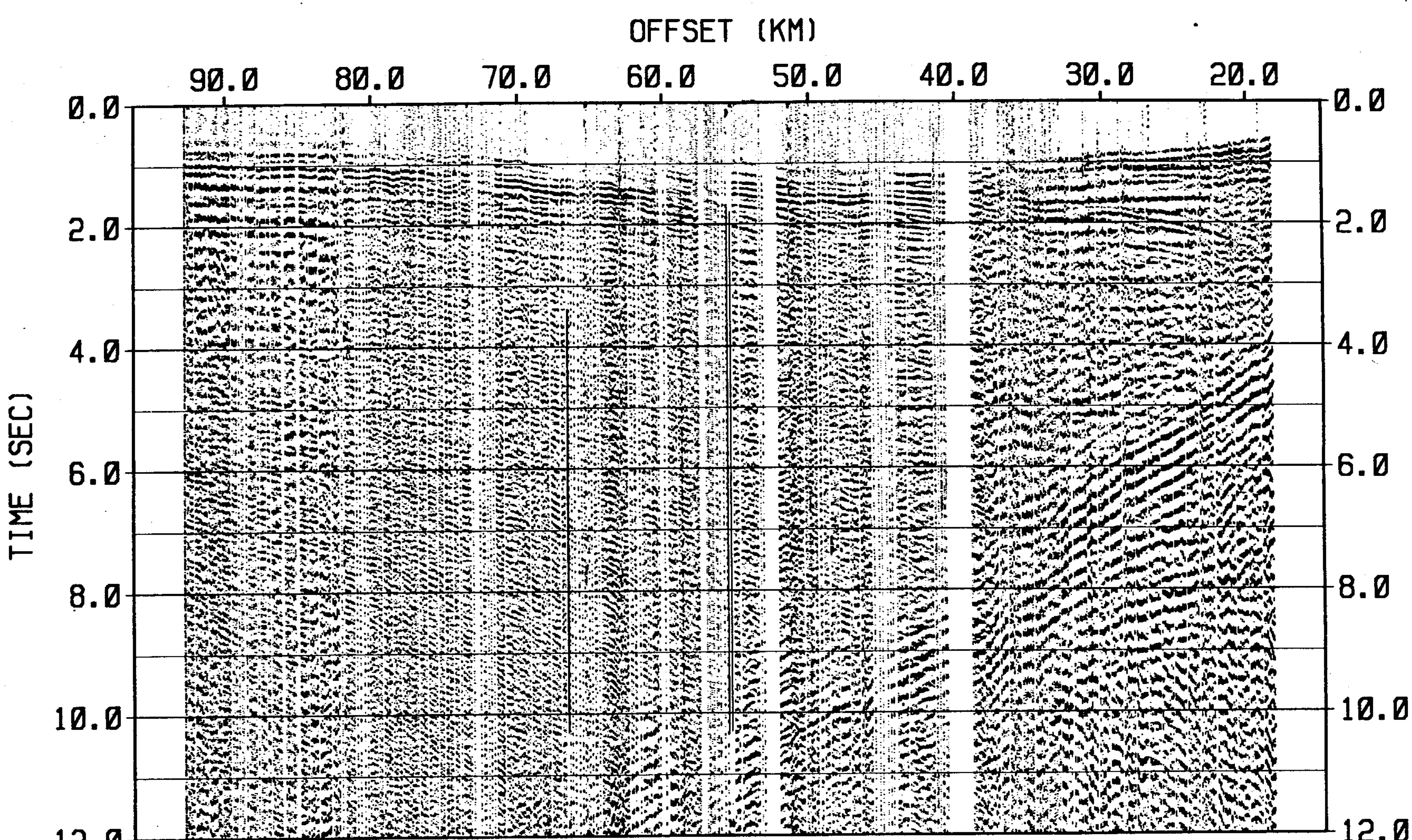

Figure 52 Profile 3

Shot 29 Shot Point 142 AGC = 2 sec

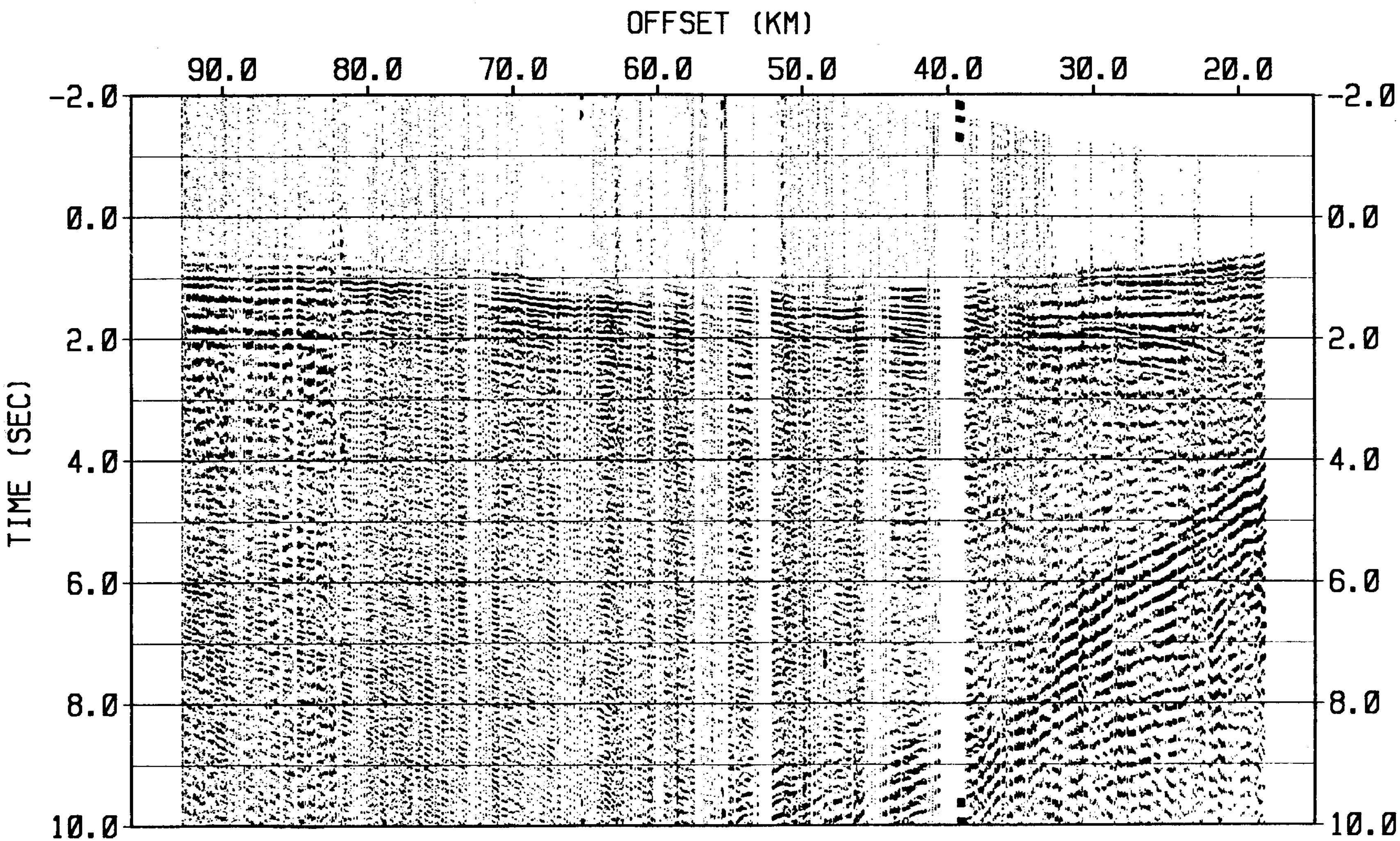

Figure 53 Profile 3

Shot 29 Shot Point 142 AGC = 12 sec

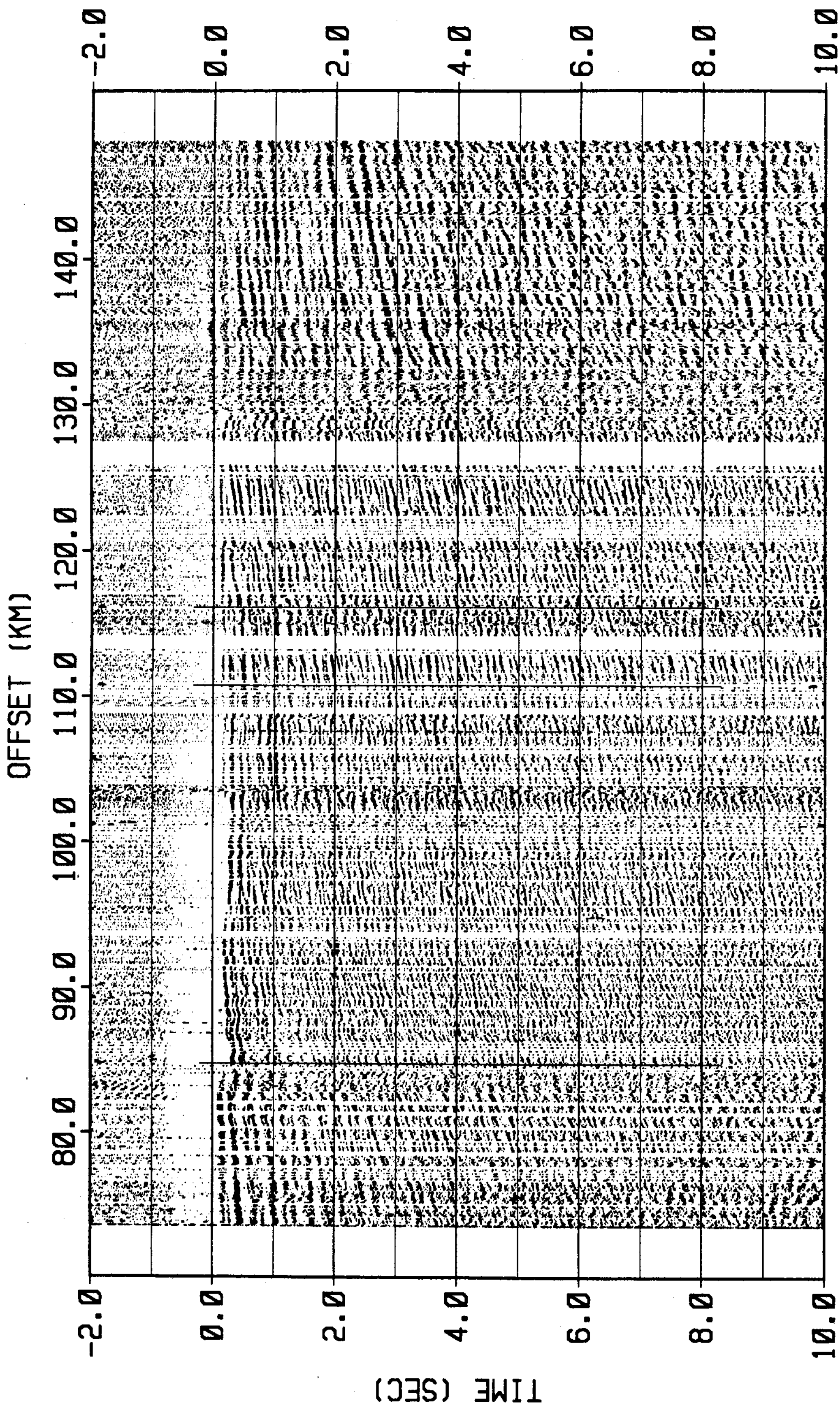

Figure 54 Profile 3

Shot 30 Shot Point 126 AGC = 2 sec

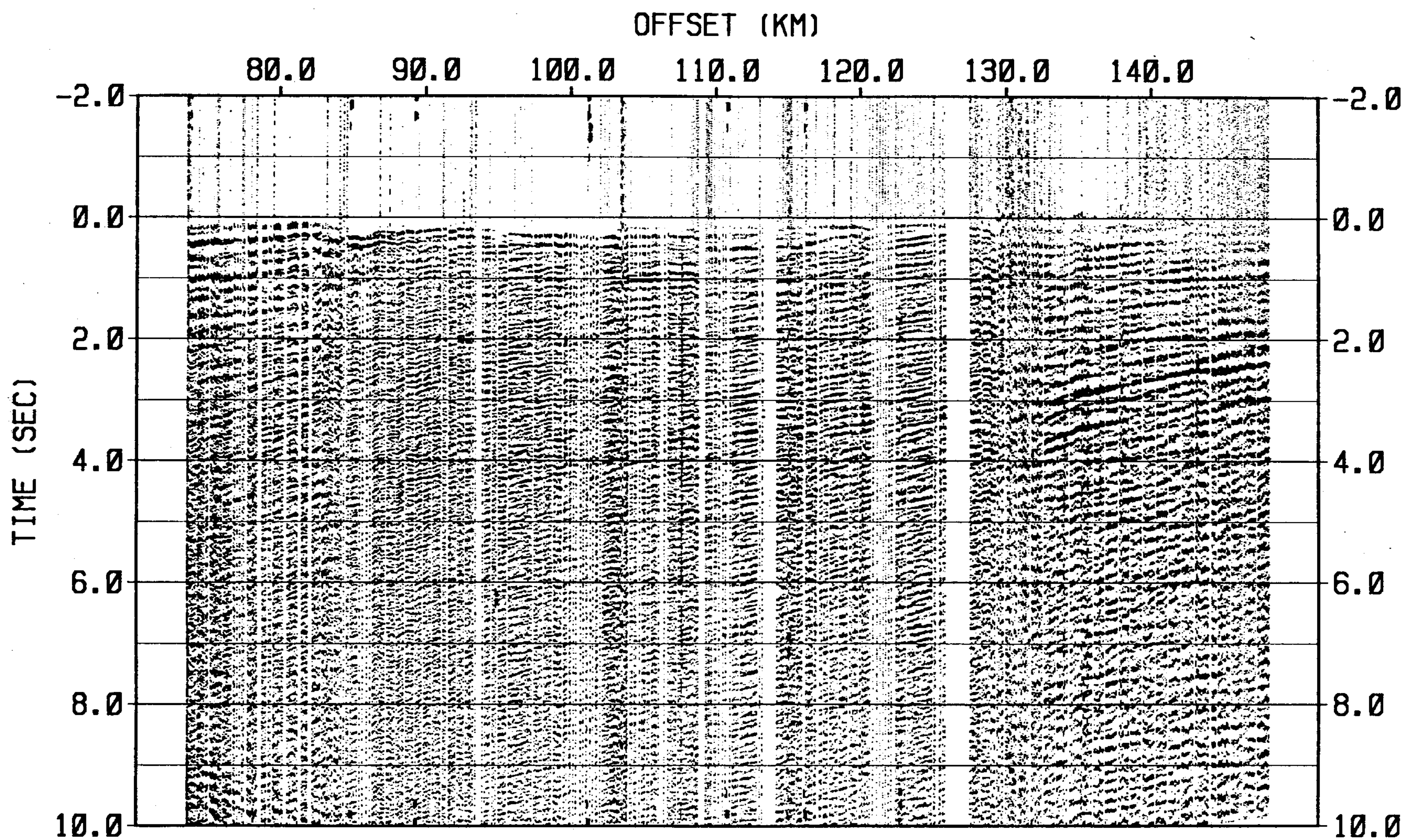

Figure 55 Profile 3

Shot 30 Shot Point 126 AGC = 12 sec

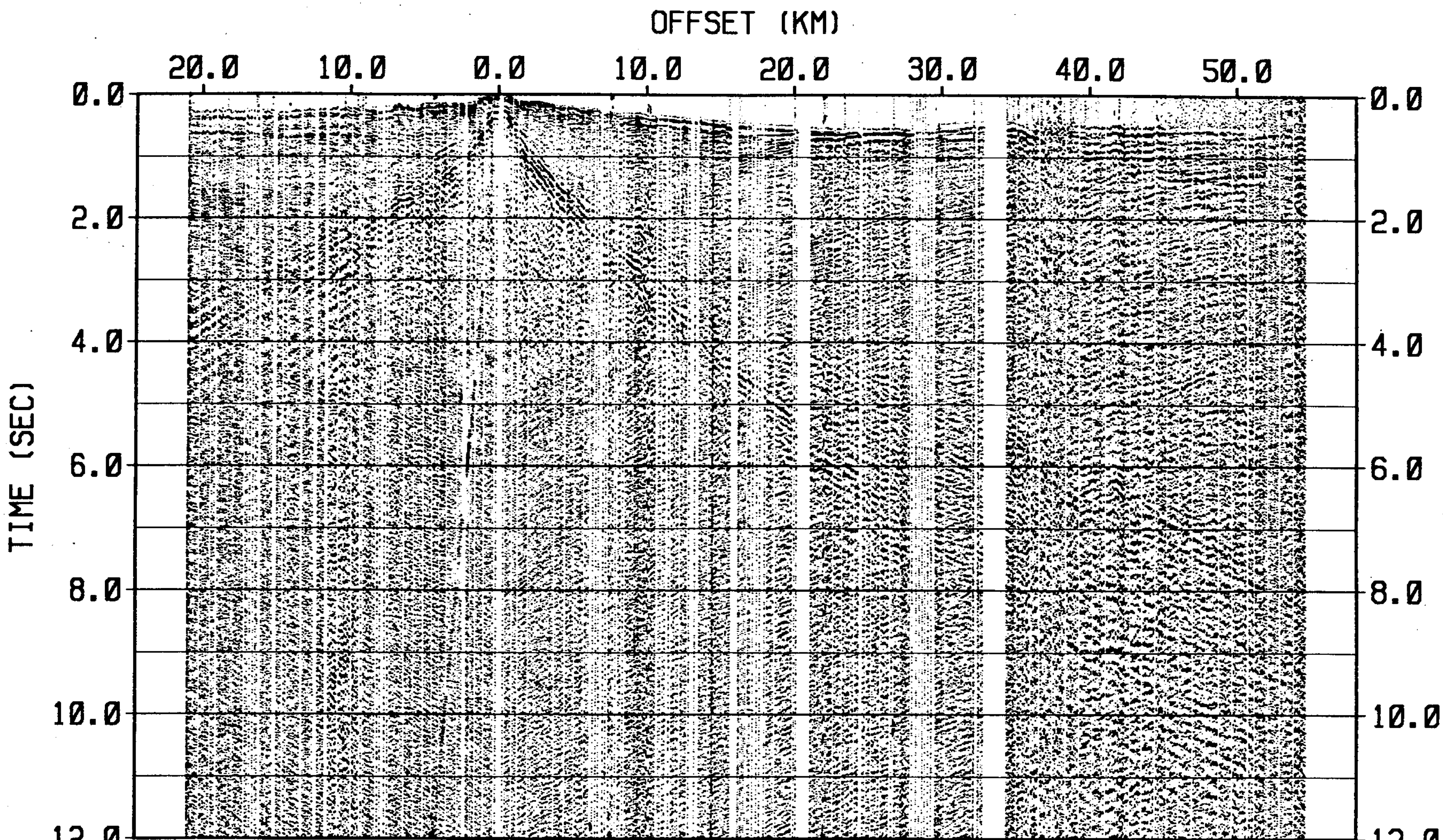

Figure 56 Profile 3

Shot 31 Shot Point 136 AGC = 2 sec

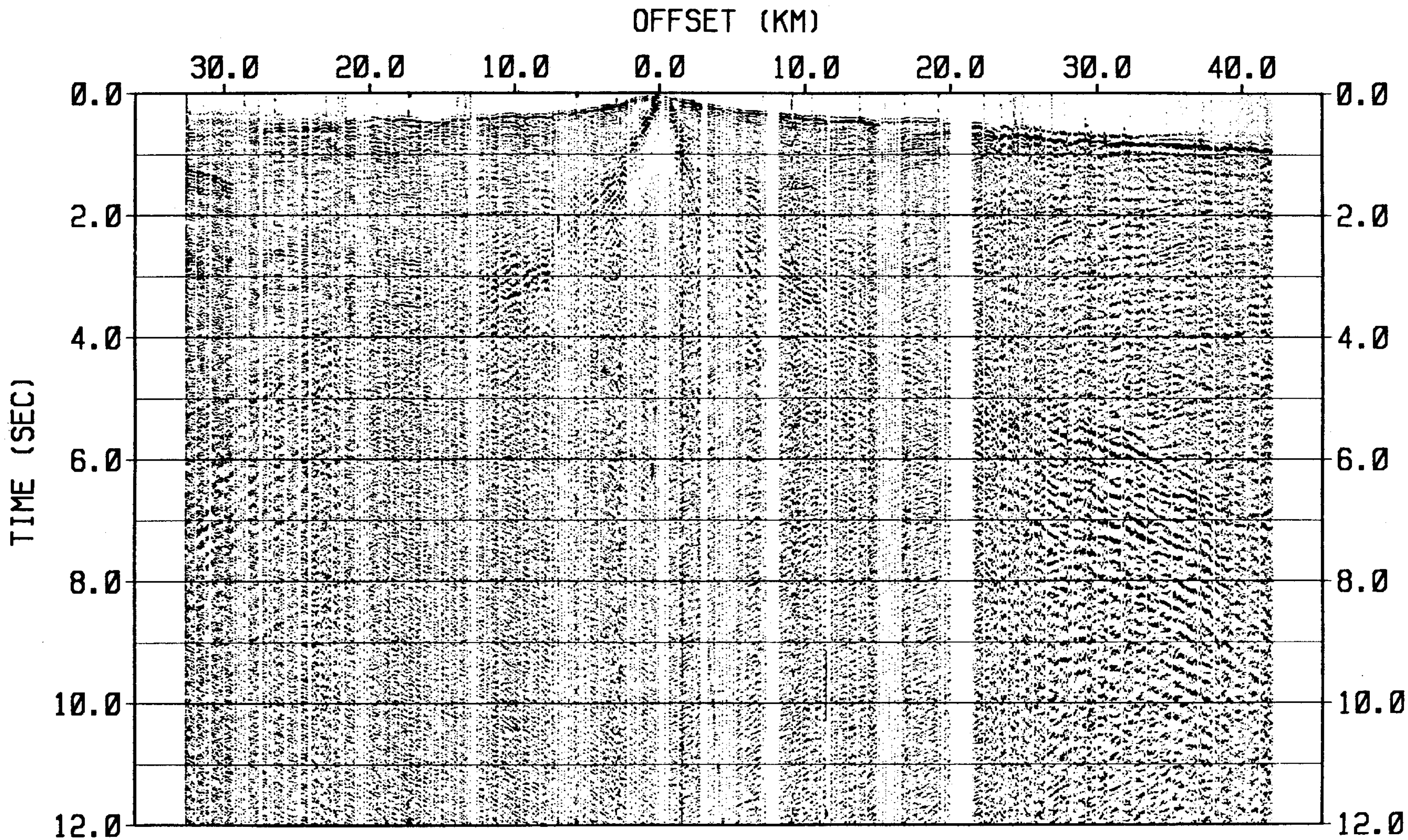

Figure 57 Profile 3

Shot 32 Shot Point 137 AGC = 12 sec

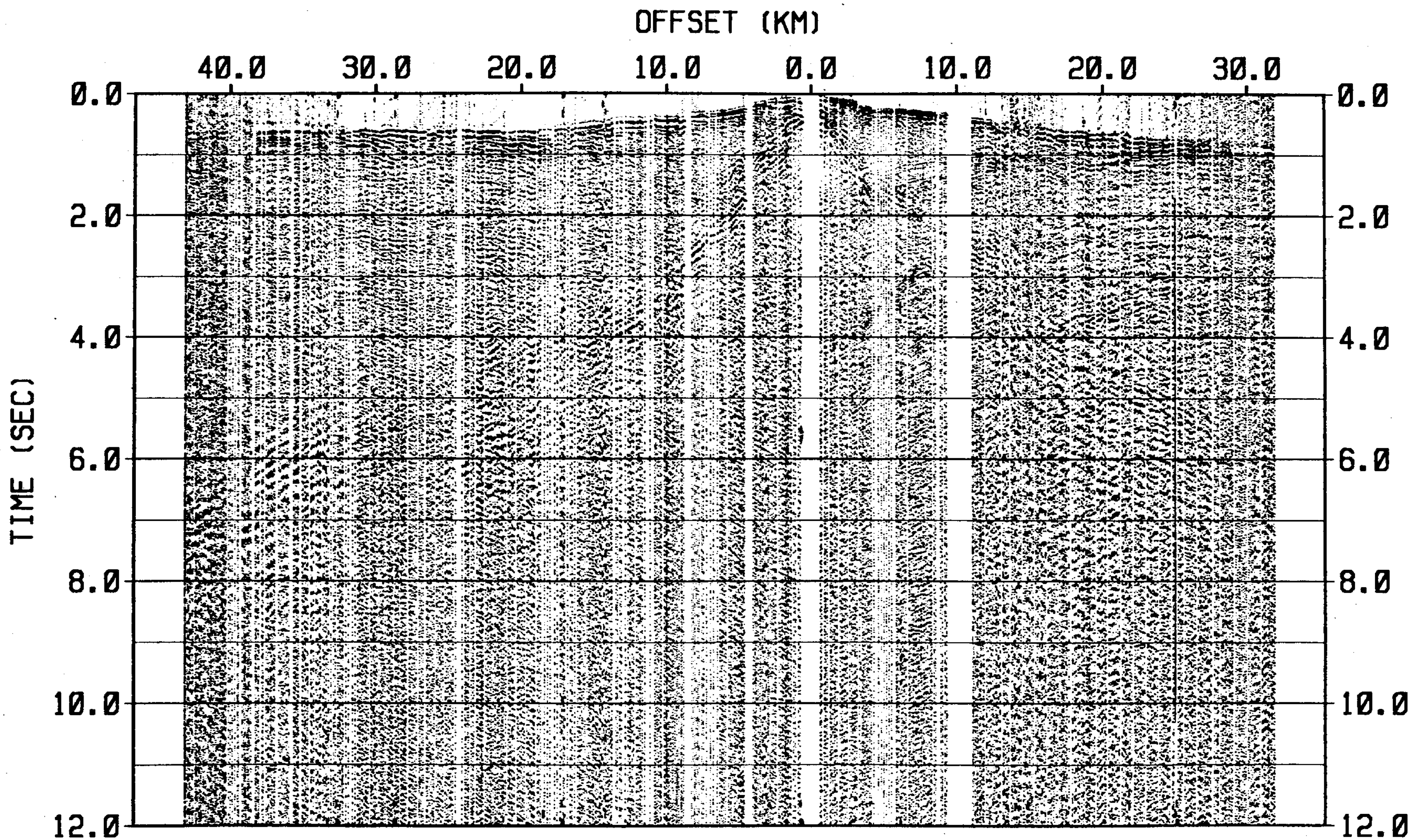

Figure 58 Profile 3

Shot 33 Shot Point 177 AGC = 2 sec

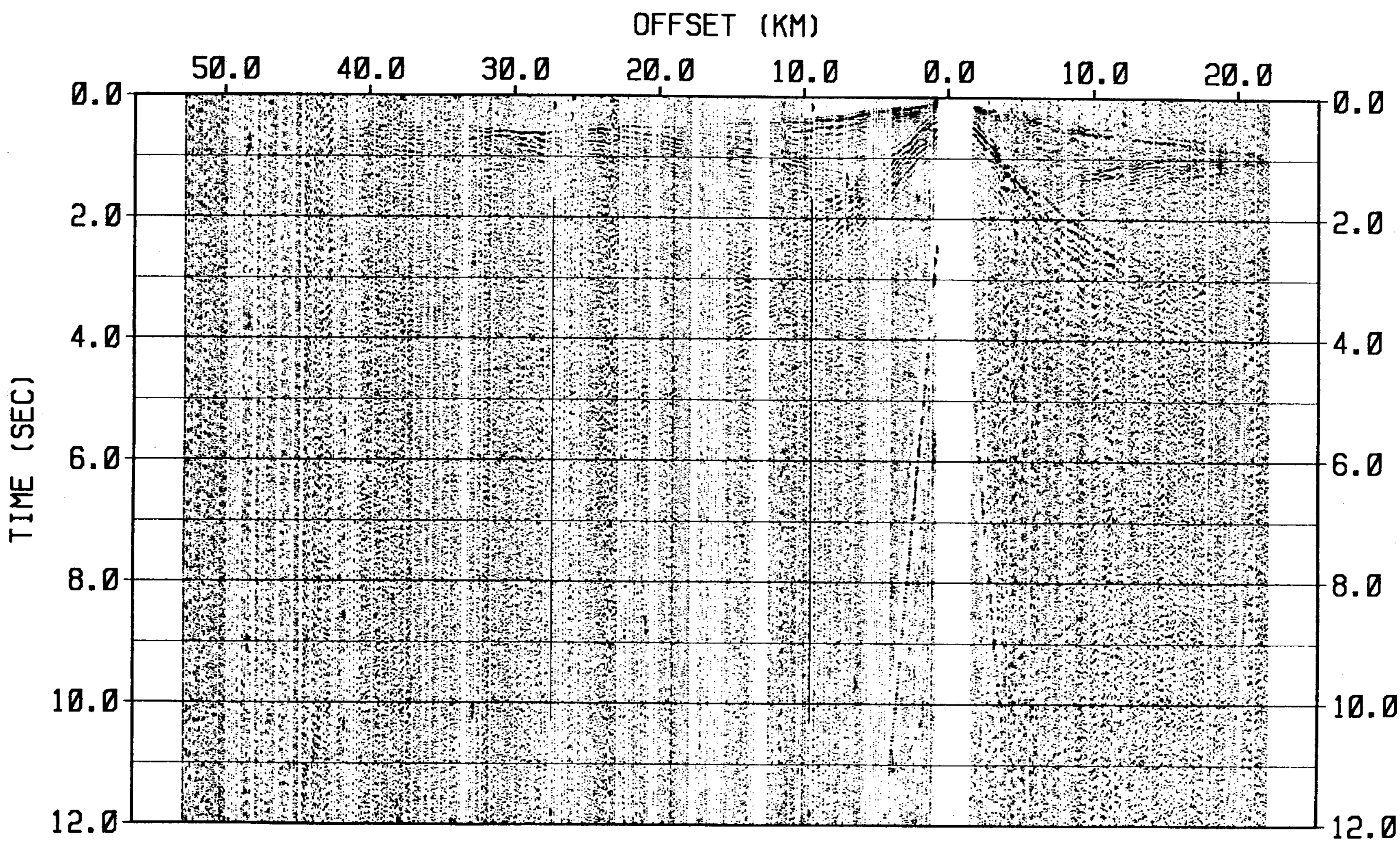

Figure 59 Profile 3

Shot 34 Shot Point 178 AGC = 2 sec

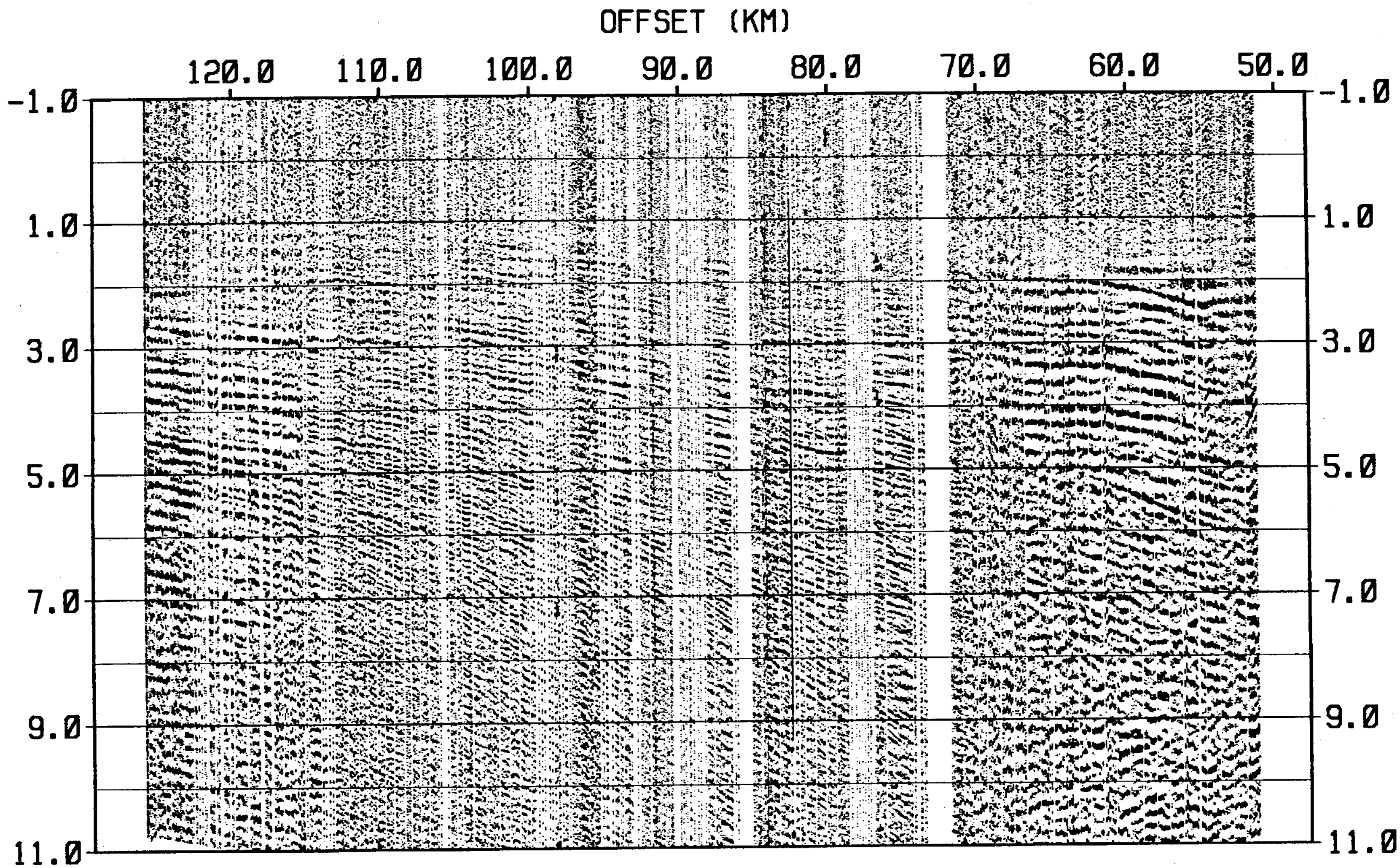

Figure 60 Profile 3

Shot 35 Shot Point 143 AGC = 2 sec

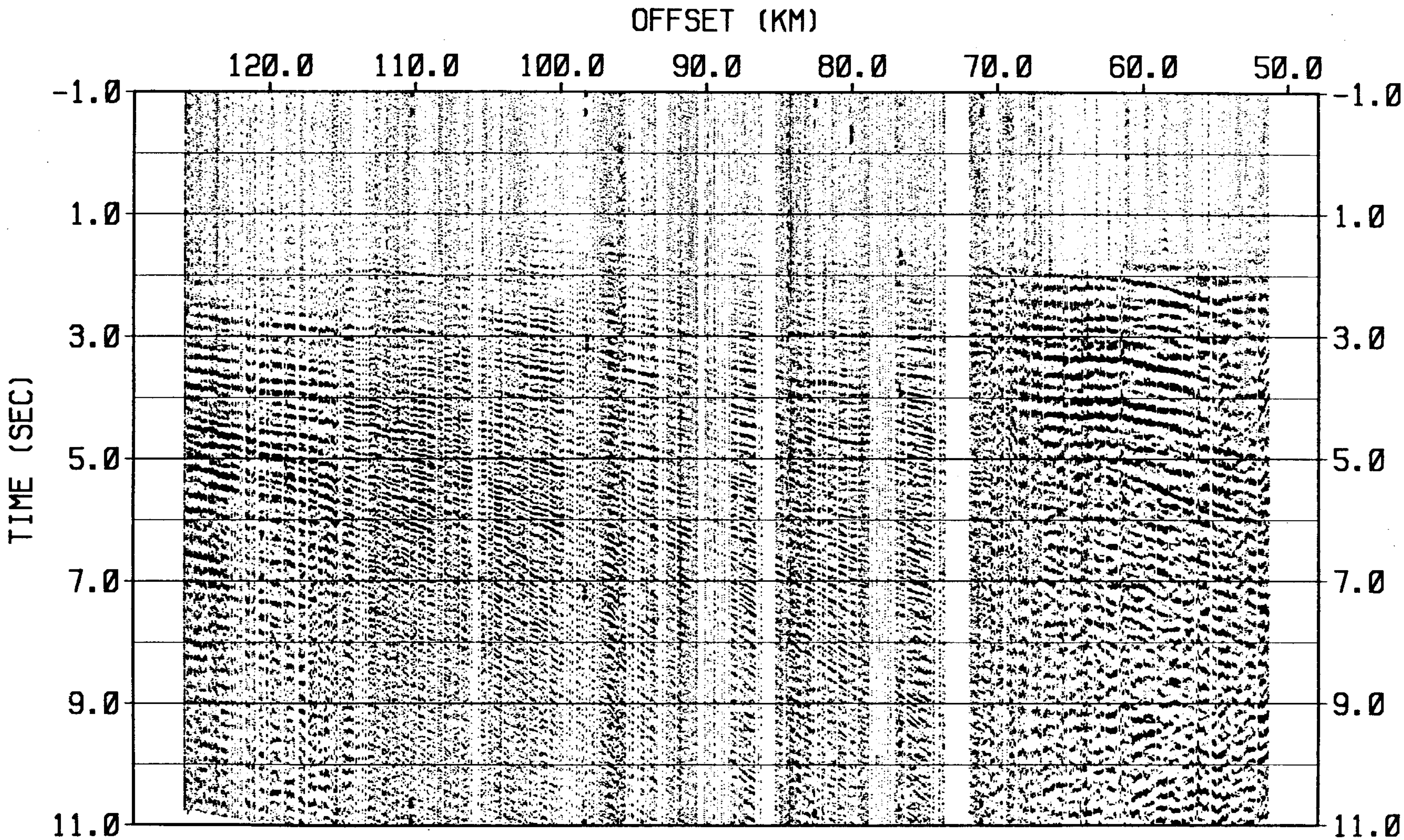

Figure 61 Profile 3

Shot 35 Shot Point 143 AGC = 12 sec

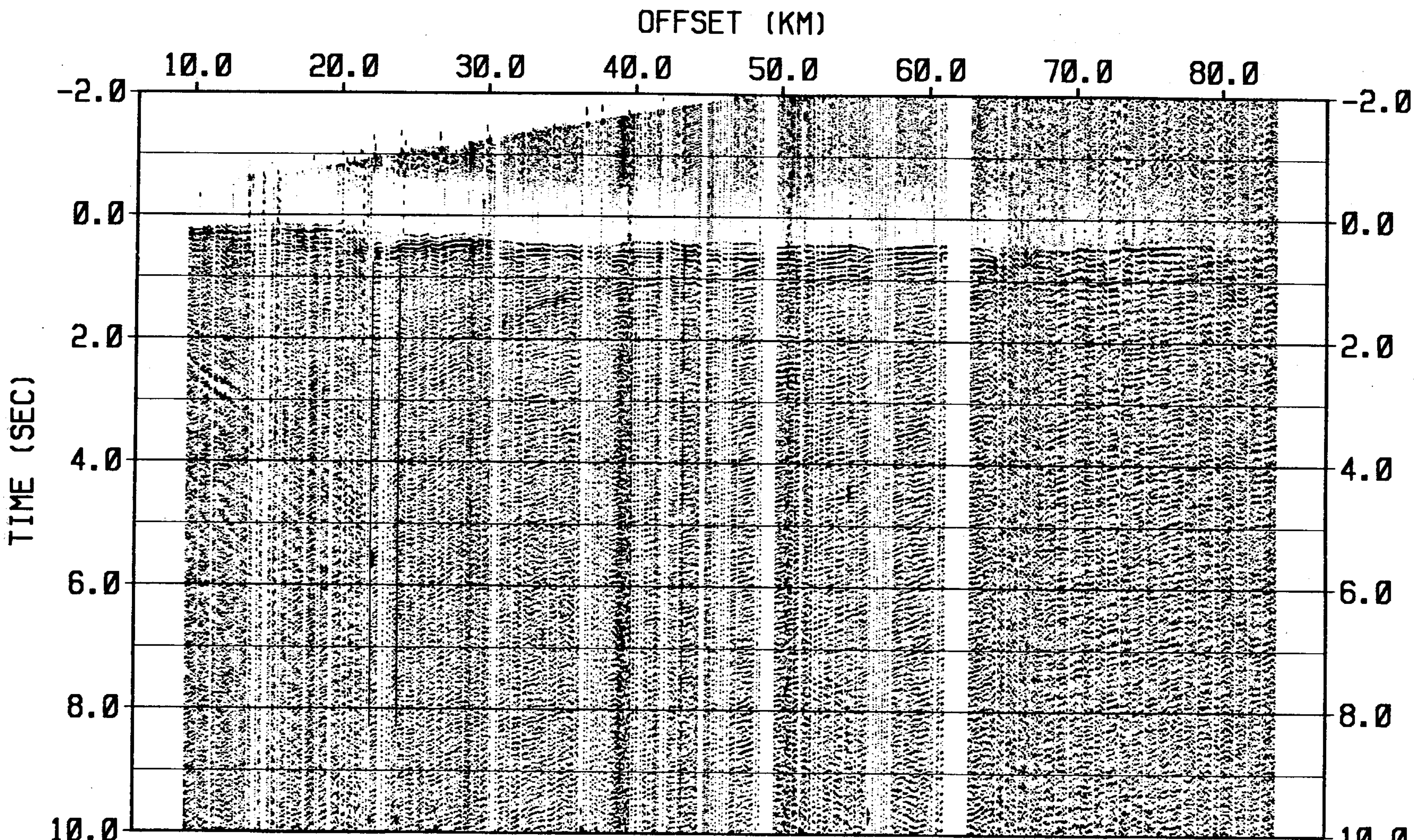

Figure 62 Profile 3

Shot 36 Shot Point 132 AGC = 2 sec

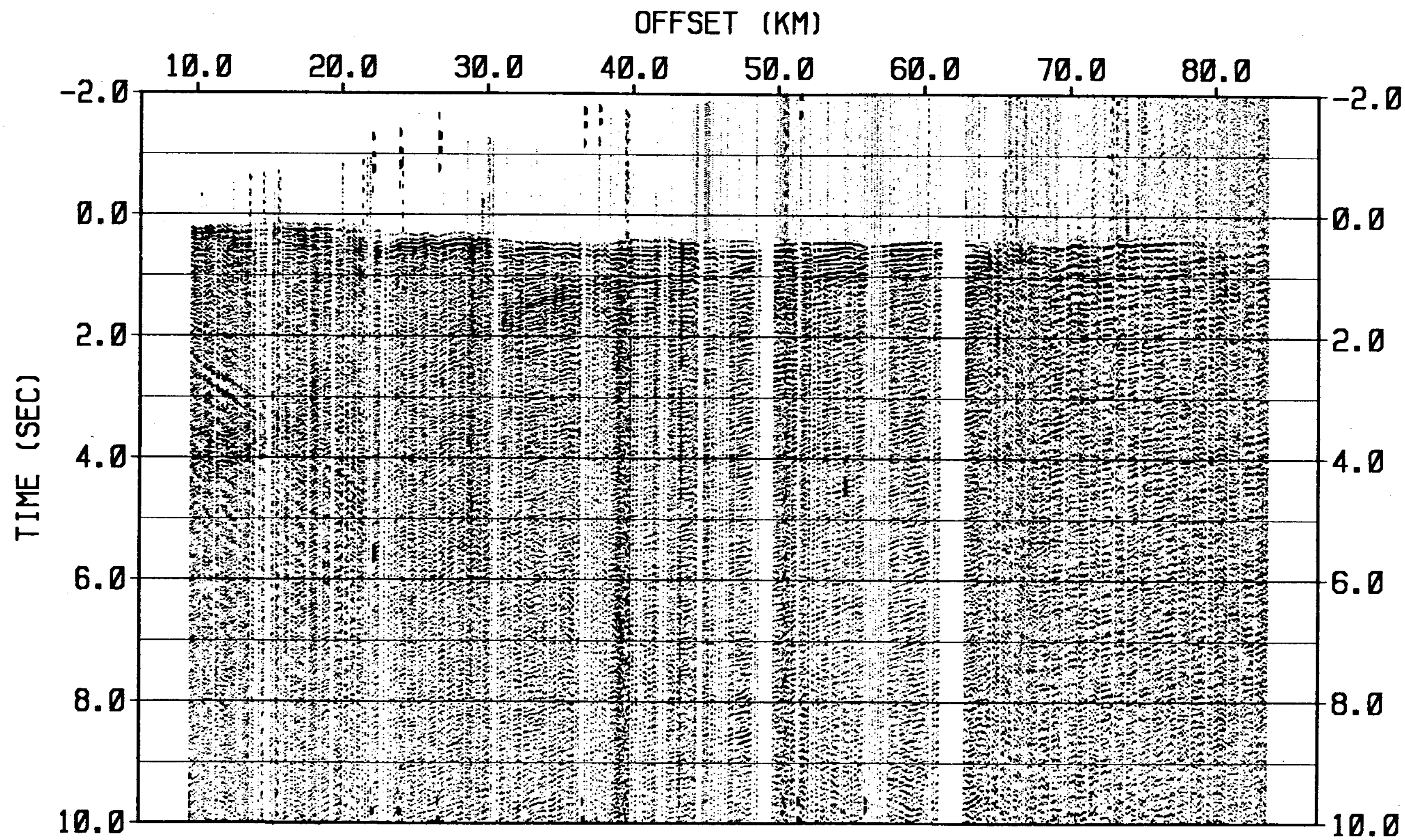

Figure 63 Profile 3

Shot 36 Shot Point 132 AGC = 12 sec

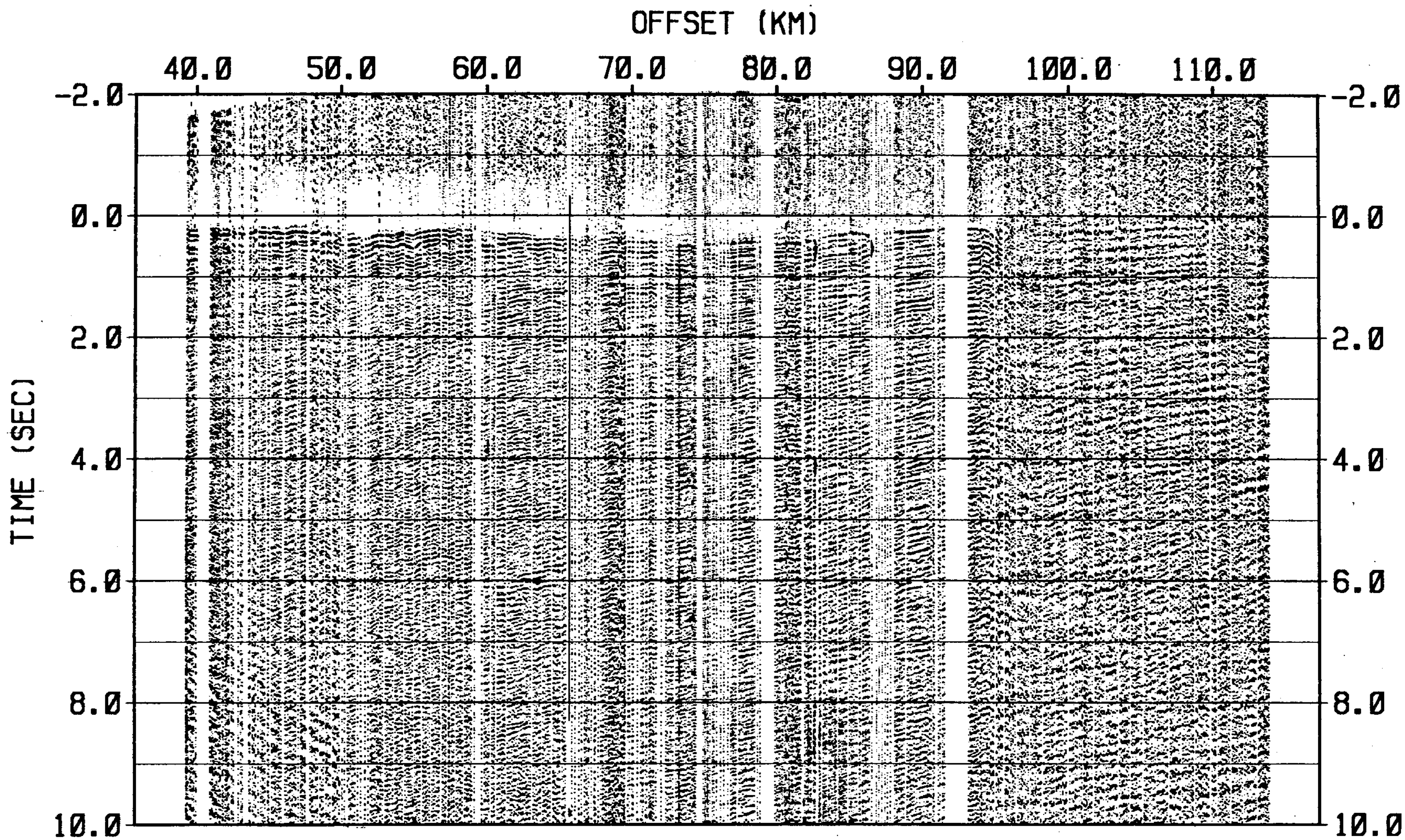

Figure 64 Profile 3

Shot 37 Shot Point 130 AGC = 2 sec

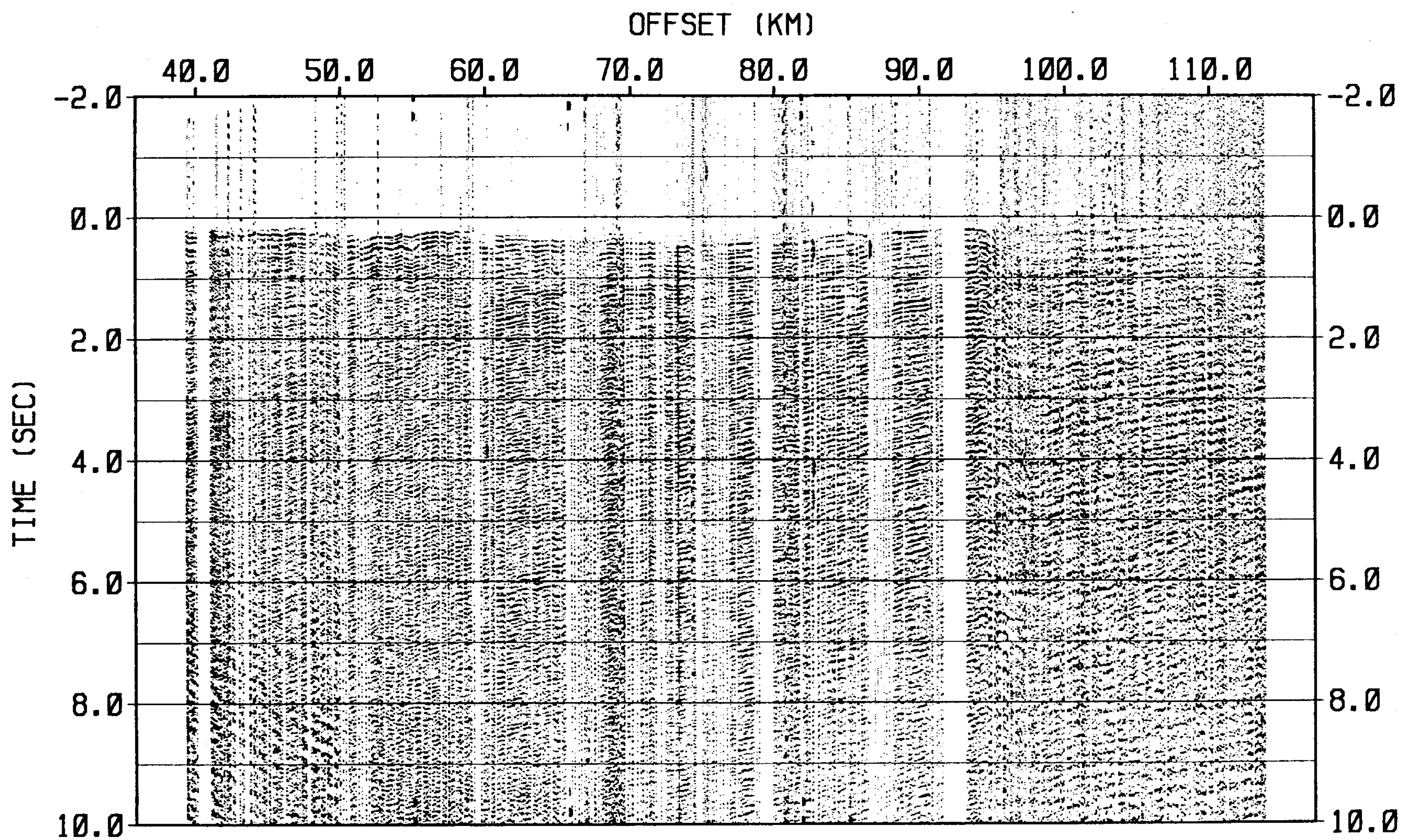

Figure 65 Profile 3

Shot 37 Shot Point 130 AGC = 12 sec

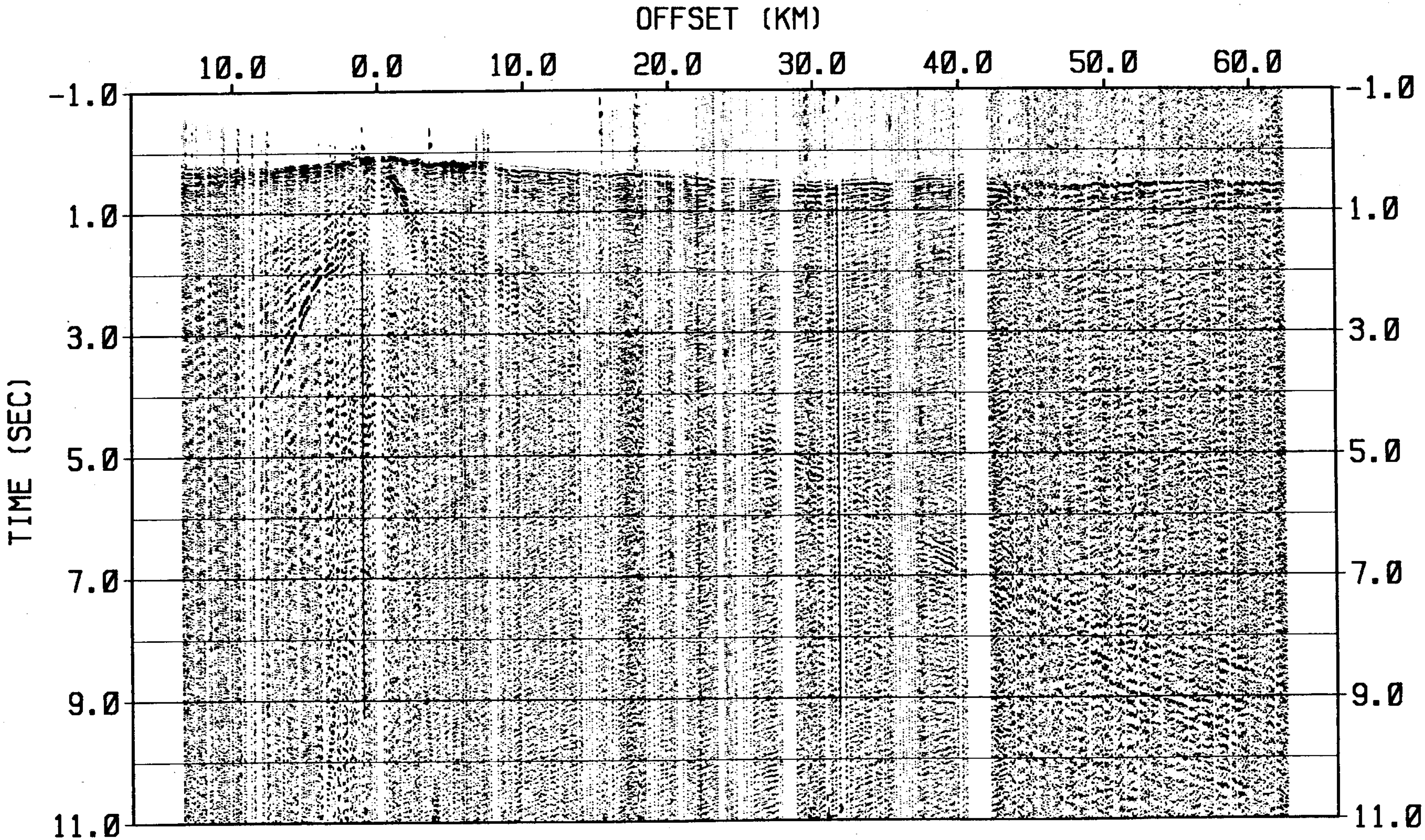

Figure 66 Profile 3

Shot 38 Shot Point 135 AGC = 2 sec

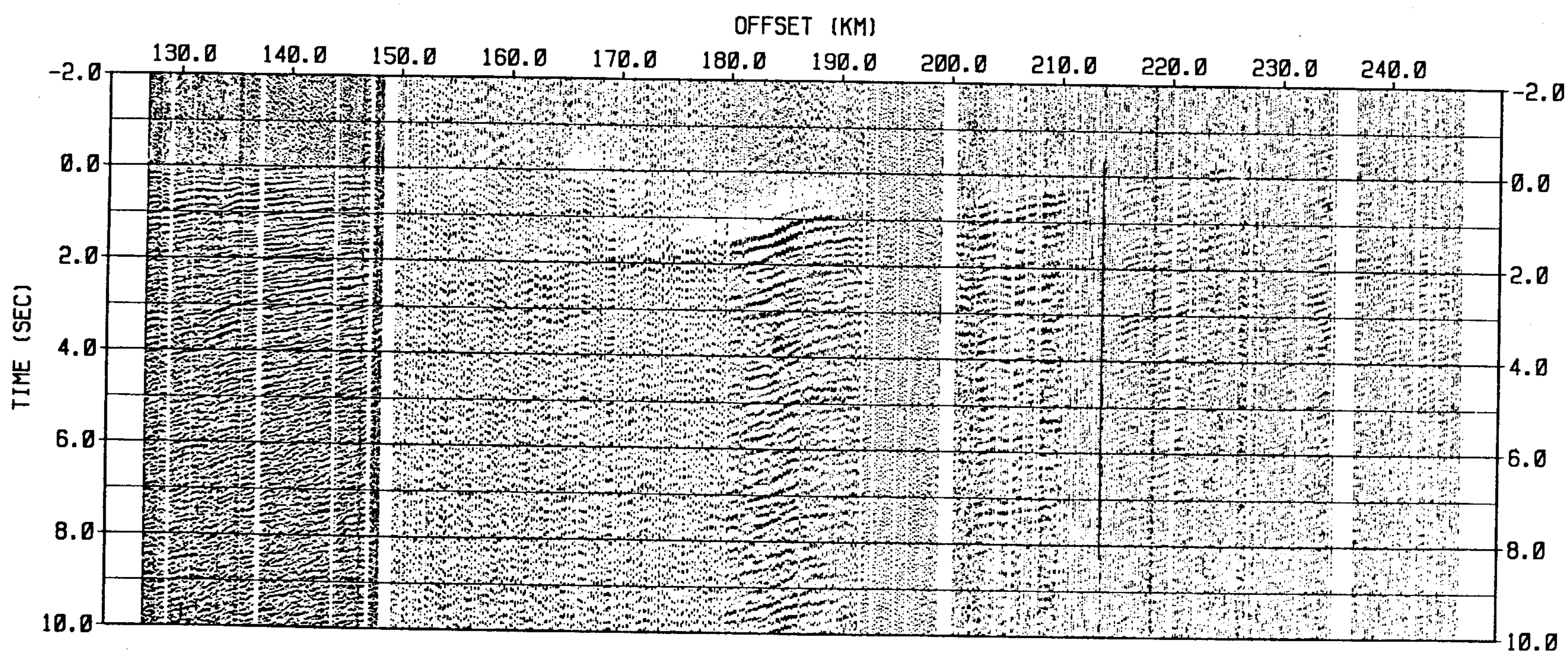

Figure 67 Profile 4

Shot 39 Shot Point 126 AGC = 2 sec

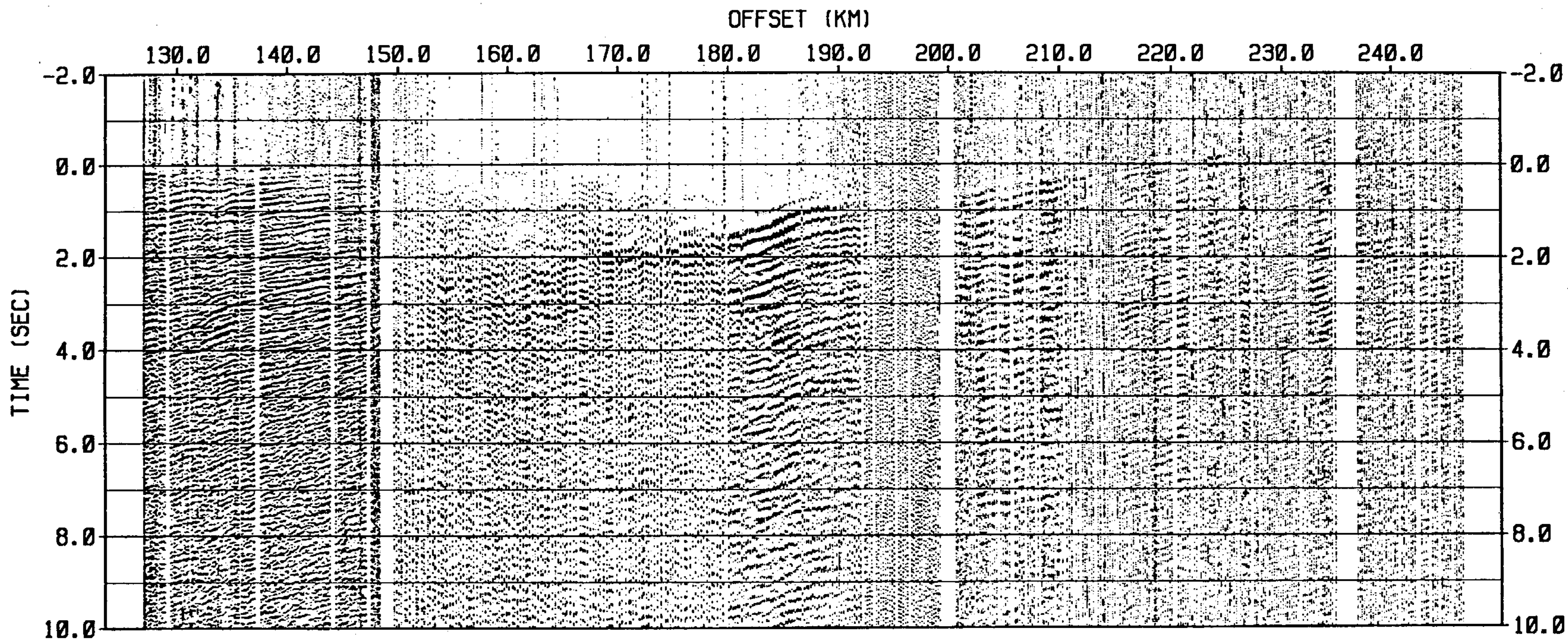

Figure 68 Profile 4

Shot 39 Shot Point 126 AGC = 12 sec

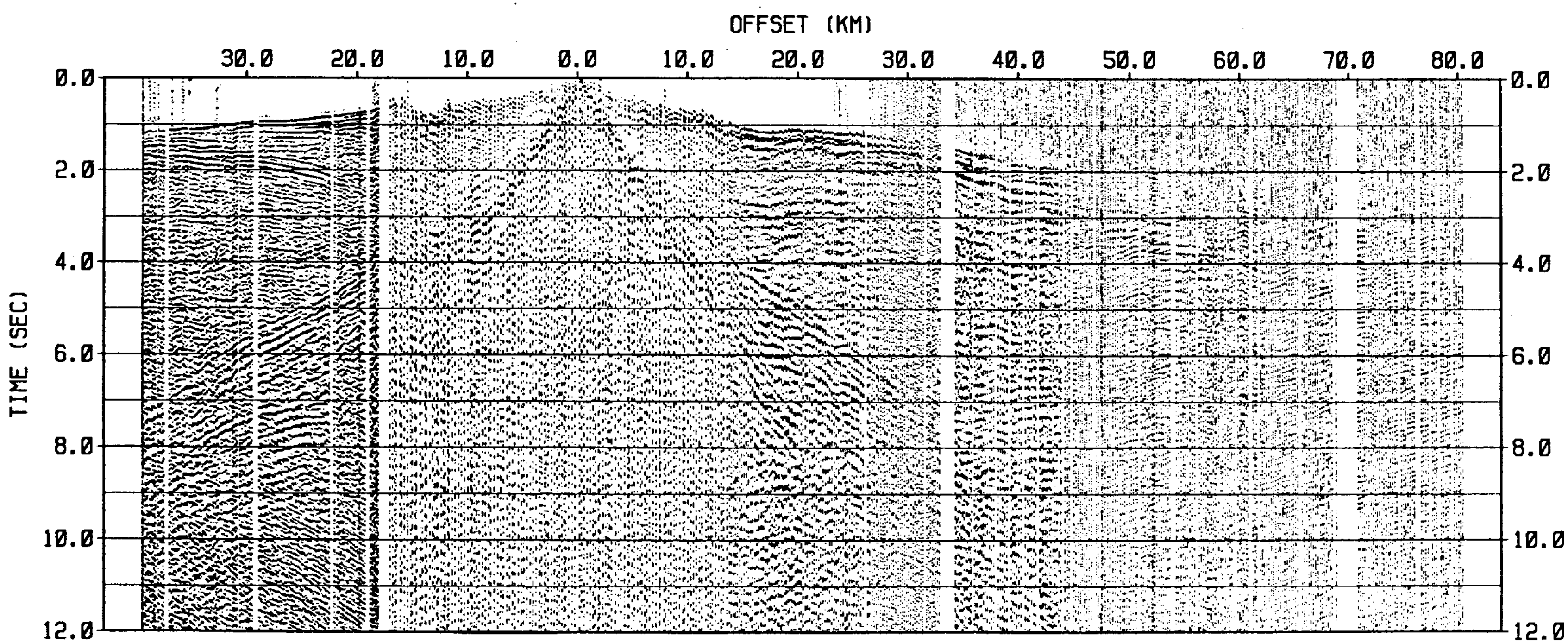

Figure 69 Profile 4

Shot 40 Shot Point 142 AGC = 2 sec

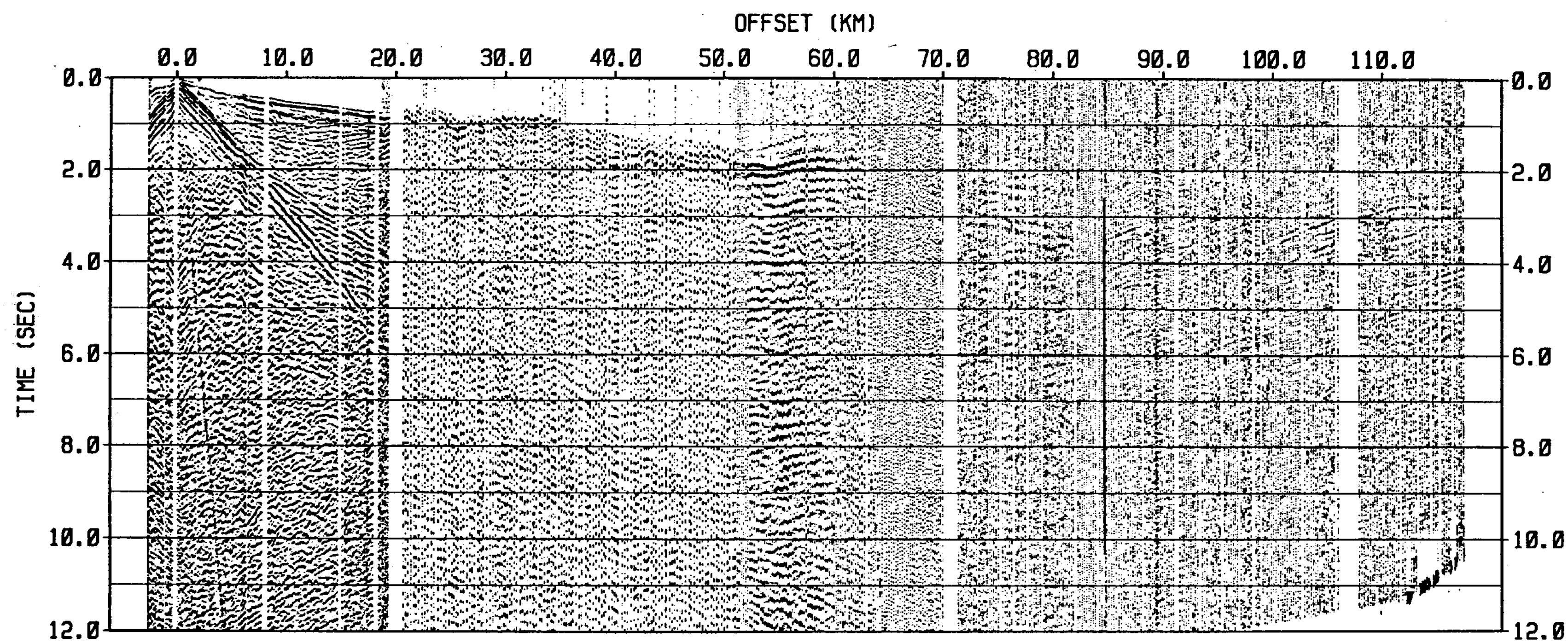

Figure 70 Profile 4

Shot 41 Shot Point 179 AGC = 2 sec

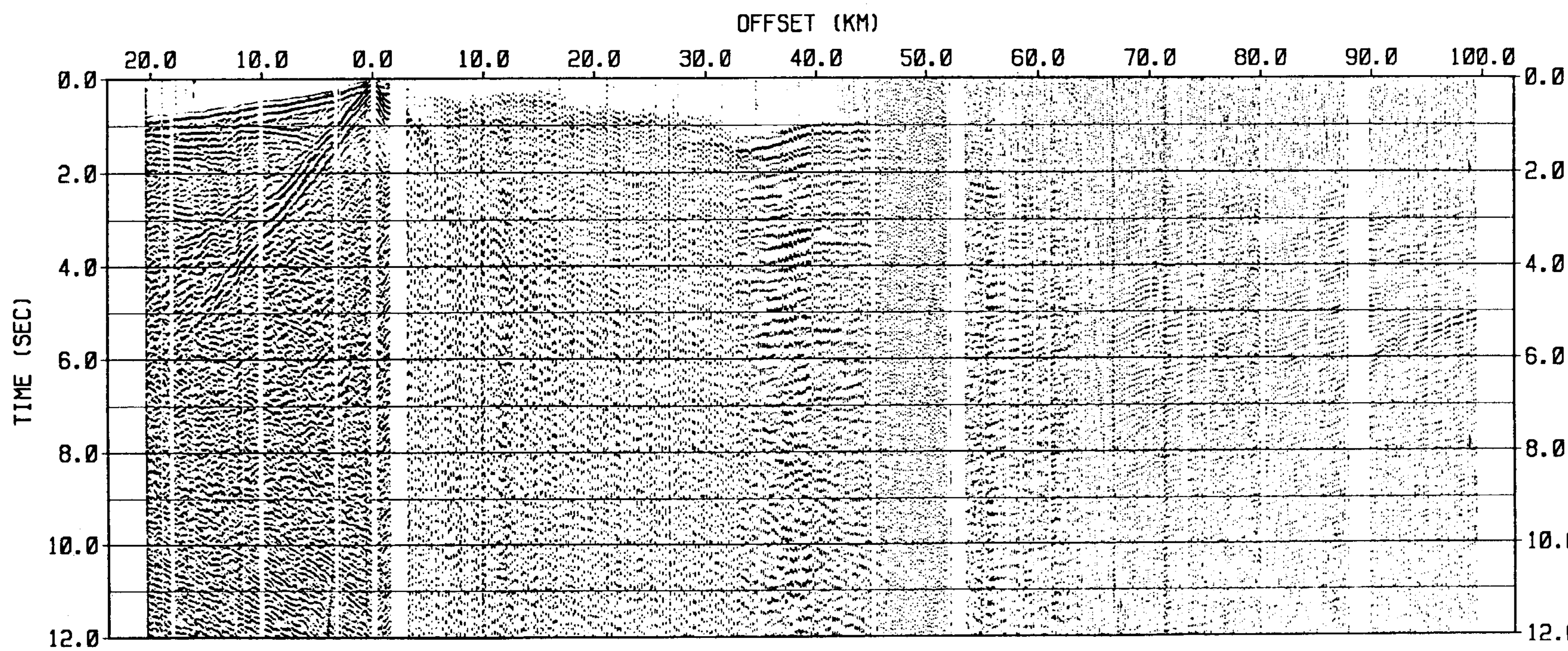

Figure 71 Profile 4

Shot 42 Shot Point 141 AGC = 2 sec

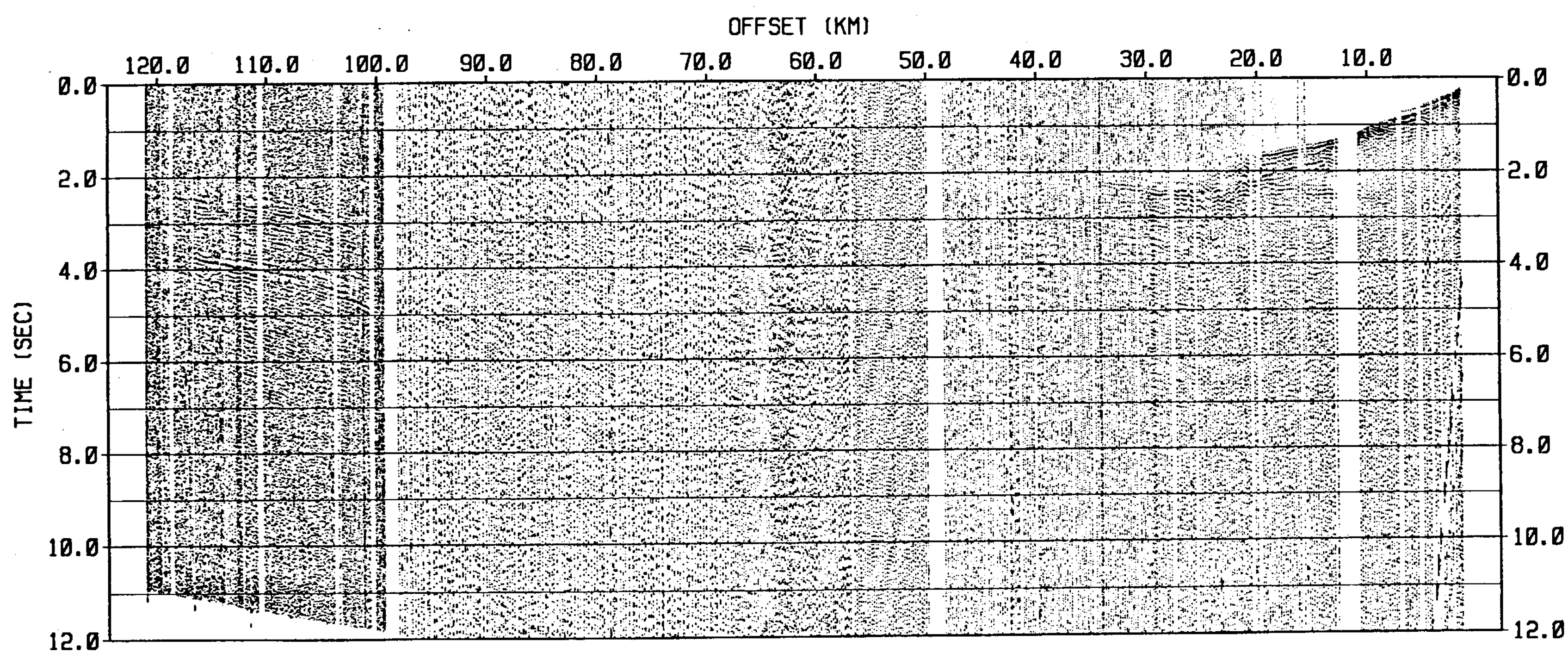

Figure 72 Profile 4

Shot 43 Shot Point 189 AGC = 2 sec

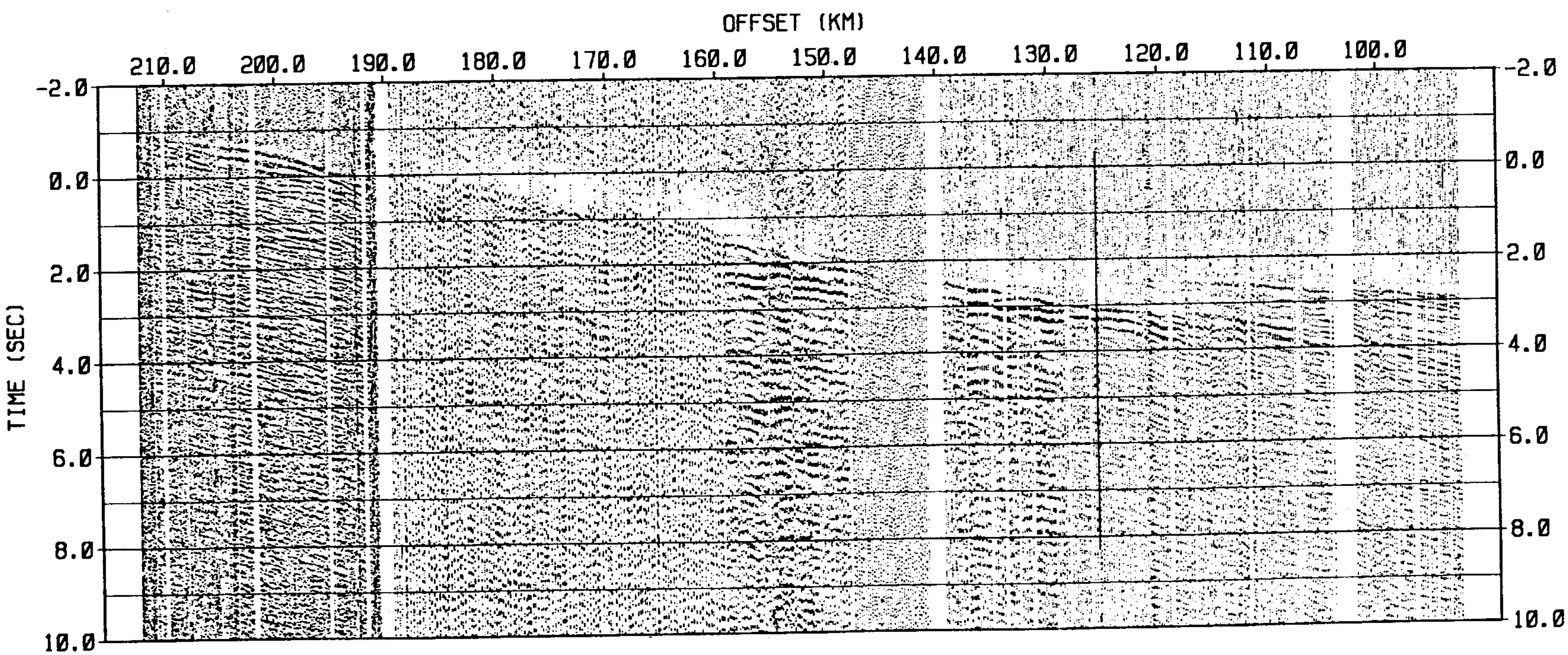

Figure 73 Profile 4

Shot 44 Shot Point 153 AGC = 2 sec

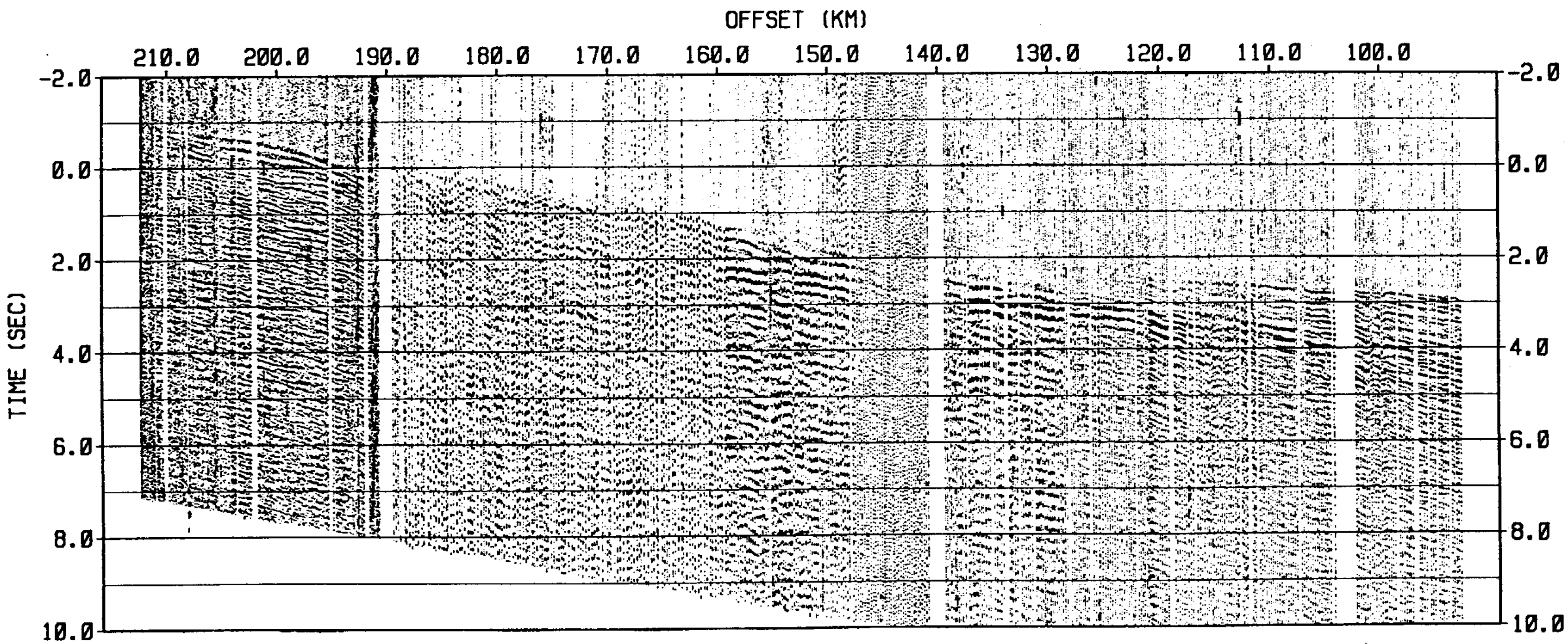

Figure 74 Profile 4

Shot 44 Shot Point 153 AGC = 12 sec

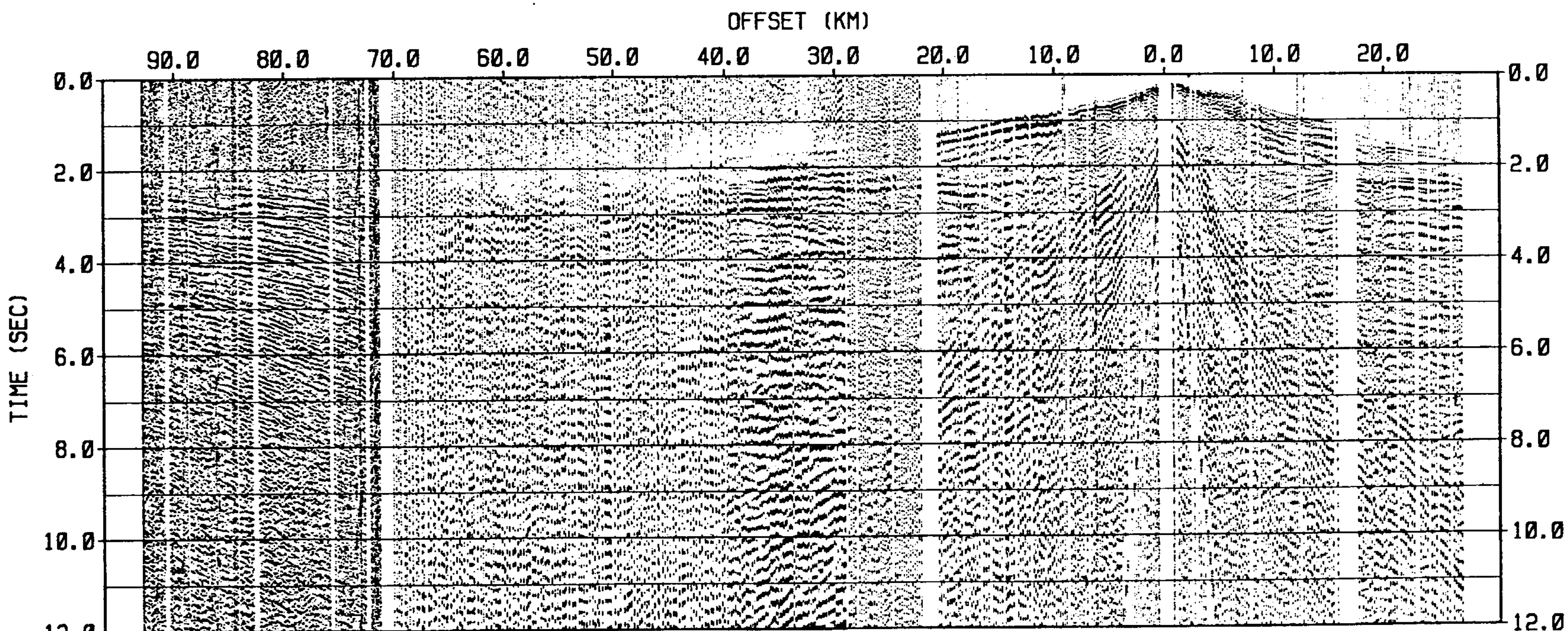

Figure 75 Profile 4

Shot 45 Shot Point 145 AGC = 2 sec

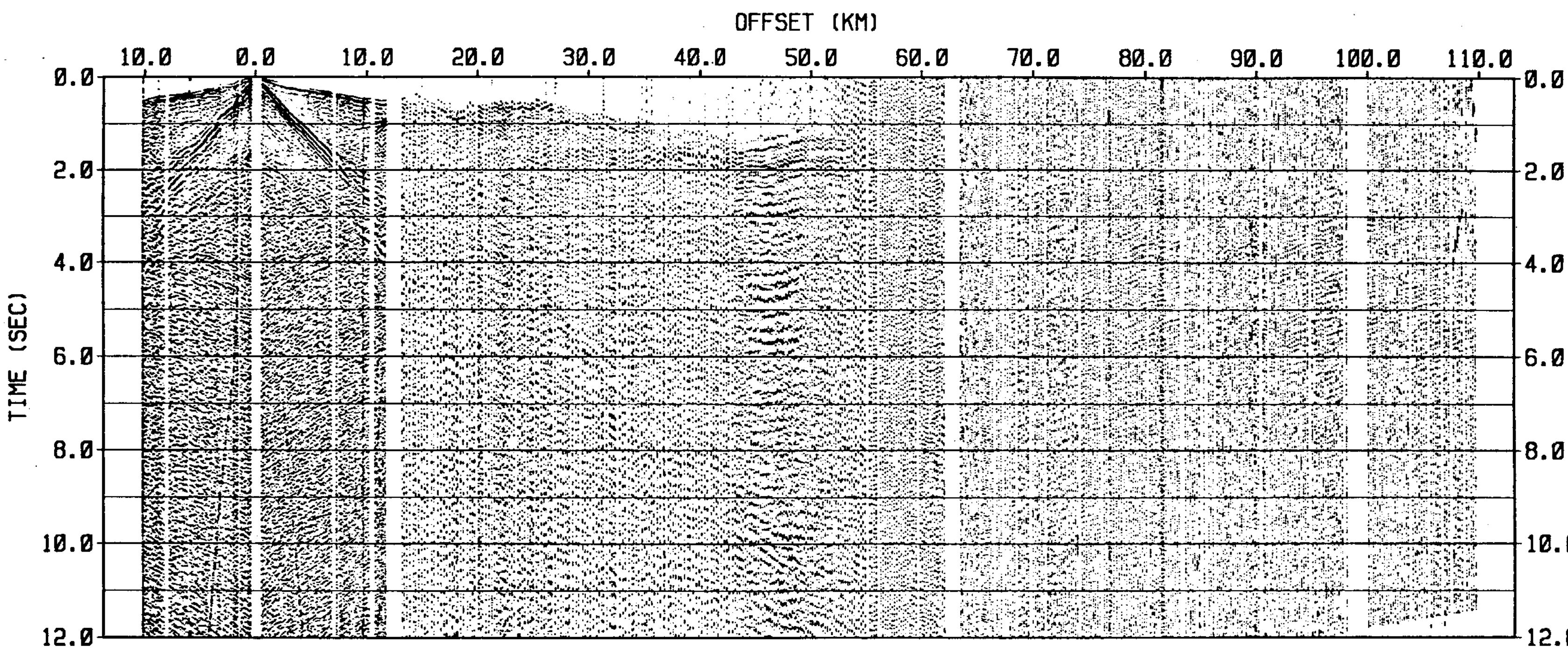

Figure 76 Profile 4

Shot 46 Shot Point 180 AGC = 2 sec

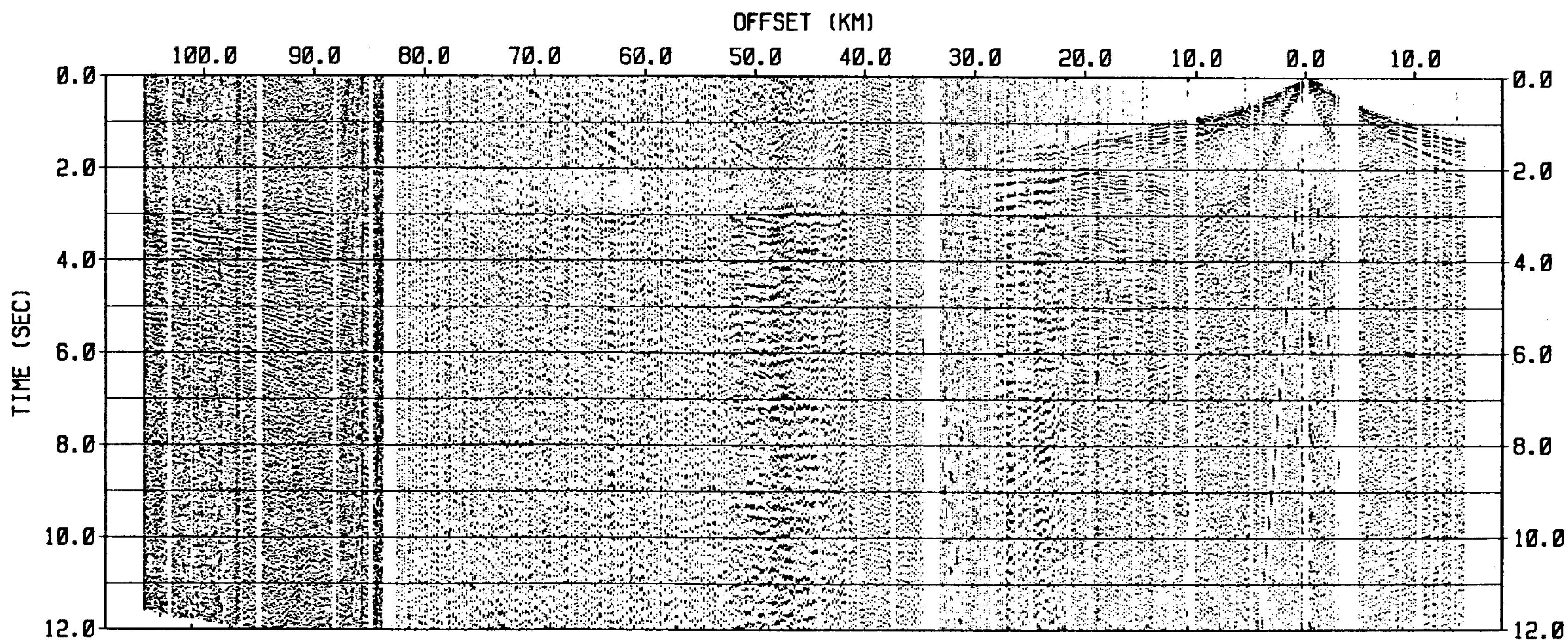

Figure 77 Profile 4

Shot 47 Shot Point 188 AGC = 2 sec

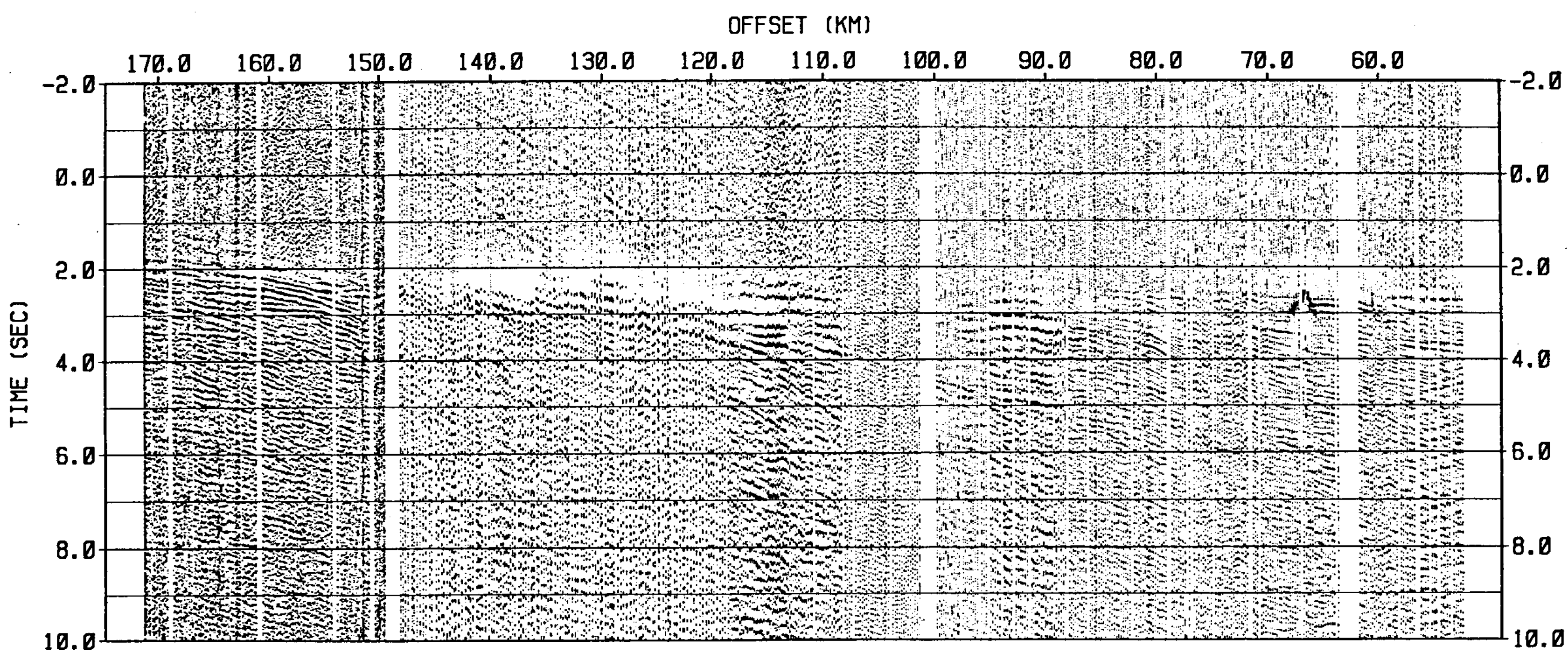

Figure 78 Profile 4

Shot 48 Shot Point 149 AGC = 2 sec

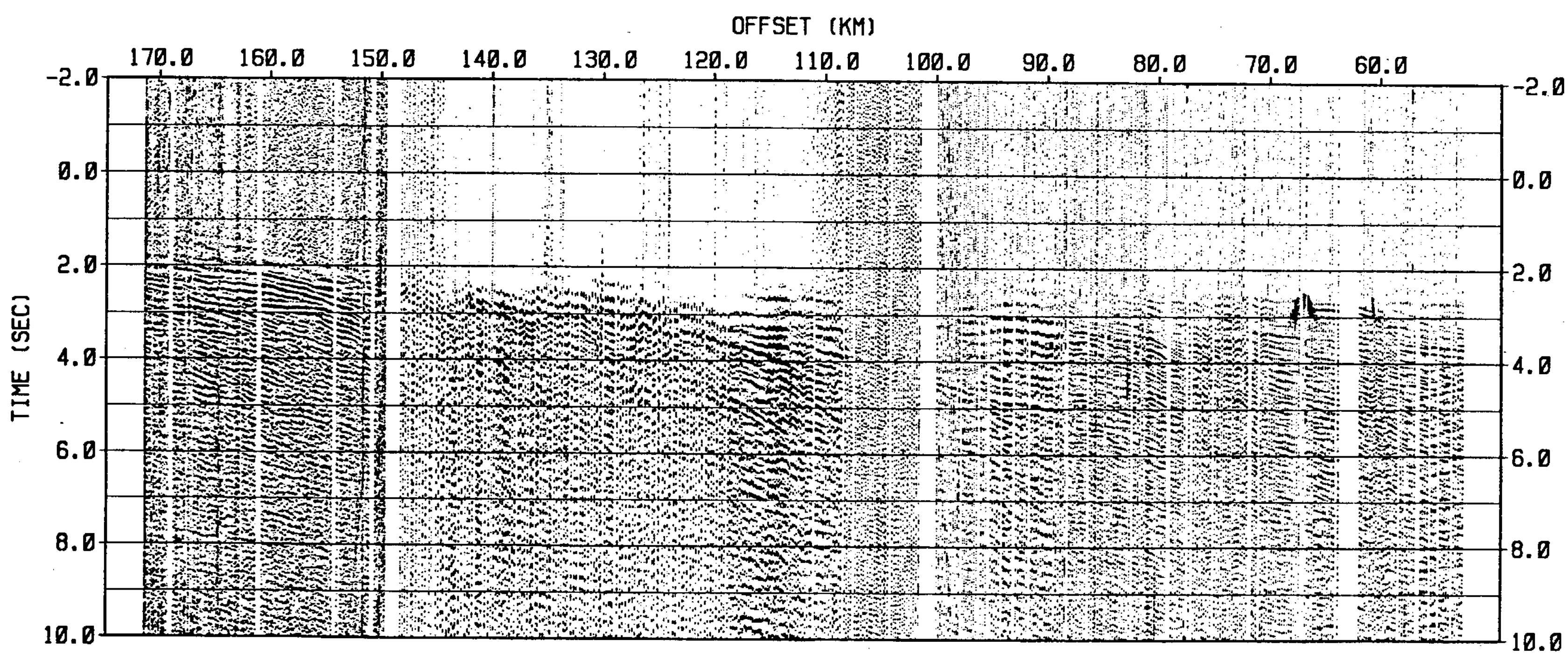

Figure 79 Profile 4

Shot 48 Shot Point 149 AGC = 12 sec

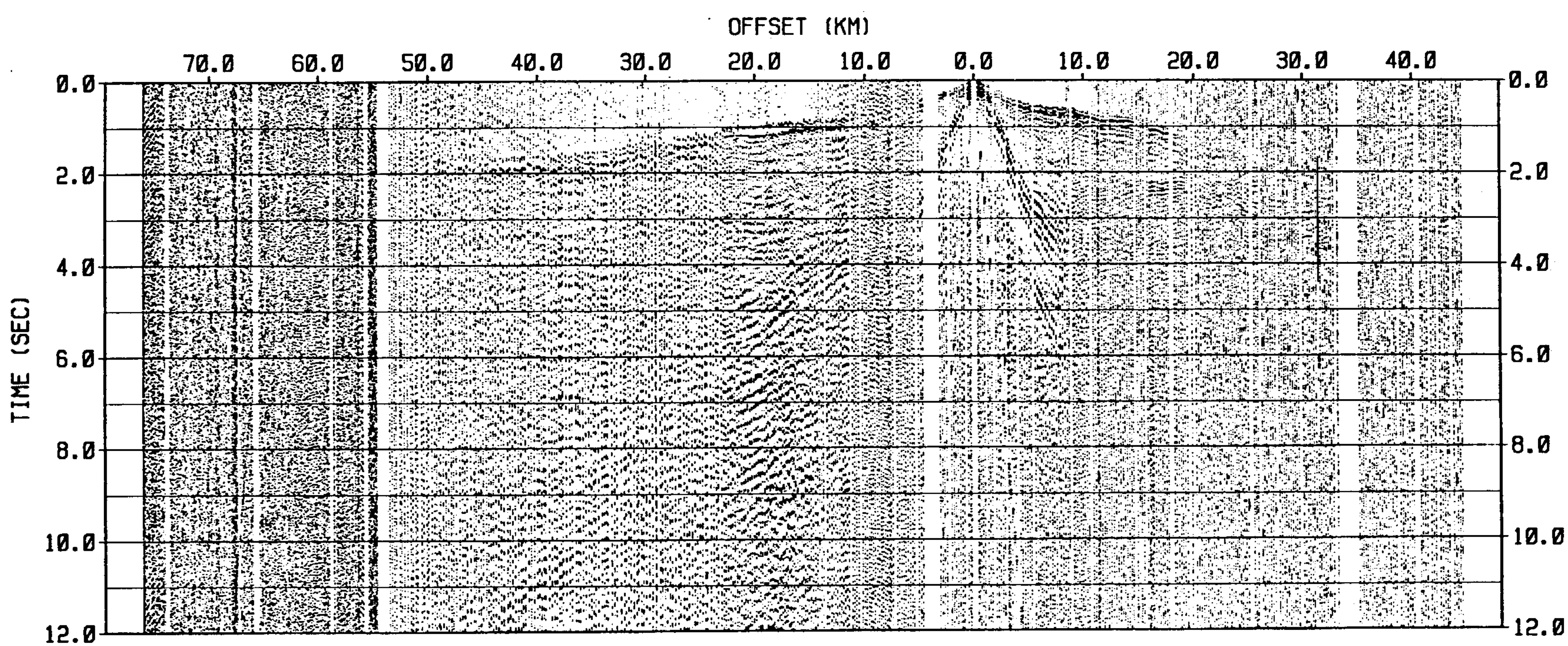

Figure 80 Profile 4

Shot 49 Shot Point 186 AGC = 2 sec

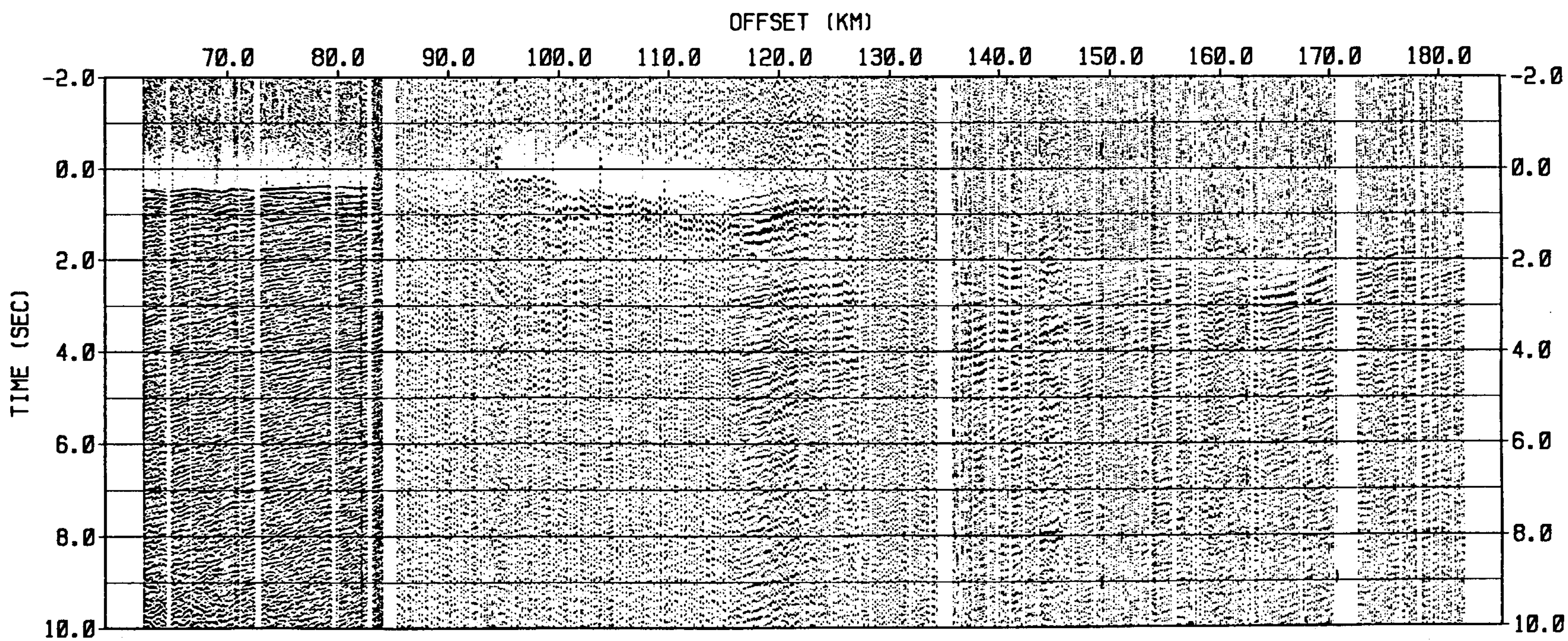

Figure 81 Profile 4

Shot 50 Shot Point 132 AGC = 2 sec

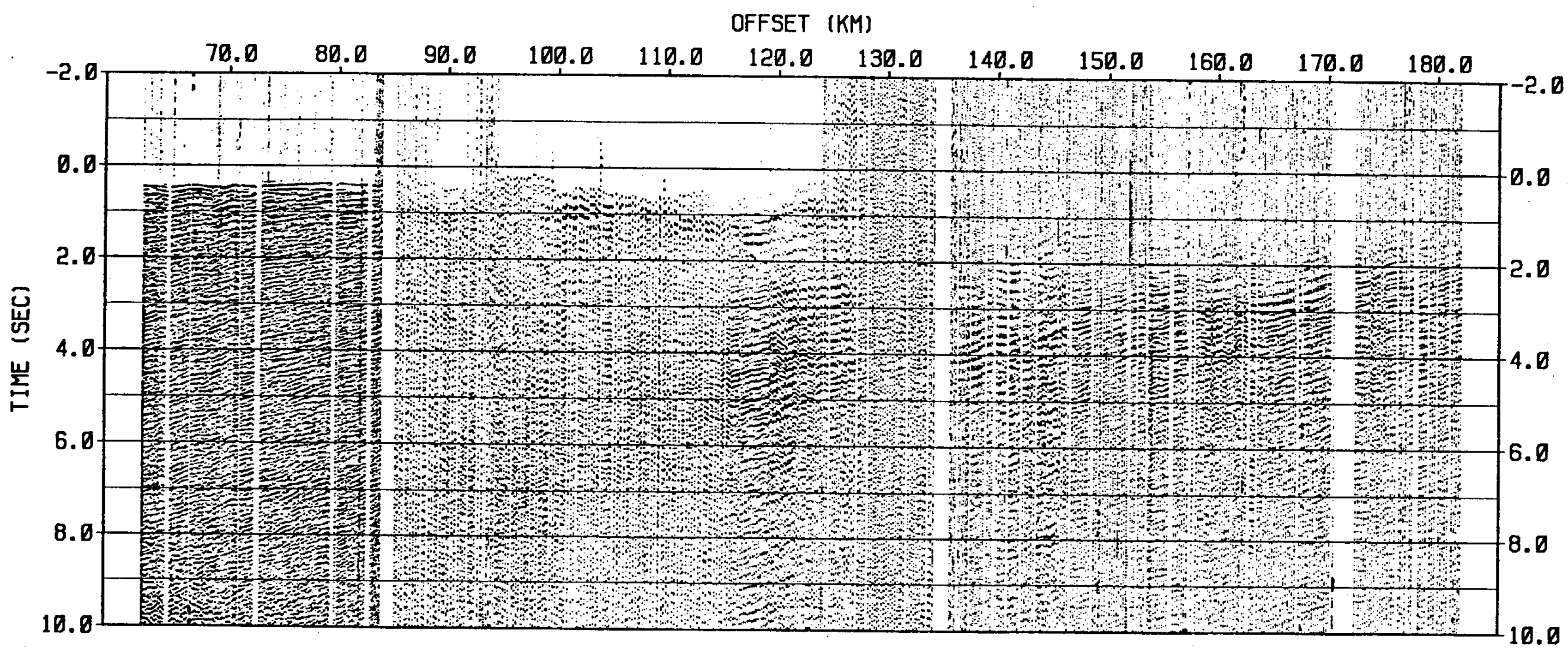

Figure 82 Profile 4

Shot 50 Shot Point 132 AGC = 12 sec

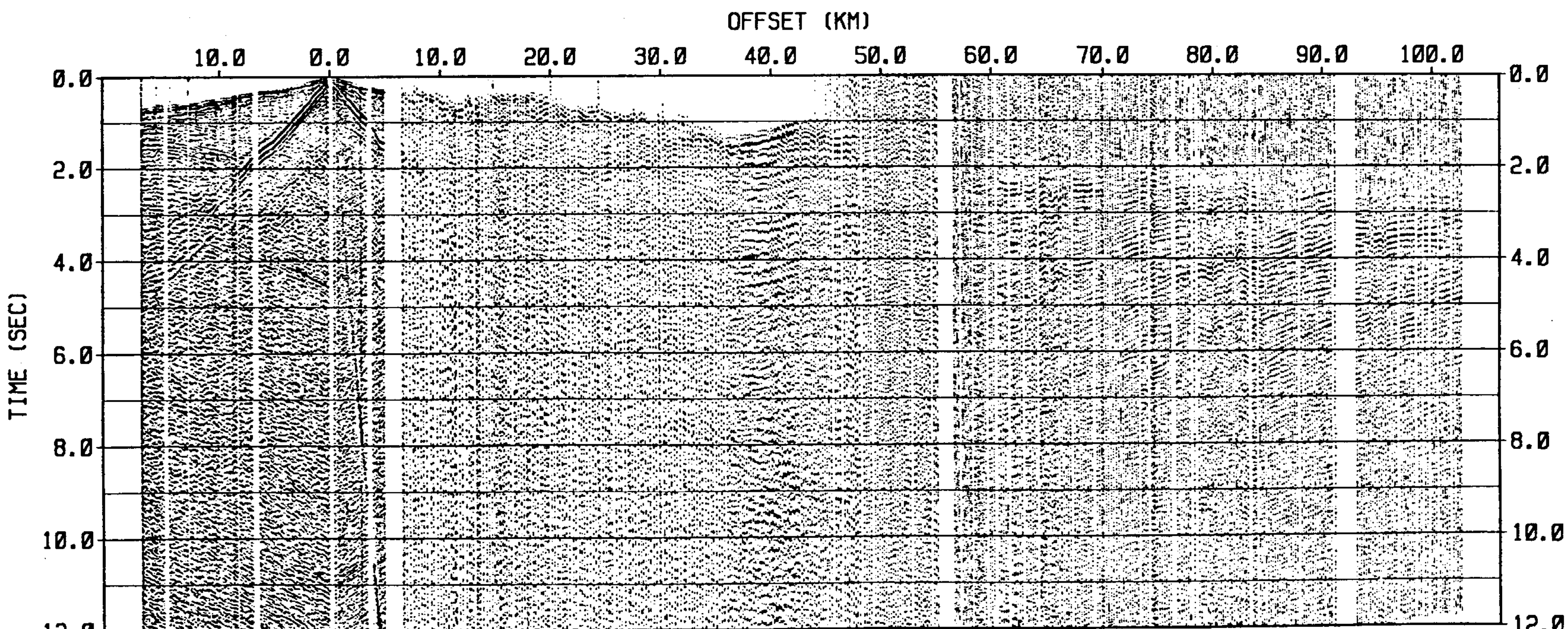

Figure 83 Profile 4

Shot 51 Shot Point 139 AGC = 2 sec

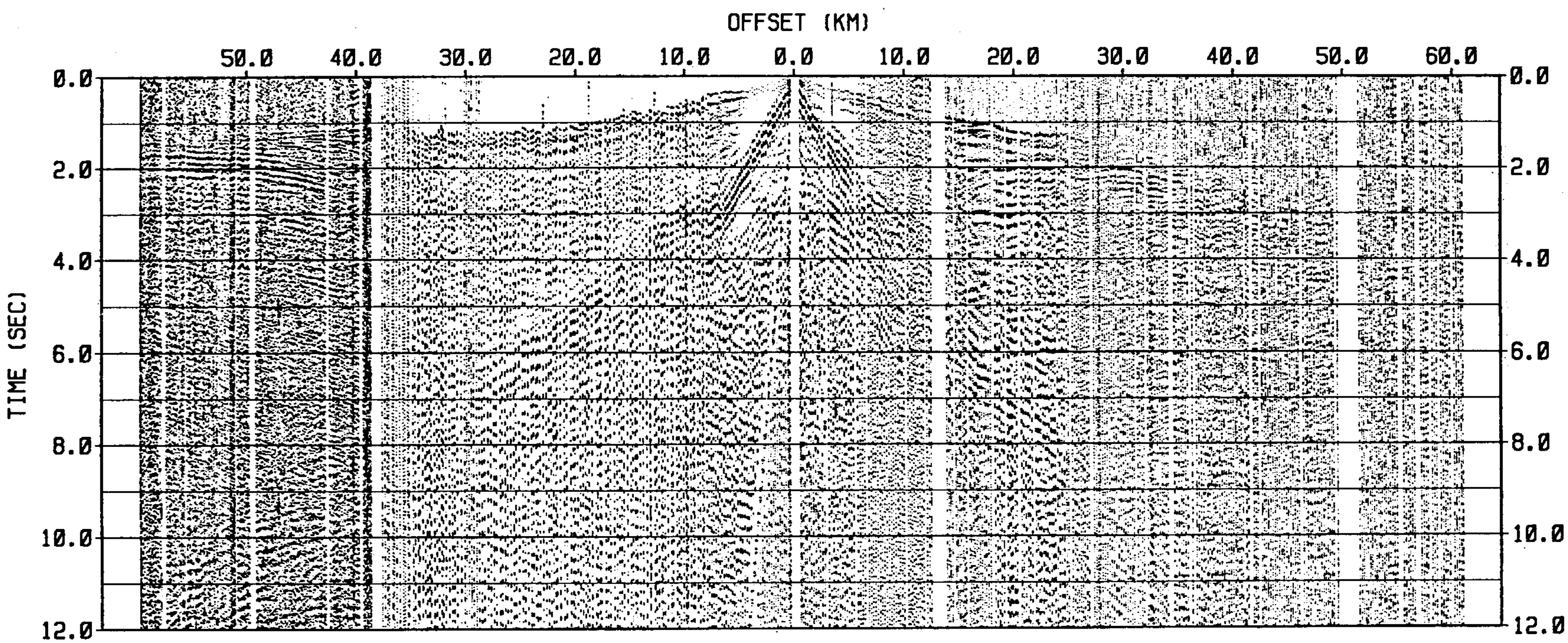

Figure 84 Profile 4

Shot 52 Shot Point 150 AGC = 2 sec

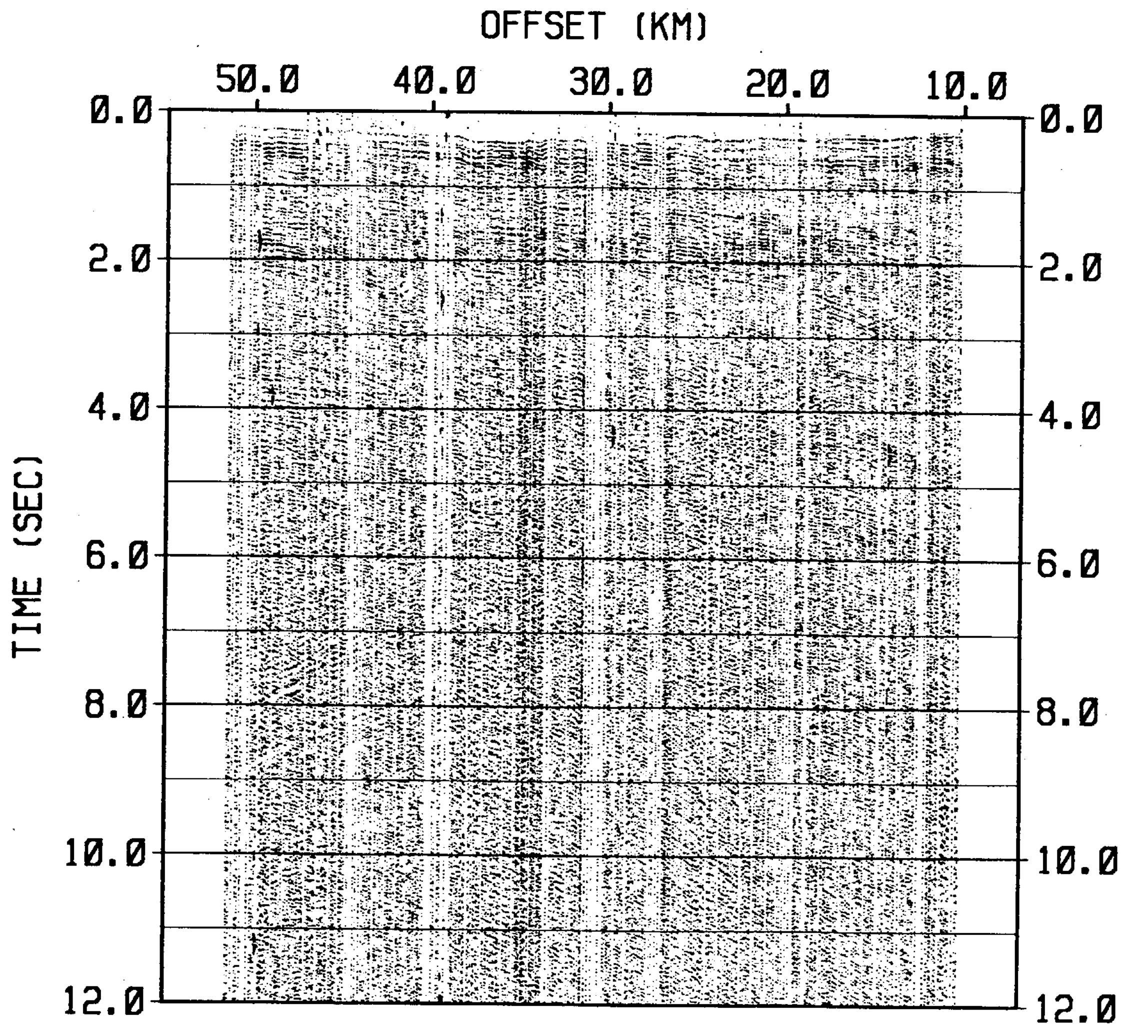

Figure 85 Profile 5

Shot 53 Shot Point 136 AGC = 2 sec

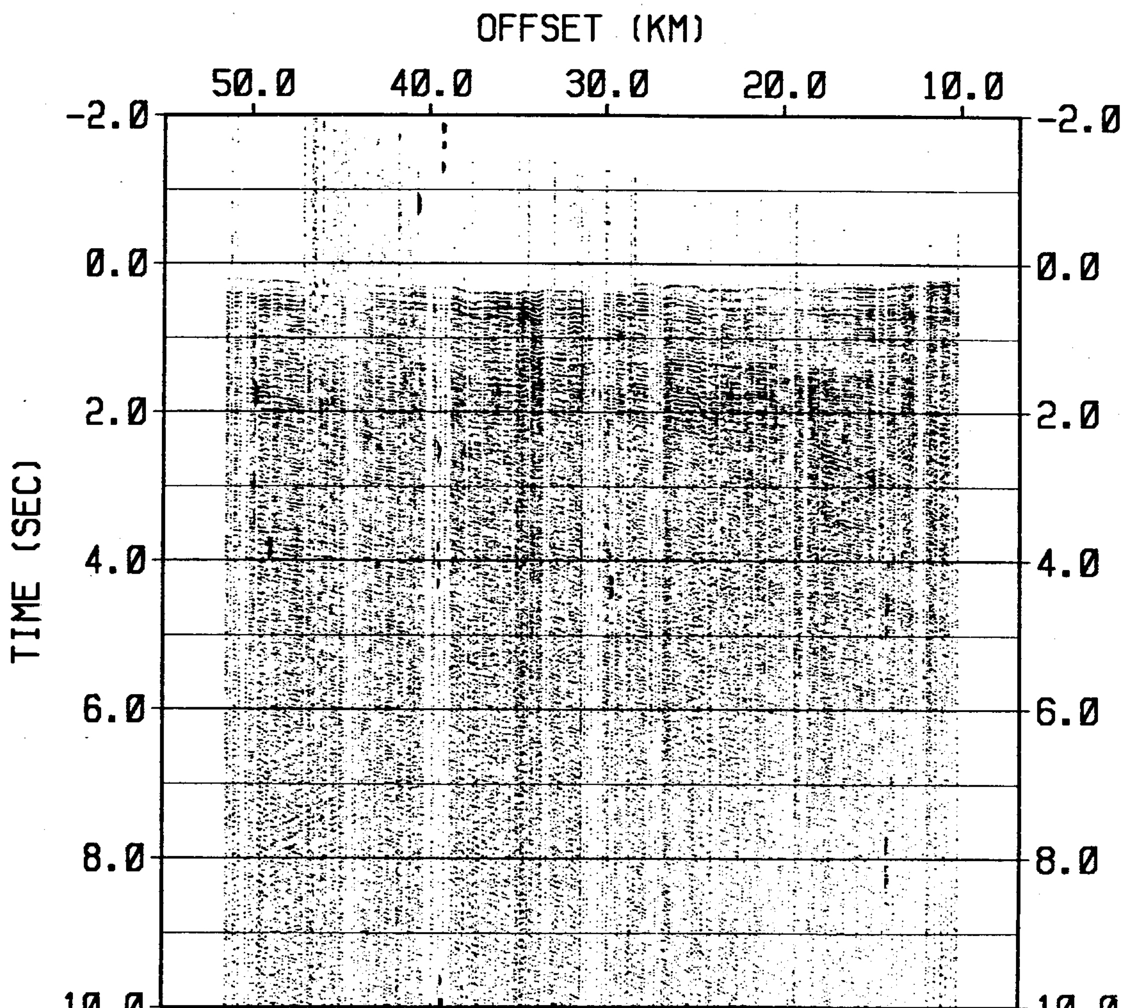

Figure 86 Profile 5

Shot 53 Shot Point 136 AGC = 12 sec

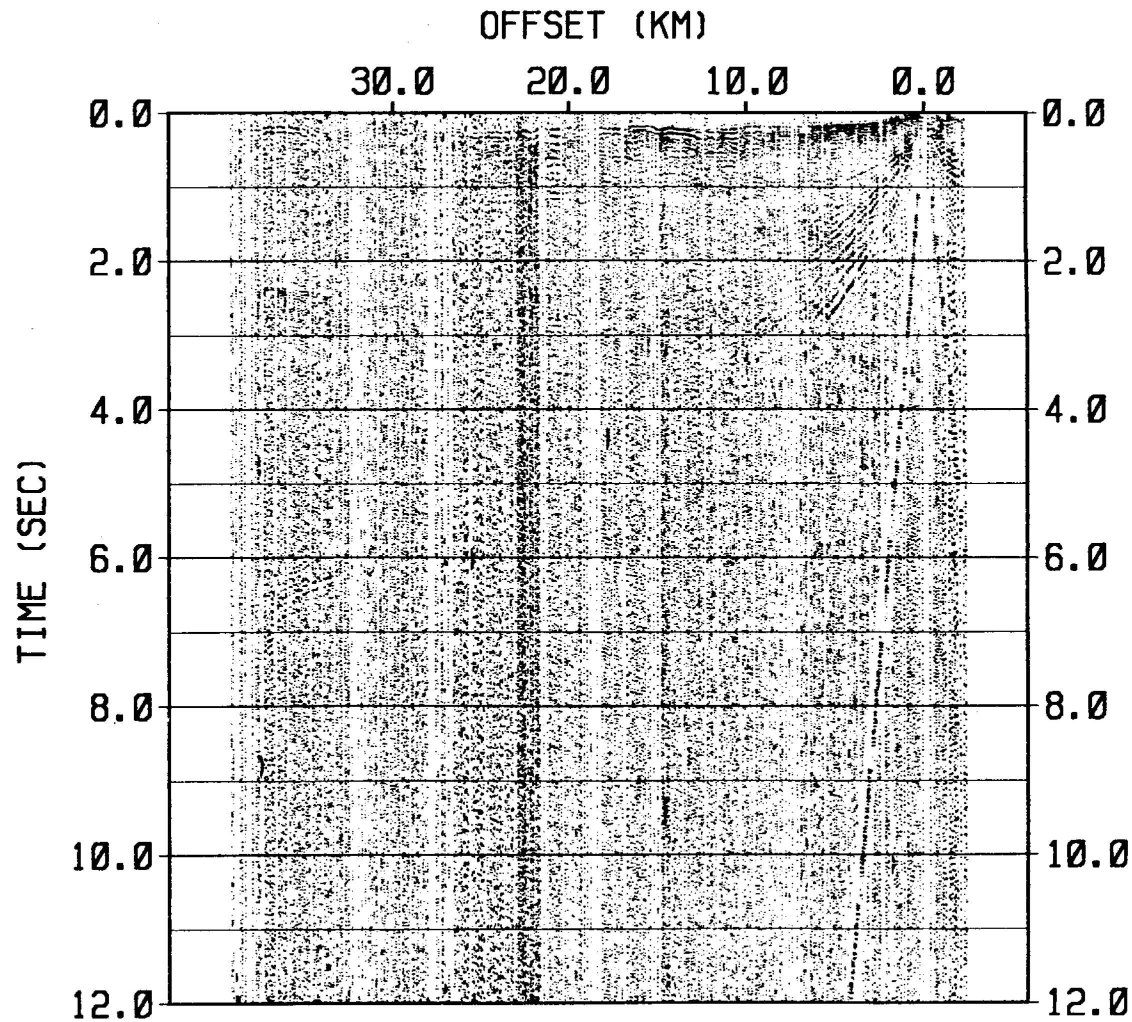

Figure 87 Profile 5

Shot 54 Shot Point 134 AGC = 2 sec

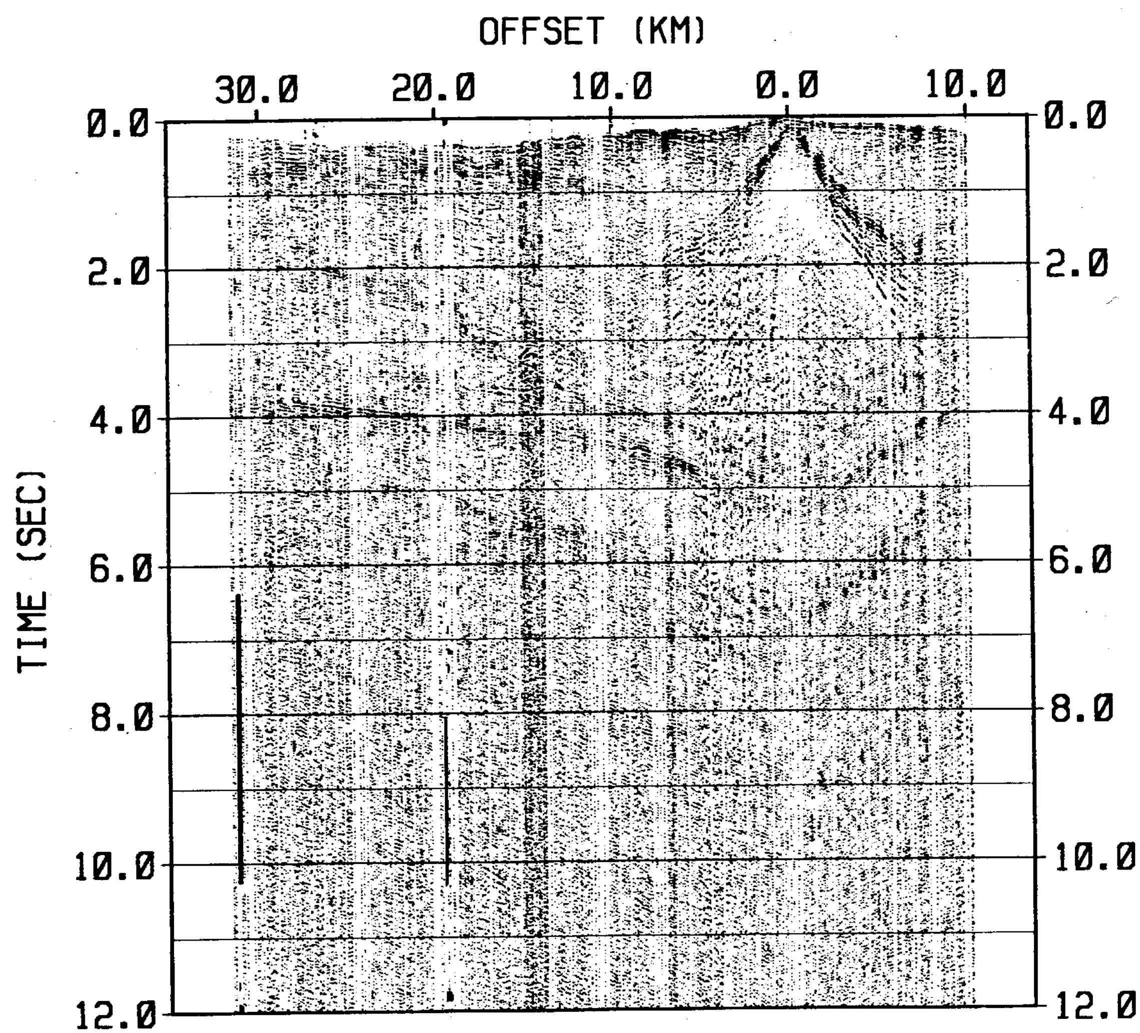

Figure 88 Profile 5

Shot 55 Shot Point 133 AGC = 2 sec

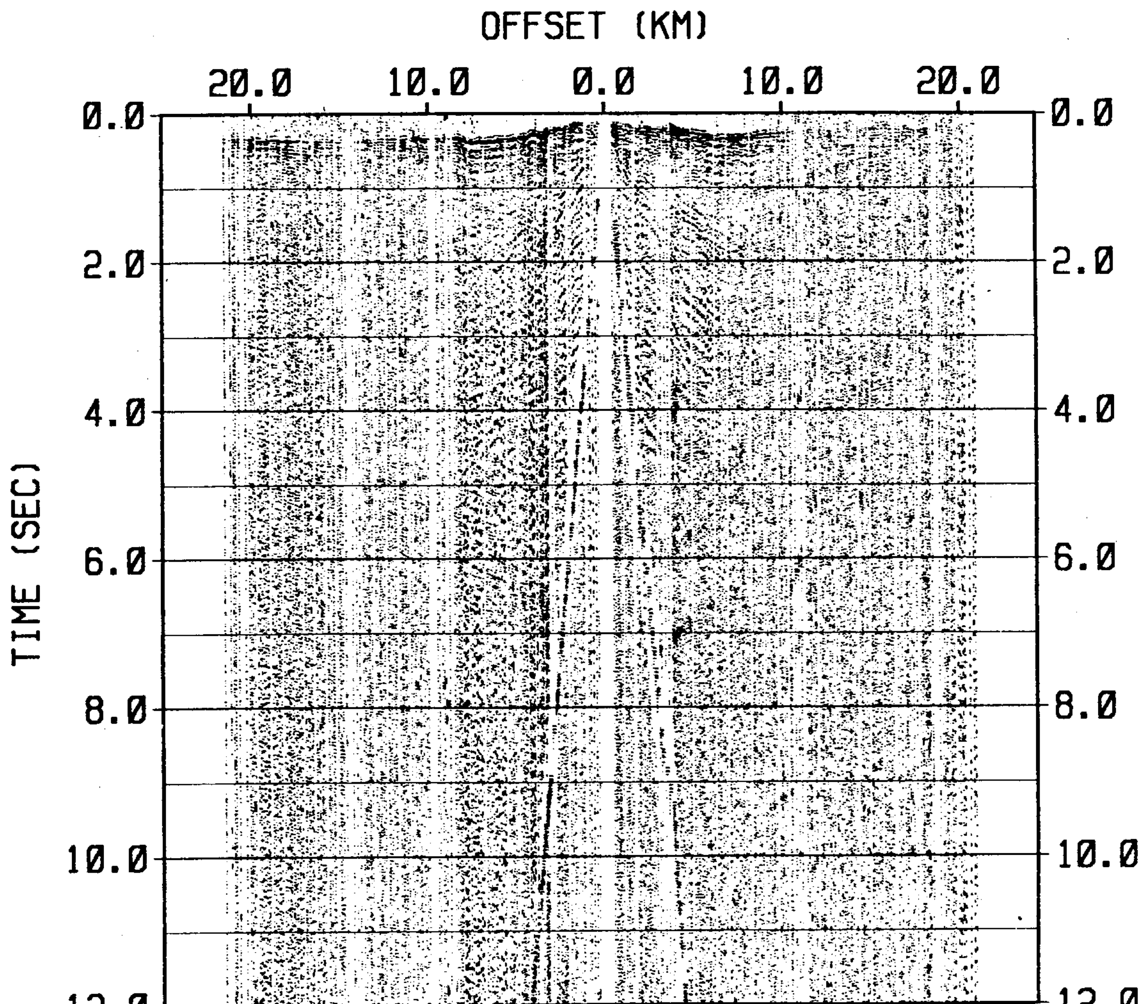

Figure 89 Profile 5

Shot 56 Shot Point 132 AGC = 2 sec

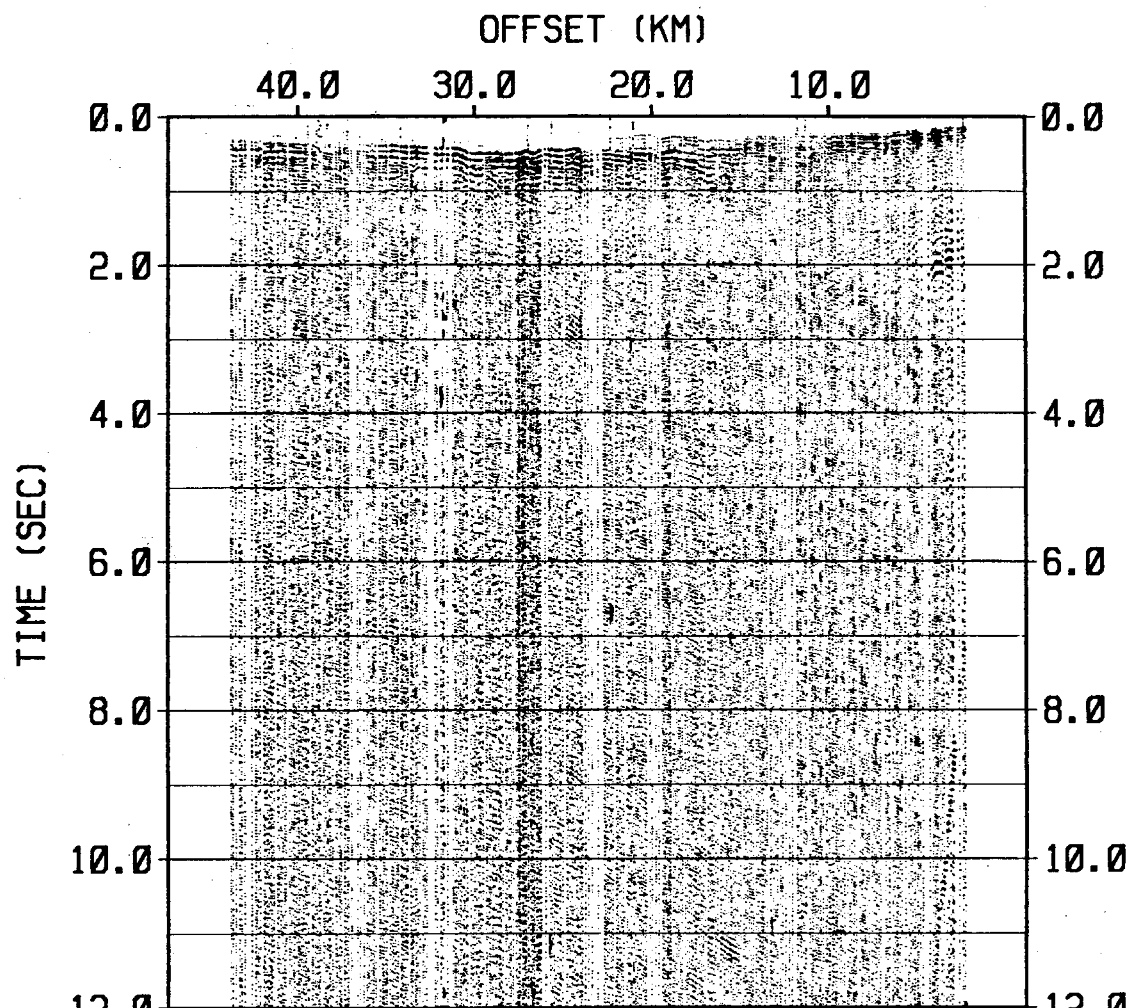

Figure 90 Profile 5

Shot 57 Shot Point 135 AGC = 2 sec

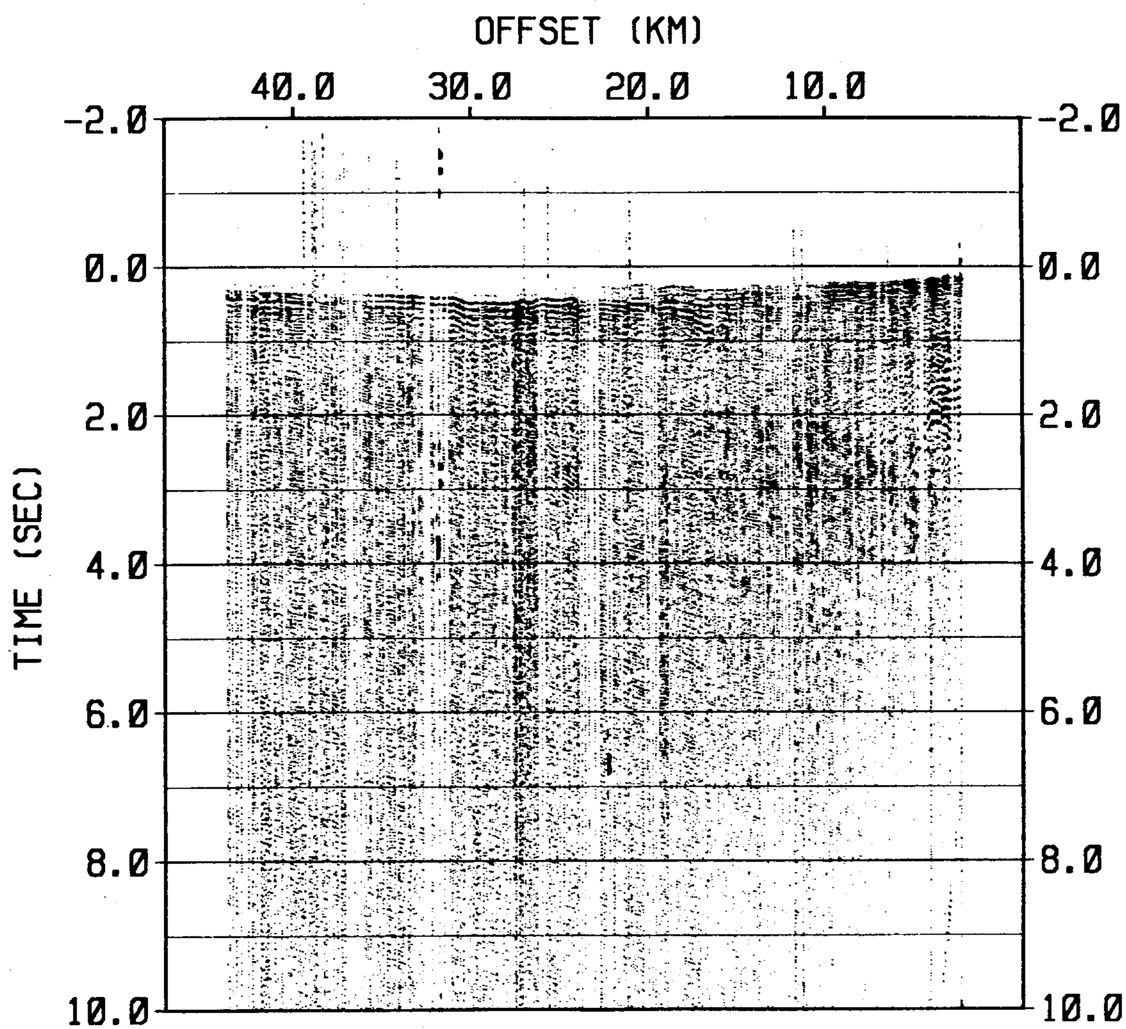

Figure 91 Profile 5
Shot 57 Shot Point 135 AGC = 12 sec

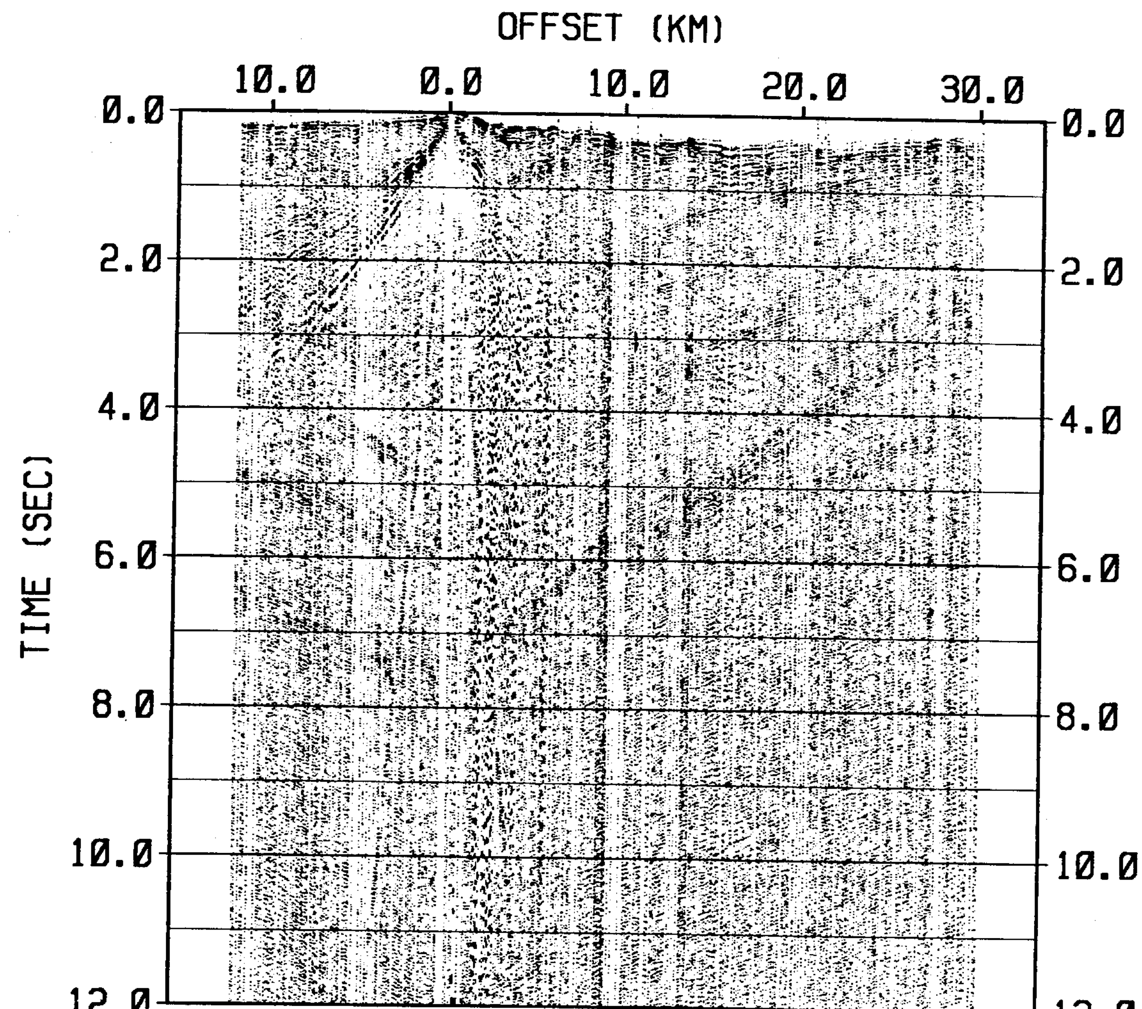

Figure 92 Profile 5

Shot 58 Shot Point 174 AGC = 2 sec

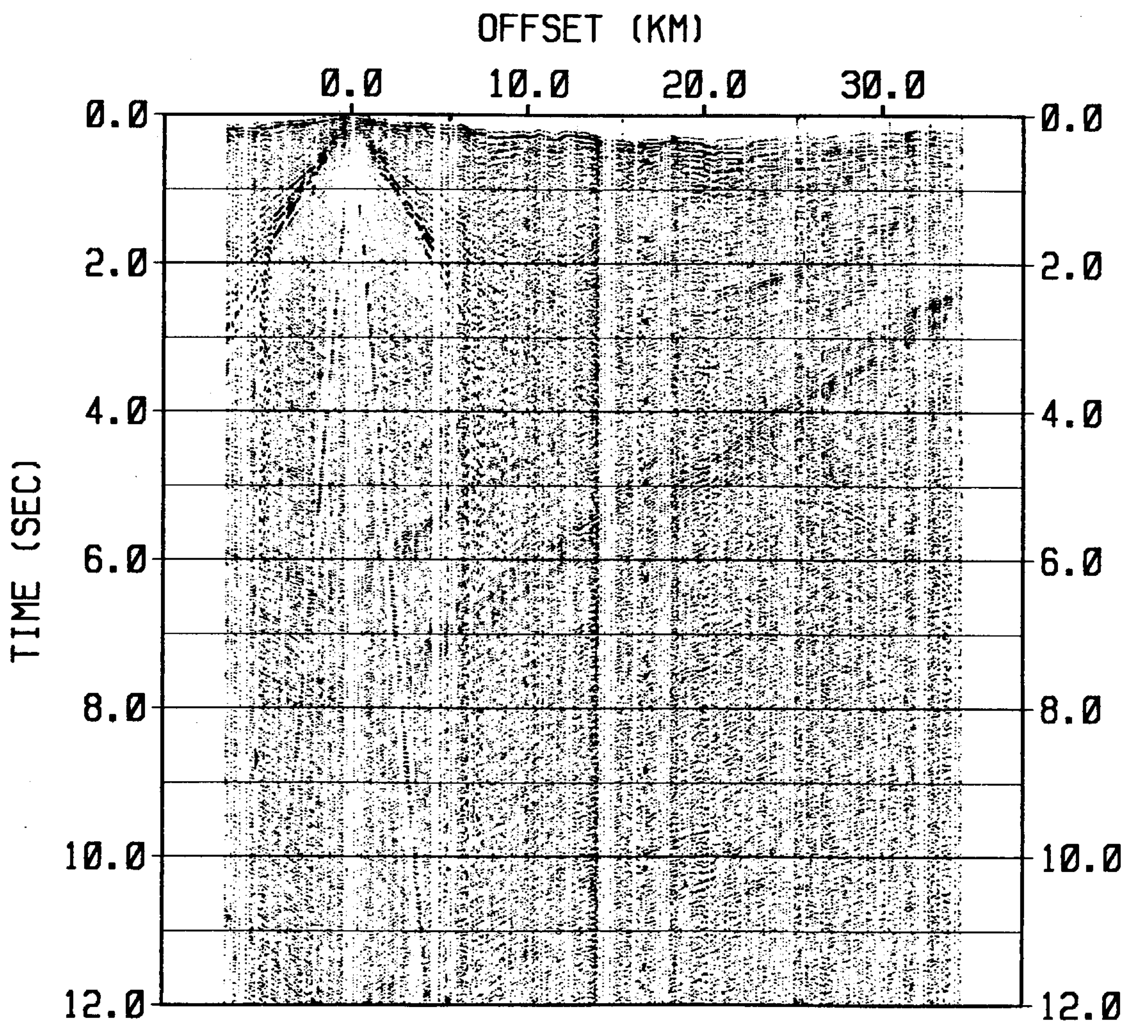

Figure 93 Profile 5

Shot 59 Shot Point 173 AGC = 2 sec

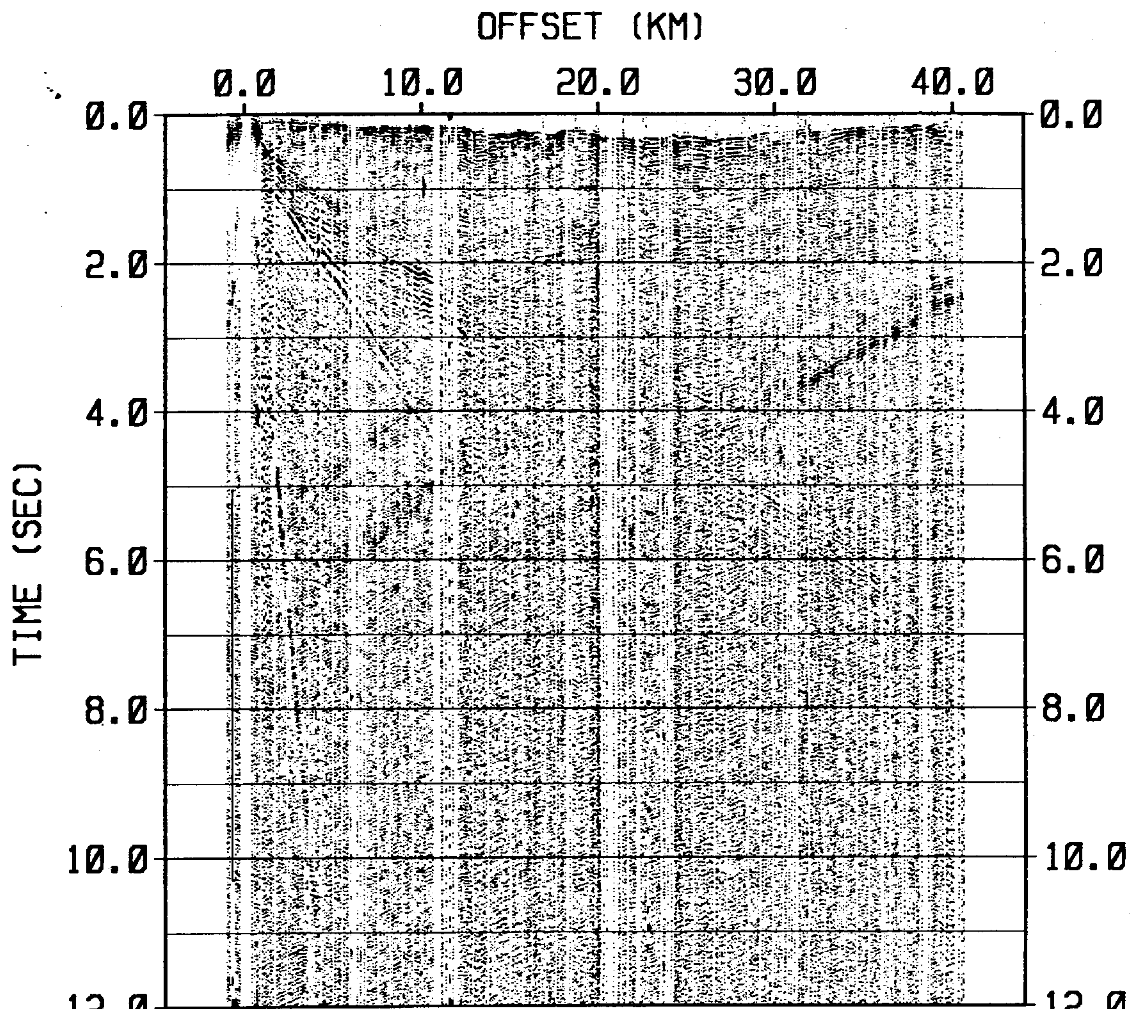

Figure 94 Profile 5

Shot 60 Shot Point 131 AGC = 2 sec

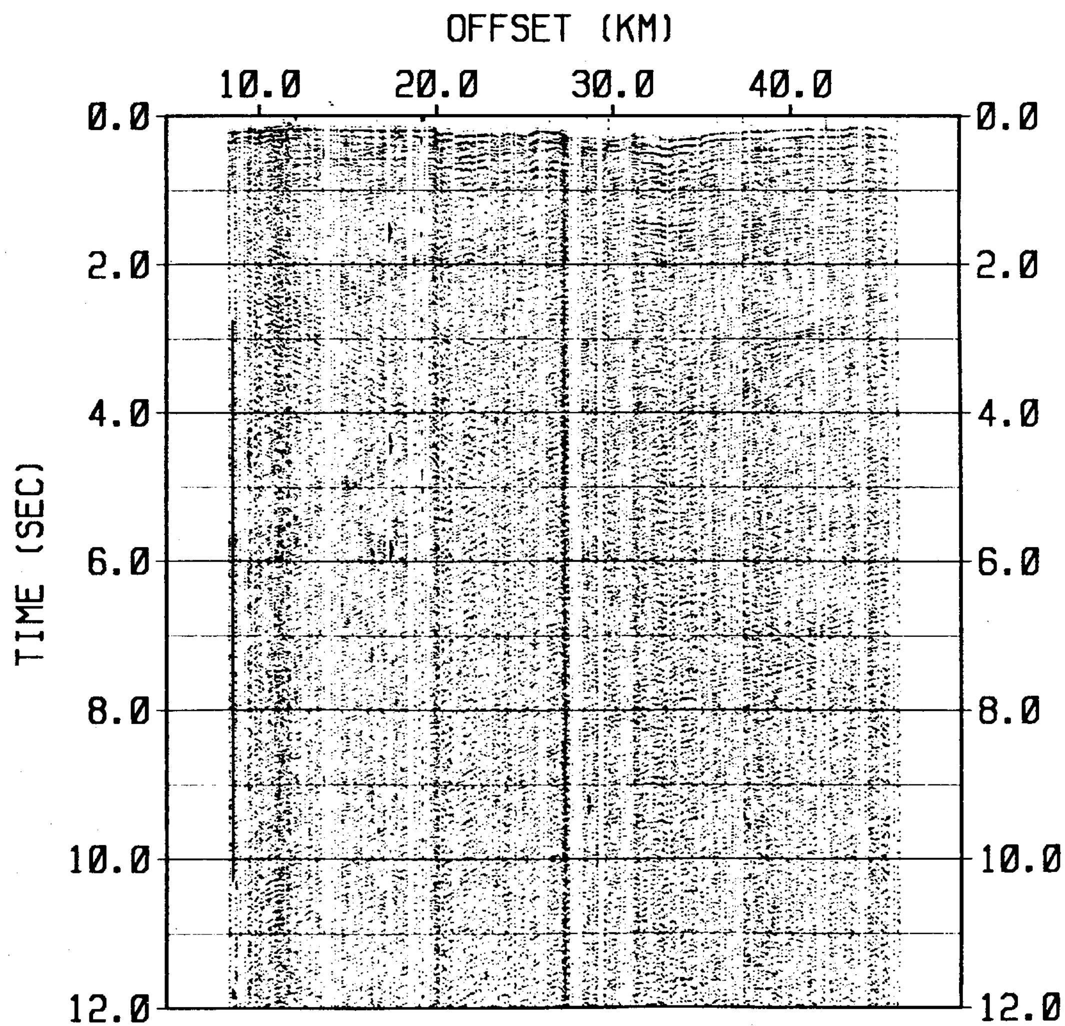

Figure 95 Profile 5

Shot 61 Shot Point 172 AGC = 2 sec

APPENDIX B

TABLE B1

Typical maximum data length for different instrument types, in-lineshots, and off-end shots.

Instrument/Boxtype	In-line shot data length (sec)	Off-end shot data length (sec)
SCR / 1	30	38
SGR / 2	30 - X/8	63 - X/8
PRS1 / 3	45 - X/8	55
Ref Tek / 4	58 - X/8	60

where X is the absolute value of offset distance. Maximum trace lengths vary slightly for different deployments, but may be significantly shorter for alternate shot windows.