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Open File 1317

PRAISE 1985: CRUSTAL SEISMIC REFRACTION PROFILES IN THE PEACE RIVER ARCH REGION, NORTHWESTERN ALBERTA AND NORTHEASTERN BRITISH COLUMBIA

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Abstract

The Peace River Arch is a regional geological structure located within the Western Canada Sedimentary Basin in north-central western Alberta and northeastern British Columbia which, in contrast to adjacent parts of the Basin, was an anomalously positive tectonic element during the Devonian period and possibly earlier parts of the Paleozoic Era. In Carboniferous and later Paleozoic time, in association with the development of economically and tectonically significant basement and intrabasinal fault systems, the Peace River Arch inverted and became a site of (relatively) excess subsidence and sediment accumulation.

As one component of the ISPG's multidisciplinary Peace River Arch Project, aimed at discovering those fundamental processes leading to the formation of intrabasinal arches and troughs generally, a major crustal seismic refraction programme was undertaken in June 1985 in association with a number of Canadian universities, particularly the Universities of British Columbia and Saskatchewan, and EMR's Earth Physics Branch. The Peace River Arch Seismic Experiment - PRASE 1985 - involved the acquisition of deep refraction seismic data along approximately 1300 km of line from explosive detonations at eleven sites in Alberta and British Columbia. Fifty-six recorder systems were repeatedly deployed along four separate 300-350 km lines.

The complete set of recorded seismic data is stored on magnetic tape and is documented here, including presentation of all preliminary seismic sections.

Introduction

The Peace River Arch is a geological structure in north-central western Alberta and eastern British Columbia (Figure 1) which has been a site of anomalous subsidence history during much of the development of the western Canada sedimentary basin system. The supracrustal geology of the Peace River Arch comprises a detailed record of its Phanerozoic vertical motions and is reasonably well known. The exploration programme conducted by the oil and gas industry in the Peace River Arch area is one of the most significant in western Canada both historically and recently.

The nature of the crystalline crust and upper mantle in the Peace River Arch area on the other hand is poorly known. Of pertinent geophysical observations, only reconnaissance gravity maps are available to the public. Regional scale aeromagnetic maps of the area surrounding the Peace River Arch will be published by the Geological Survey of Canada (GSC) in the near future. In 1985, the GSC's Institute of Sedimentary and Petroleum Geology (ISPG) conducted an extensive crustal seismic refraction survey in the area in cooperation with several Canadian universities. The purpose of this Open File is to facilitate the public release of the seismic refraction data, as compiled by the University of British Columbia under contract to the Department of Supply and Services (DSS). Included are a brief tectonic history of the study area; the scientific objectives of the refraction programme, especially in terms of the relationship between crust and upper mantle structure and the subsidence and thermal history of sedimentary basins; and a complete description of the acquisition and compilation stages, including instrumentation and file characteristics, leading to the final seismic refraction data set documented here. In the present fiscal year (April 1986-March 1987) the Universities of British Columbia and Saskatchewan, under separate DSS contracts, are analyzing portions of these seismic refraction data in order to provide a best possible structural interpretation of the Earth's crust underlying the Peace River Arch.

The 1985 crustal scale "Peace River Arch Seismic Experiment" (PRASE '85) described here is one component of an ongoing "Peace River Arch Project" being developed and carried out by personnel of the Institute of Sedimentary and Petroleum Geology, GSC, Calgary. The Peace River Arch Project is aimed at a comprehensive, multidisciplinary "basin analysis" of a complete spectrum of geological, geophysical, and geochemical problems focused on the "Peace River Arch" structure of the Western Canada Sedimentary Basin and has the objective of quantitatively understanding the driving mechanisms and "life histories" of intrabasinal arches and troughs generally.

Tectonic History of Peace River Arch Area

The history of the sedimentary basins of southwestern Canada probably began in late Precambrian time when continental rifting established a passive (or "Atlantic-type") continental margin, with adjacent ocean to the west; this margin subsided during much of Early Paleozoic time in response to conductive cooling of the underlying lithosphere which had been stretched, thinned, and heated during rifting. The sedimentation history supporting such a model is recorded by the Cambro-Ordovician stratigraphy of the southern Canadian Rockies (Bond and Kominz, 1984) comprising a sedimentary basin known as the Early Paleozoic miogeosyncline. It may have been tectonically analogous to the Mesozoic and Cenozoic sedimentary basin formed along the rifted Atlantic continental margin of Canada (*e.g.* Keen, 1979; Beaumont *et al.*, 1982a). Little or no Cambro-Ordovician miogeosynclinal or associated platformal sediments are preserved in the Peace River area, hence its stratigraphic designation as an "arch". It is thought that the Peace River Arch was uplifted and eroded after Early Paleozoic sedimentation and prior to renewed Late Devonian and later subsidence (*e.g.* DeMille, 1958). It is possible, however, that the Arch was a positive paleo-geographic feature throughout the Early Paleozoic, perhaps as a result of some speculative anomalous Proterozoic cratonic ancestry (*cf.* Stelck *et al.*, 1978). In this regard there appears to be nothing definitively unusual about the composition and age of the Precambrian crystalline basement which underlies the Peace River area.

Attenuation of tectonically-driven subsidence and sedimentary choking possibly combined with eustatic sea level lowering led to subaerial exposure as a coastal plain of much of the Cambro-Ordovician miogeosynclinal continental shelf sequence during the Silurian Period. In the Devonian Period a marine transgression from the north, probably related to eustatic sea level changes and Ellesmerian tectonics in northwestern Canada, reflooded much of the Albertan region, permitting renewed sedimentation which encroached upon the Peace River Arch. The Arch at this time may have been isolated or possibly linked to the Western Alberta Arch, a positive feature which lay in the vicinity of the present Rocky Mountains and foothills. Whether the Peace River and Western Alberta Arches were genetically linked is not known.

Reef complexes in which commercial oil pools were later discovered (*ibid.*) developed in the vicinity of the Peace River Arch in Late Devonian time but marine transgression progressed continuously until the Arch was completely submerged near the close of the Devonian Period. Thereafter, during the Carboniferous and Permian Periods, the history of the Peace River area continued to contrast with that of surrounding regions. The region of the Arch contains the only major incursion of Permian strata into Alberta east of the present deformed belt of the Rocky Mountains (*e.g.* McGugan *et al.*, 1964). During this time, in conjunction with normal faulting and possible graben formation, the Arch became a depocentre with apparently greater subsidence and thicker accumulations of sediment than elsewhere (*e.g.* Lavoie, 1958; Procter and Macauley, 1968) and/or became a site of favoured preservation of these sediments (*e.g.* Sikabonyi and Rodgers, 1959). The precise nature and timing of Permo-Carboniferous vertical motions of the Peace River Arch are not fully understood but have a direct bearing on the economic potential of the region. During the Triassic Period, basin development in the Peace River area assumed a pattern essentially conformable with the rest of the northwest-southeast trending western Canadian Triassic basin system although there is some evidence that Triassic subsidence in the Peace River region remained somewhat favoured relative to areas north and south (Williams, 1958). Favoured subsidence of the Arch appears to be less likely in the Jurassic Period. The tectonic framework by this time consisted of the Cordilleran orogenic complex to the west and the stable continent with Paleozoic platform sediments to the east (*e.g.* Carlston, 1968). By the end of the Jurassic the sea was expelled and sedimentation interrupted in association with a rapidly emerging western Canadian landmass.

The foreland basin phase of basin formation in western Canada began during the Early Cretaceous and culminated in the Eocene at the end of the Laramide orogeny (*e.g.* Beaumont *et al.*, 1982b). Foreland basin subsidence occurred as the flexural isostatic response of rigid lithosphere to the weight of eastward verging thrust sheets in the Rocky Mountains (*e.g.* Price, 1973) and has been quantitatively modelled by Beaumont (1981). The Peace River Arch area may have been a favoured centre of Early Cretaceous foreland subsidence (Rudkin, 1964). By the close of the Cretaceous Period the Peace River Arch may have reverted to being a positive geographic feature, possibly as a peripheral flexural upwarp linked to more intense Laramide foreland thrusting farther south, in a manner analogous to that described by Beaumont (1981) for the more southeasterly region.

Objectives of the Crustal Seismic Refraction Project

The scientific justification of studying the crust in the vicinity of the Peace River Arch are those of the multidisciplinary Lithoprobe Project (*cf.* CANDEL, 1981): to elucidate the deep structure and composition of the continental lithosphere and relate it to surface geology. While deep crustal studies in regions of exposed crystalline crust are facilitated by potential correlations between inferred deep structure and surface structural features, studies in regions of Phanerozoic sedimentary cover rocks, such as the Peace River Arch, have the very great advantage of having their tectonic histories recorded in the overlying sedimentary sections.

There are two fundamental sedimentary basin subsidence mechanisms (*cf.* Beaumont *et al.*, 1982b) relevant to the Peace River area: thermal subsidence, possibly, but not necessarily, related to continental rifting with associated cratonward platformal sedimentation; and foreland basin flexural subsidence. A major problematic element of the Peace River Arch's stratigraphy is the anomalous Permo-Carboniferous preserved section. The duration, apparent structural control, and general form of this anomaly, coupled possibly with the preceding Devonian or earlier uplift, is suggestive of a crustal and/or upper mantle driving mechanism, possibly related to thermal events at a passive margin. In the context of finding quantitative geodynamic models to explain the anomalous vertical motions in the Peace River Arch region, one of the most important modelling constraints is the relationship between the observed basin histories and variations in intracrustal and crustal thicknesses and seismic velocities as well as upper mantle seismic velocities. These observations are necessary to credibly constrain isostatic mechanisms. Knowledge of the structure of the Mohorovicic discontinuity and/or intracrustal horizons in the direction perpendicular to the deformed Cordilleran fold-thrust belt are also expected to be helpful in determining the flexural properties of the lithosphere which controlled the more recent foreland phase of basin development in western Canada. Existing seismic refraction studies in the Rocky Mountains and foothills in southern Alberta (Kanasewich, 1968; Chandra and Cumming , 1972; Mereu *et al.*, 1977) do not resolve very clearly the nature of the crustal thickening in front of and beneath the deformed belt.

An important ancillary unresolved problem in the Peace River Arch area is the geometry and extent of basement penetrating faults, periodically reactivated during the various Phanerozoic uplift and subsidence events, a problem potentially addressed by regional seismic reflection imaging of the basement and deeper crustal levels. In this context, the crustal refraction studies undertaken in 1985 can be viewed as providing a structural framework in terms of which future deep reflection profiling may be more reliably interpretable.

Refraction Survey

Introduction. The recording of the Peace River Arch seismic refraction data was conducted under DSS contract 01SG.23294-5-0572 to the University of British Columbia (UBC) and was a cooperative effort of UBC, the Universities of Toronto, Western Ontario and Alberta, the Earth Physics Branch, and the Institute of Sedimentary and Petroleum Geology (Geological Survey of Canada), each of which contributed both personnel and equipment. Canterra Energy Limited and Chevron Canada Resources Limited, both of Calgary, made substantial financial contributions to the University of British Columbia which significantly enhanced the data acquisition program. The provision of seismic energy for the Peace River Arch refraction survey was conducted under a separate DSS contract, O1SG.23294-5-0573, to the University of Saskatchewan. Table 1 lists the persons from each of these institutions who participated in the field programme. The "Statements of Work" forming parts of the DSS contracts to the Universities of British Columbia and Saskatchewan are reproduced as Appendices A and B.

Table 1: Participants[1], Peace River Arch Seismic Refraction survey.
Asterisks identify each institution's principal organizer.

Division of Seismology and Geomagnetism, Earth Physics Branch[2]: Patrick Morel*, Blake Wright

Institute of Sedimentary and Petroleum Geology: Sean Lavery, Randell Stephenson*

University of Alberta: David Anholt

University of British Columbia: Andy Boland, Doug Brown, John Cassidy, Ben Ciammaichella, Connie Cudrak, Jeff Drew, Michael Ehling, Bob Ellis*, Bob Meldrum, Colin Zelt

University of Saskatchewan: Geoff Coleman, Zoli Hajnal*, Brian Reilkoff, Doug Scott, Dave Wilkonson

University of Toronto: Andrew Gunstensen, Doug Northey, Trevor Shortt

University of Western Ontario: Tina Hewak, Bob Mereu*, Karin Michel, Karen Morrissey

1 In addition, Gordon West (University of Toronto) and Ernie Kanasewich (University of Alberta) organized the participation of the recording teams from their institutions; and Jim Wright (Memorial University of Newfoundland) and Doug Bingham (Alberta Environment) arranged for the use of the seismic systems from their organizations.

2 Now Institute of Lithospheric and Precambrian Geoscience, Geological Survey of Canada.

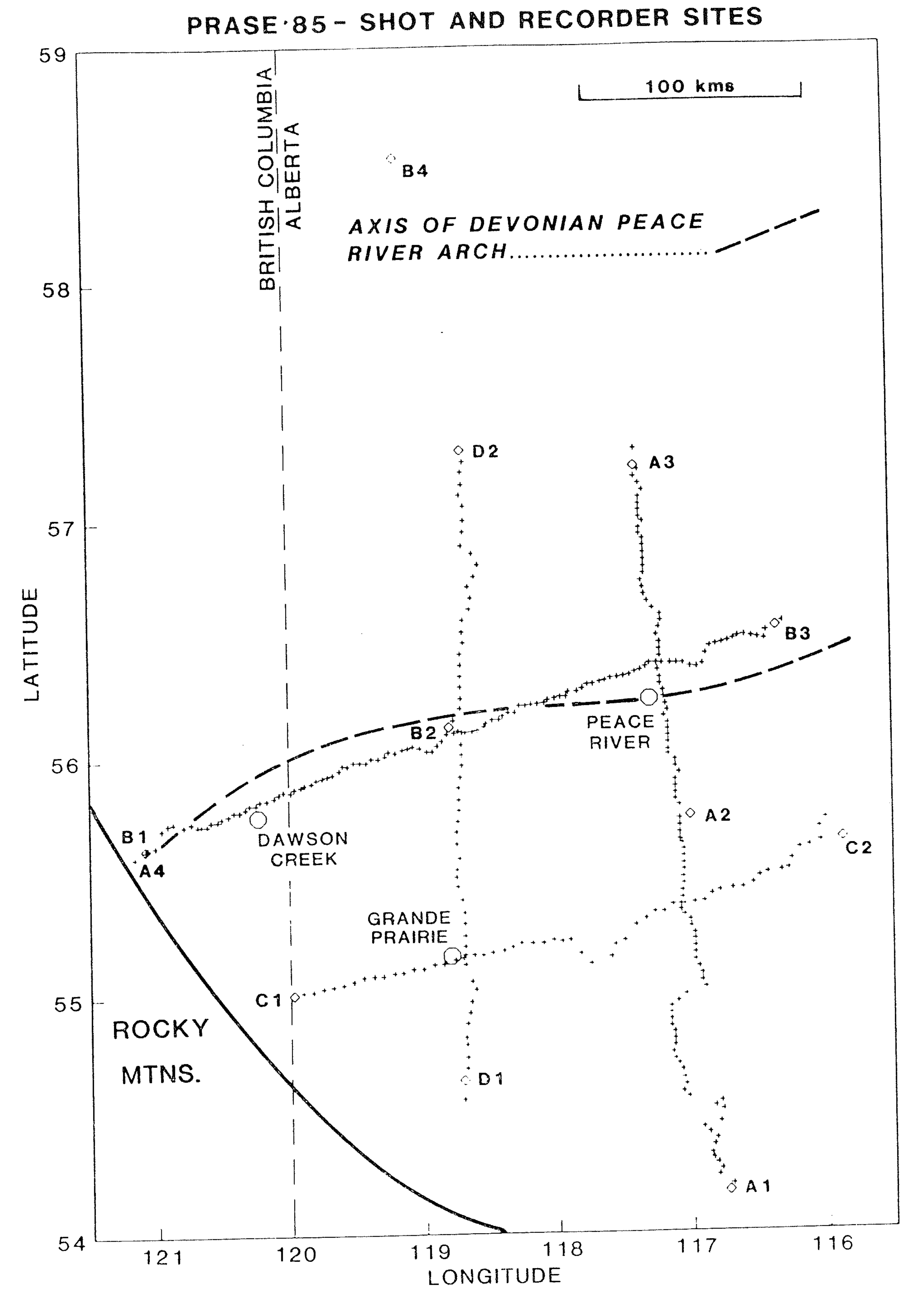

Figure 1. Shotpoints (diamonds) and receiver sites (crosses) for the Peace River Arch Seismic Experiment.

Seismic Profiles. Preliminary scouting of the survey area was conducted in August 1984. In order to fulfil the principal objective of the refraction survey, to acquire a data set which could be interpreted to outline the crust and upper mantle structure on and in the vicinity of the Peace River Arch, four seismic lines (Figure 1) were laid out: Line A approximately orthogonal to the Arch; Line B along the axis of the Arch; and two subsidiary lines, C and D, parallel on the south side and orthogonal to the Arch, respectively. Ideally, a fifth line would have been located parallel and north of the Arch; however, the very limited road access prevented this. To obtain some data in this area, a fan shot was used from the north (shot point B4) into line B.

Fifty-six seismographs were available for recording each shot. Briefly, the data were acquired as follows: for Line A (south) the 56 available seismographs were laid out between shot points A1 and A2 and shot into from A1, A2, A3 and A4. The seismographs were then distributed between A2 and A3 (Line A north) and the same shot sequence repeated. For Line B (west) the seismographs were distributed between B1 and B2 and shots detonated at B1, B2, and B3. The same shot sequence was repeated with the recorders located between B2 and B3 (B east). The fan shot (B4) was detonated with the stations distributed over the whole profile, *i.e.* B1 to B3. For Line C, the seismographs were distributed between C1 an C2 with shots at the end points (C1 and C2) only. Similarly, for Line D the seismographs were distributed between D1 and D2 with shots at the end points (D1 and D2).

Recording sites were selected and flagged by a team from the University of British Columbia in late May 1985. The sites are identified by a three digit code (see Table 2); the first digit is associated with the line (*e.g.* 1 indicates Line A south) and the second and third digits indicate the site number within the line which range from 1 to 56.

Shotpoints. Shotpoint sites (*cf.* Figure 1) were located in early May by a team from the University of Saskatchewan and in early June by a team from the Institute of Sedimentary and Petroleum Geology, and were subject to inspection and approval by local land use officials of Alberta Energy and Natural Resources (Forest Service Division) per File Geo-85-0032, Schedules I and II, or, in the case of shot-points A1 and B4, the British Columbia Ministry of Energy, Mines, and Petroleum Resources

Table 2: Recording site designations

Line	Site Nos.
A south	1xx [1]
A north	5xx
B west	2xx
B east	6xx
B fan	2xx & 6xx
C	3xx
D	4xx

1 The last 2 digits (xx) are the site no. (1-56) within the line.

per File 85-100. Alberta Exploration License No. 4662 and Exploration Permit No. 604 were held on behalf of the drilling operations by the ISPG. No similar licenses were required in British Columbia.

Drilling operations were undertaken by Graham Drilling, Bredenbury, Saskatchewan under sub-contract to the University of Saskatchewan. Explosives were purchased by the ISPG and delivered to the driller by Explosives Limited, Grande Prairie. Shot-holes of 20 cm diameter were drilled to depths of 30 m and loaded with 200 kg of Geogel 60%. Each was primed with two detonation caps, and plugged prior to shooting. Adjacent holes were offset by a minimum of 25 m. Seismic blasts comprised a number of shot-holes detonated simultaneously. Generally, 600 kg shots (three holes) were used when station offsets were 175 km and less, and 2000 kg shots were used when offsets were greater. Blasting operations were carried out between 22 June and 4 July by teams from the University of Saskatchewan. There were four partial misfires, two each at C1 and C2, where only 200 kg of charge detonated but some useful data were acquired from these (*cf.* Figures 20, 21). One unusual occurrence, involving combustion of unexploded Geogel, took place at shotpoint B1 (see Appendix C). The shot designations and parameters are shown in Table 3.

Shot-hole completions were undertaken in compliance with the requirements of the Alberta Forest Service and the British Columbia Ministry of Forests, including reseeding with recommended grass seed at all sites to secure surface stability. Excessive cratering, due to local ground conditions, occurred at shotpoints A1, A4, and B1. Restoration at these sites was carried out in part by local heavy equipment contractors at minimal extra cost. These locations are subject to re-inspection in 1986, after spring break-up, and to correction of further deterioration, prior to issuance of final reclamation certificates.

Recorder systems. The 56 portable seismographs were of six different types, four digital and two analog, each with its own characteristic gain and frequency response. A list of the systems, the numbers of each type, and their operational mode are provided in Table 4 and their relative velocity responses shown in Figures 2 to 9. All seismometers were Mark Products L-4; as indicated, both 1 Hz and 2 Hz were used. The Geotech MCR 600 systems were operated with either a 0.8 Hz or 0.2 Hz low cut filter (Figures 2 and 3). All data have been converted to a 60 Hz sampling rate. Variations in analog tape speed were taken into account.

Table 3: Shotpoint parameters

No.	Shotpoint	Origin Time[1] y d h m	Coordinates (N)	Coordinates (W)	Elev (km)	Charge (kg)
1	C2	85 171 11 15	55.6492	115.8774	0.716	200
2	C1	85 172 11 05	54.9971	119.9985	0.884	200
3	C1	85 172 11 25	54.9971	119.9985	0.884	200
4	C2	85 172 11 35	55.6492	115.8774	0.716	200
5	C1	85 173 11 05	54.9971	119.9985	0.884	1600
6	C2	85 173 11 15	55.6492	115.8774	0.716	1600
7	A2	85 175 11 05	55.7508	117.0012	0.617	600
8	A3	85 175 11 13	57.2244	117.3871	0.465	1400
9	A1	85 175 11 21	54.1718	116.7361	0.853	600
10	A4	85 175 11 45	55.6236	121.0789	0.762	2000
11	A2	85 177 11 05	55.7497	117.0011	0.617	600
12	A3	85 177 11 13	57.2203	117.3892	0.465	600
13	A1	85 177 11 21	54.1718	116.7361	0.853	1800
14	A4	85 177 11 29	55.6224	121.0781	0.762	1200
15	B1	85 179 11 05	55.6209	121.0766	0.762	2400
16	B2	85 179 11 15	56.1300	118.7989	0.611	600
17	B3	85 179 11 25	56.5422	116.3506	0.602	600
18	B4	85 181 11 05	58.5296	119.1406	0.511	2000
19	B2	85 183 11 15	56.1300	118.7989	0.611	600
20	B3	85 183 11 25	56.5422	116.3506	0.602	2000
21	B1	85 183 11 35	55.6209	121.0766	0.762	800
22	D1	85 185 11 05	54.6444	118.7100	0.800	2000
23	D2	85 185 11 15	57.2943	118.6896	0.876	2000

1 Times are UTC. Origin times are believed to be accurate to within 10 ms.

Table 4: Recorder systems

System	No. of Units	Type	Seismometer Frequency (Hz)
Geotech MCR 600	17	digital	1
UBC FM	5	analog	1
Univ. of Toronto	11	digital	2
UWO FM	9	analog	1
EPB MK 2 Backpack	12	digital	1 & 2
Sprengnether DR 100	2	digital	1

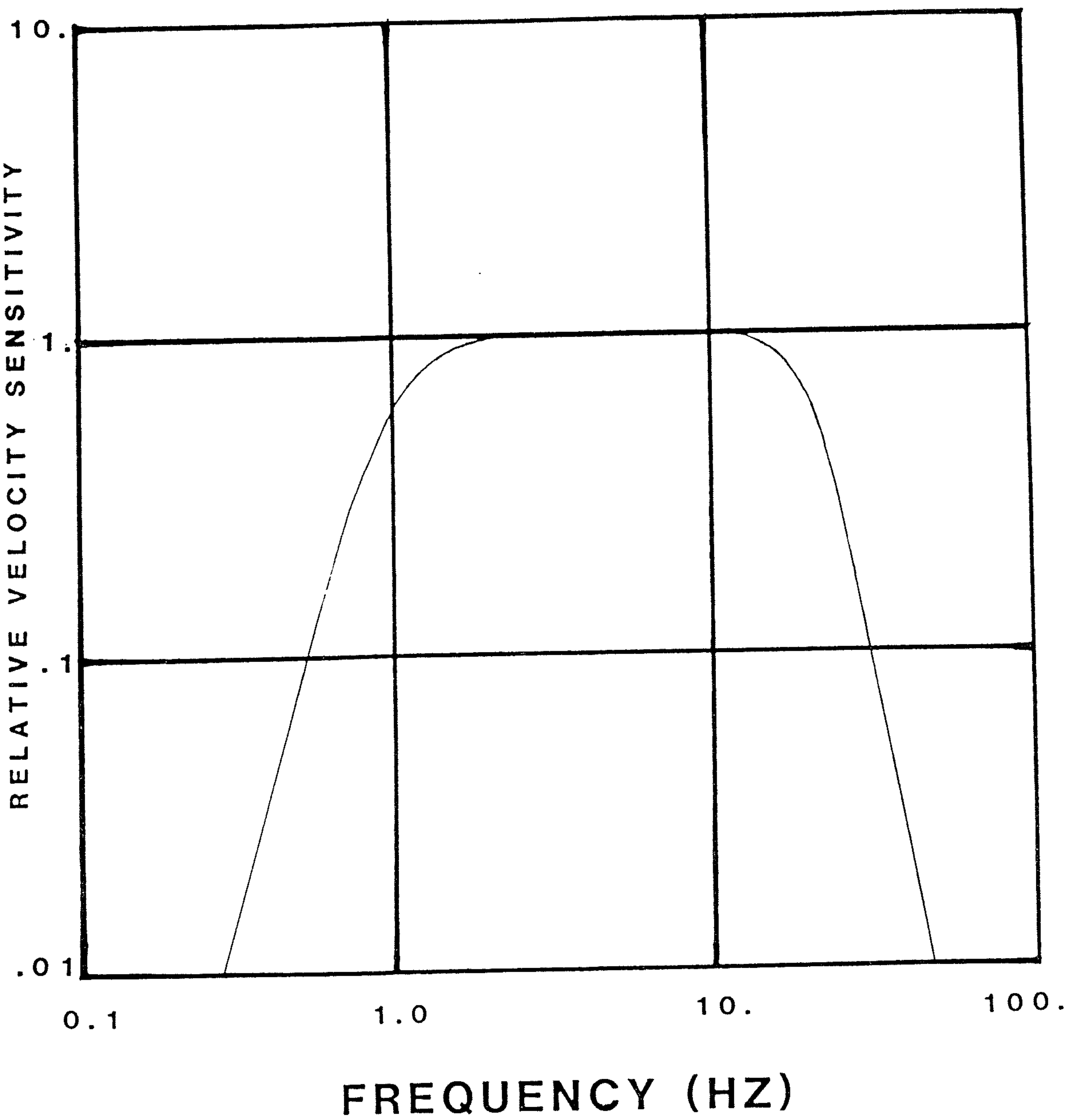

Figure 2. Relative velocity sensitivity of the Geotech MCR 600 based seismographs with 0.8 Hz low cut filter.

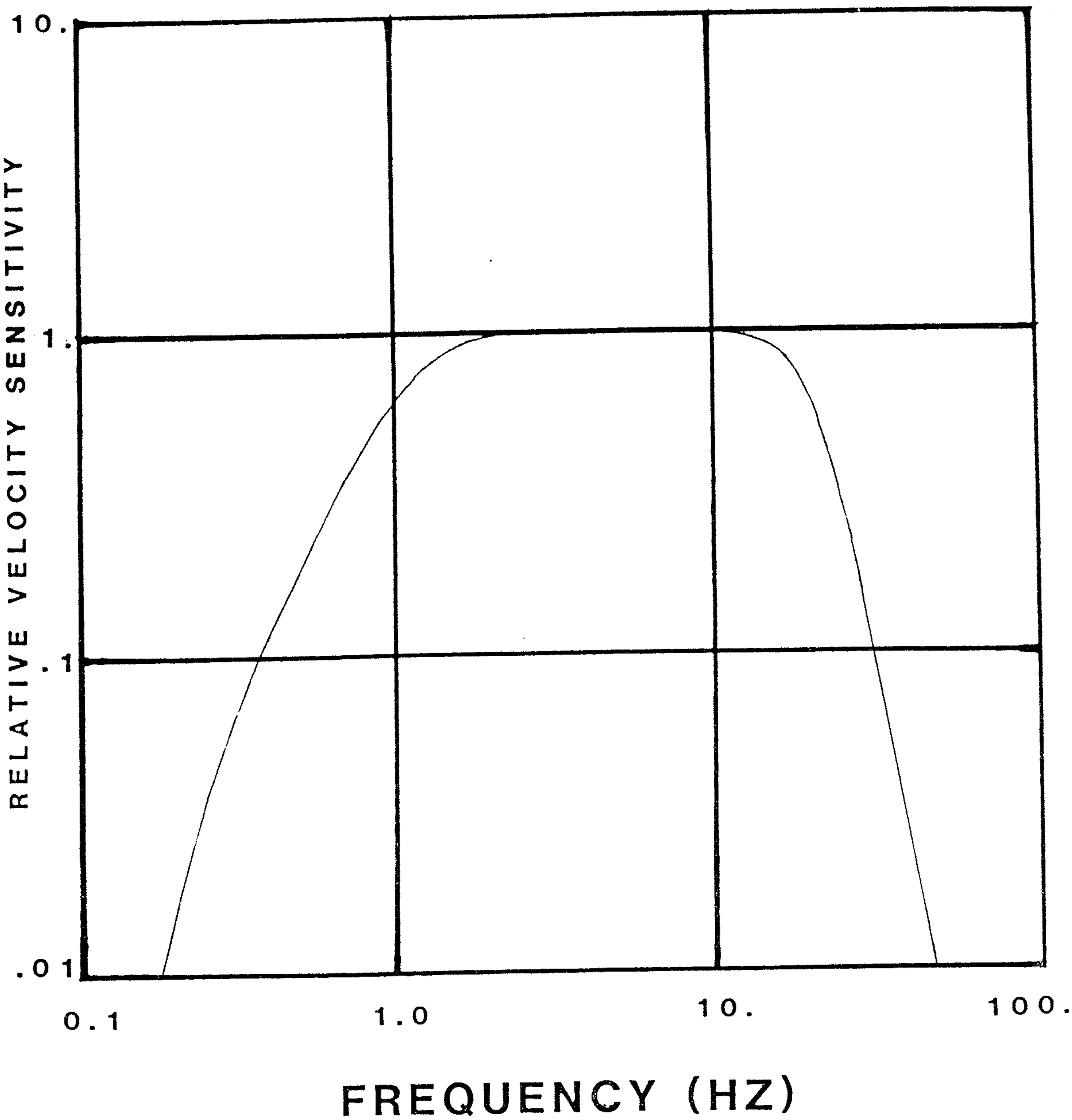

Figure 3. Relative velocity sensitivity of the Geotech MCR 600 based seismographs with 0.2 Hz low cut filter.

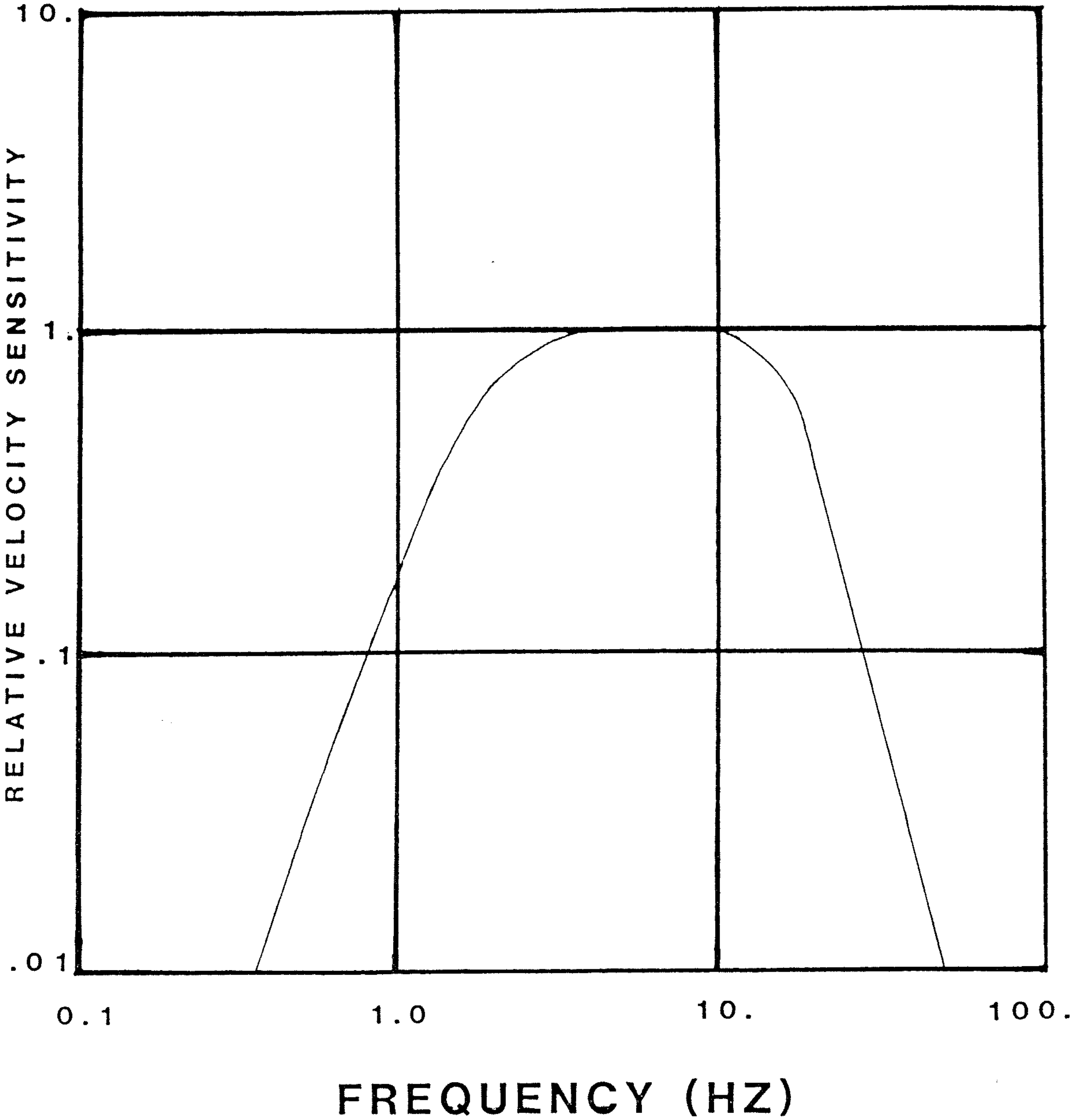

Figure 4. Relative velocity sensitivity of the University of Toronto seismographs.

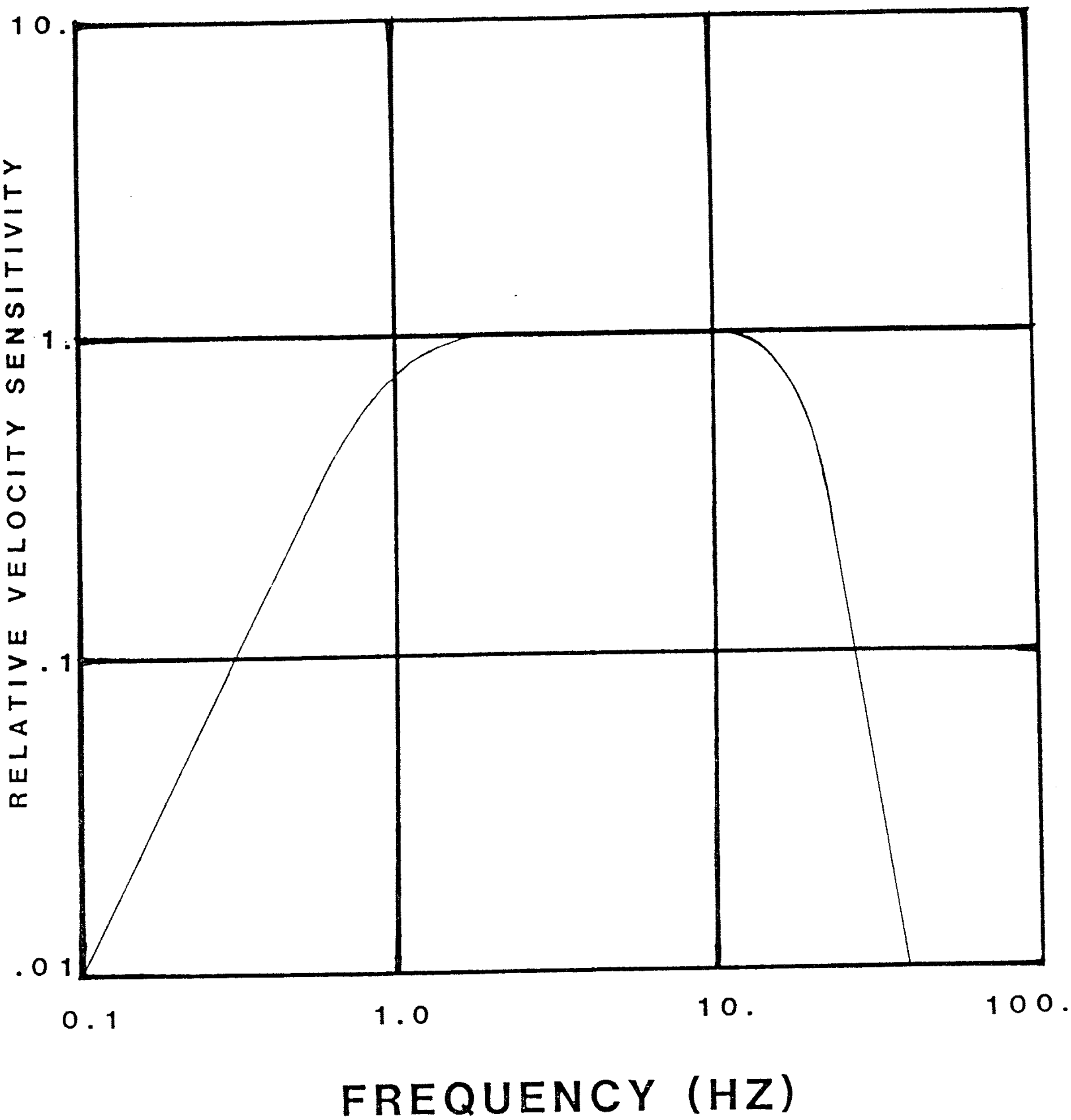

Figure 5. Relative velocity sensitivity of the University of Western Ontario FM seismographs.

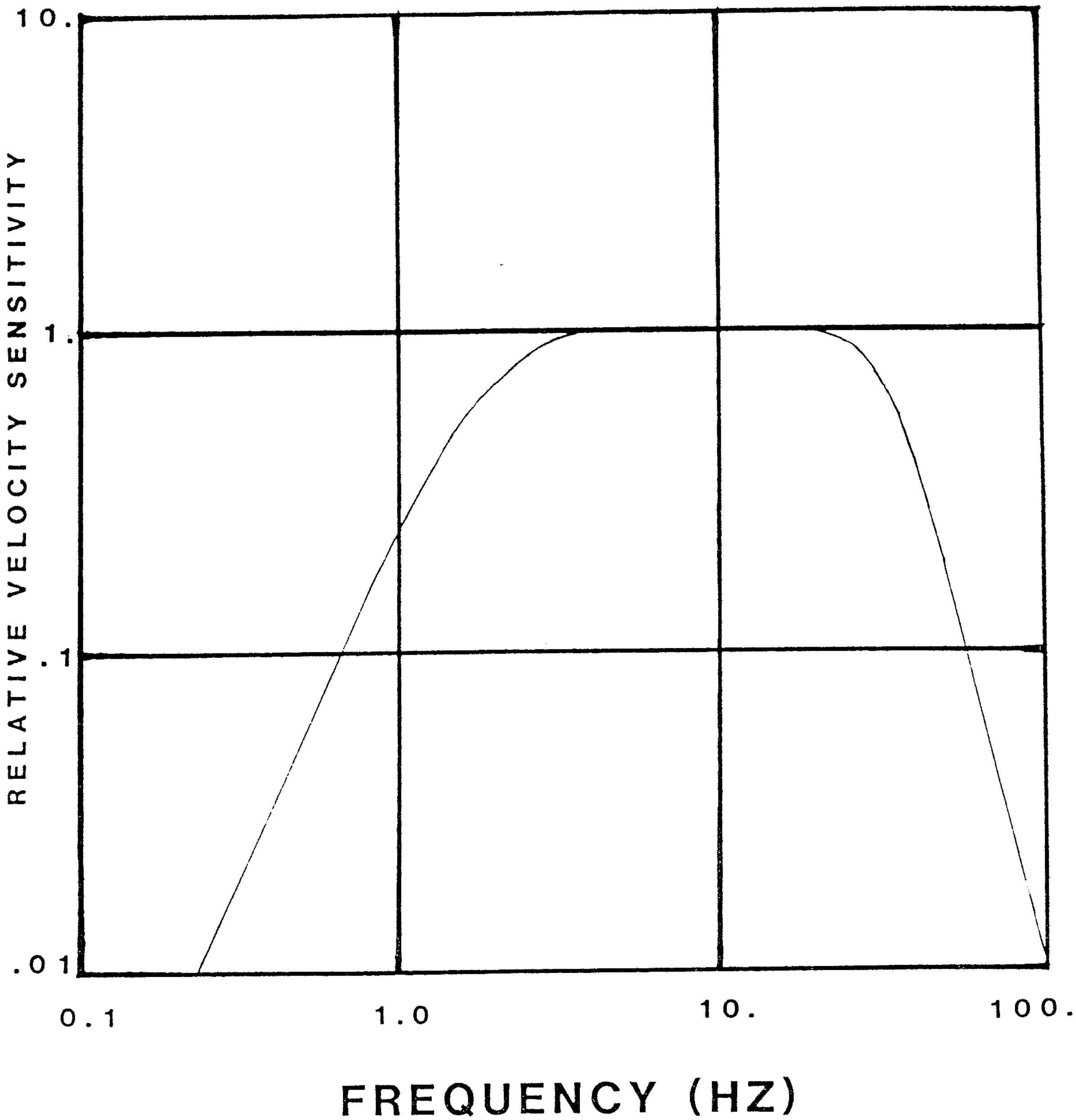

Figure 6. Relative velocity sensitivity of the Earth Physics Branch Mark 2 Backpack seismographs with 2 Hz seismometer.

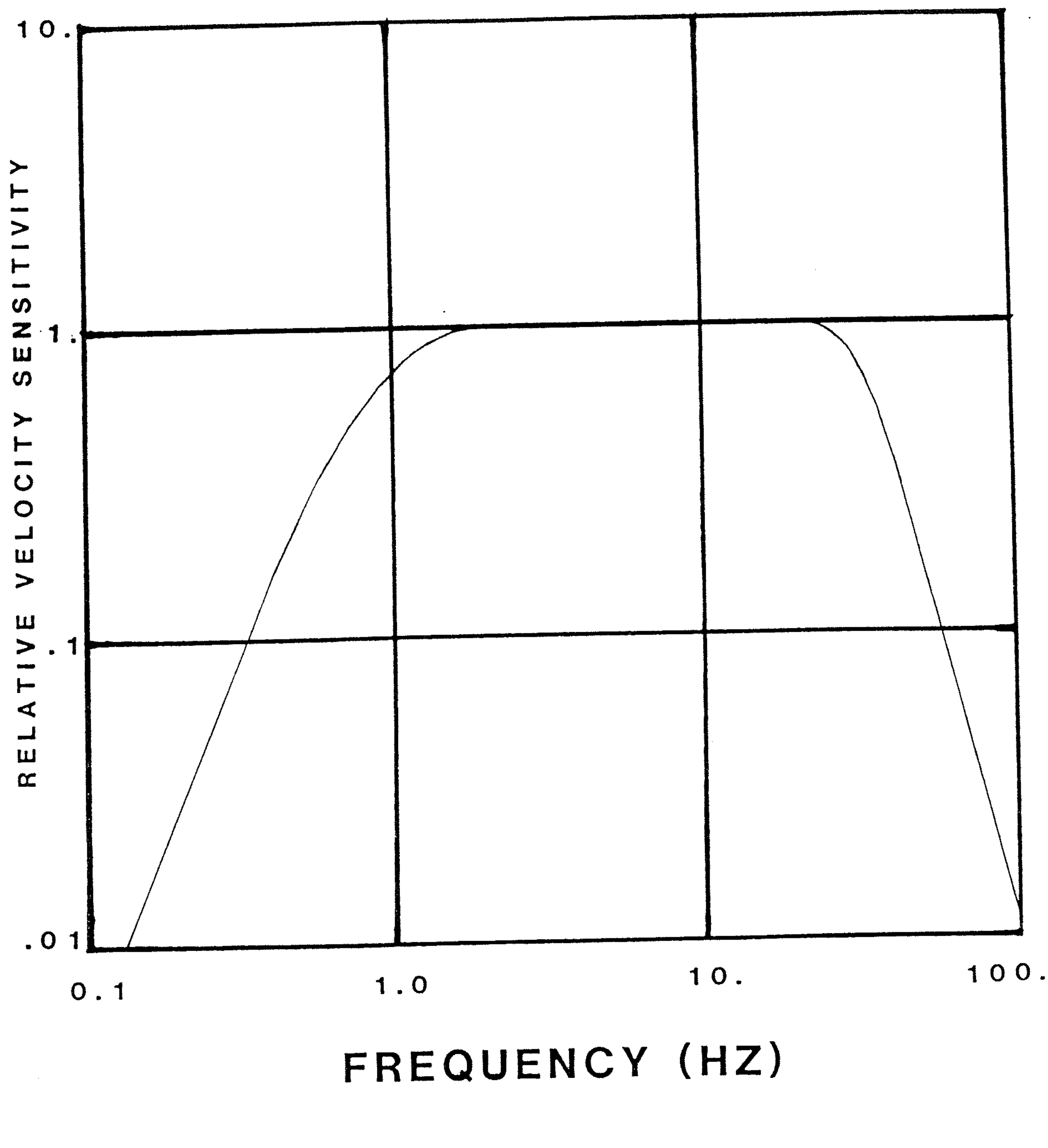

Figure 7. Relative velocity sensitivity of the Earth Physics Branch Mark 2 Backpack seismographs with 1 Hz seismometer.

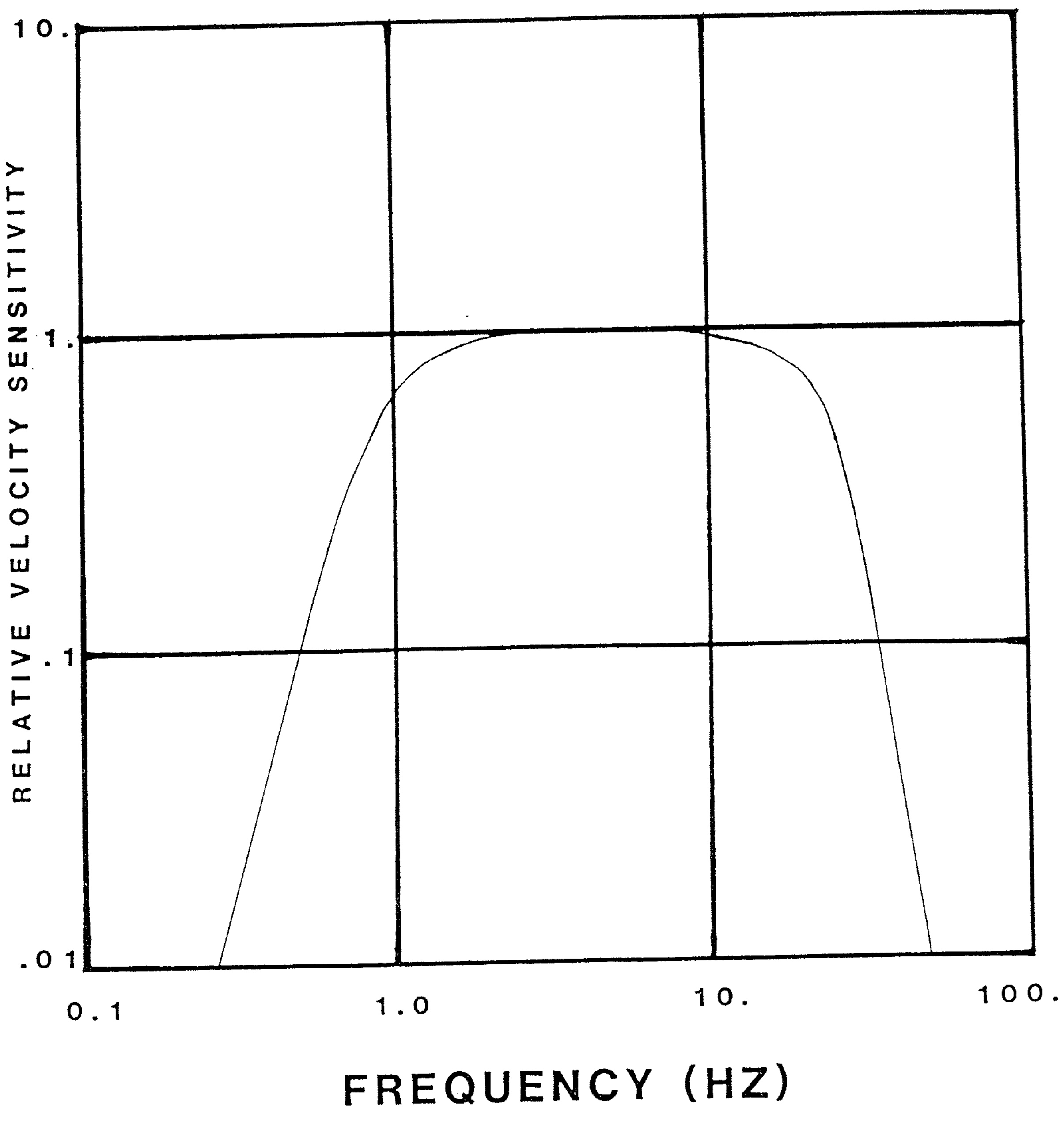

Figure 8. Relative velocity sensitivity of the University of British Columbia FM seismographs.

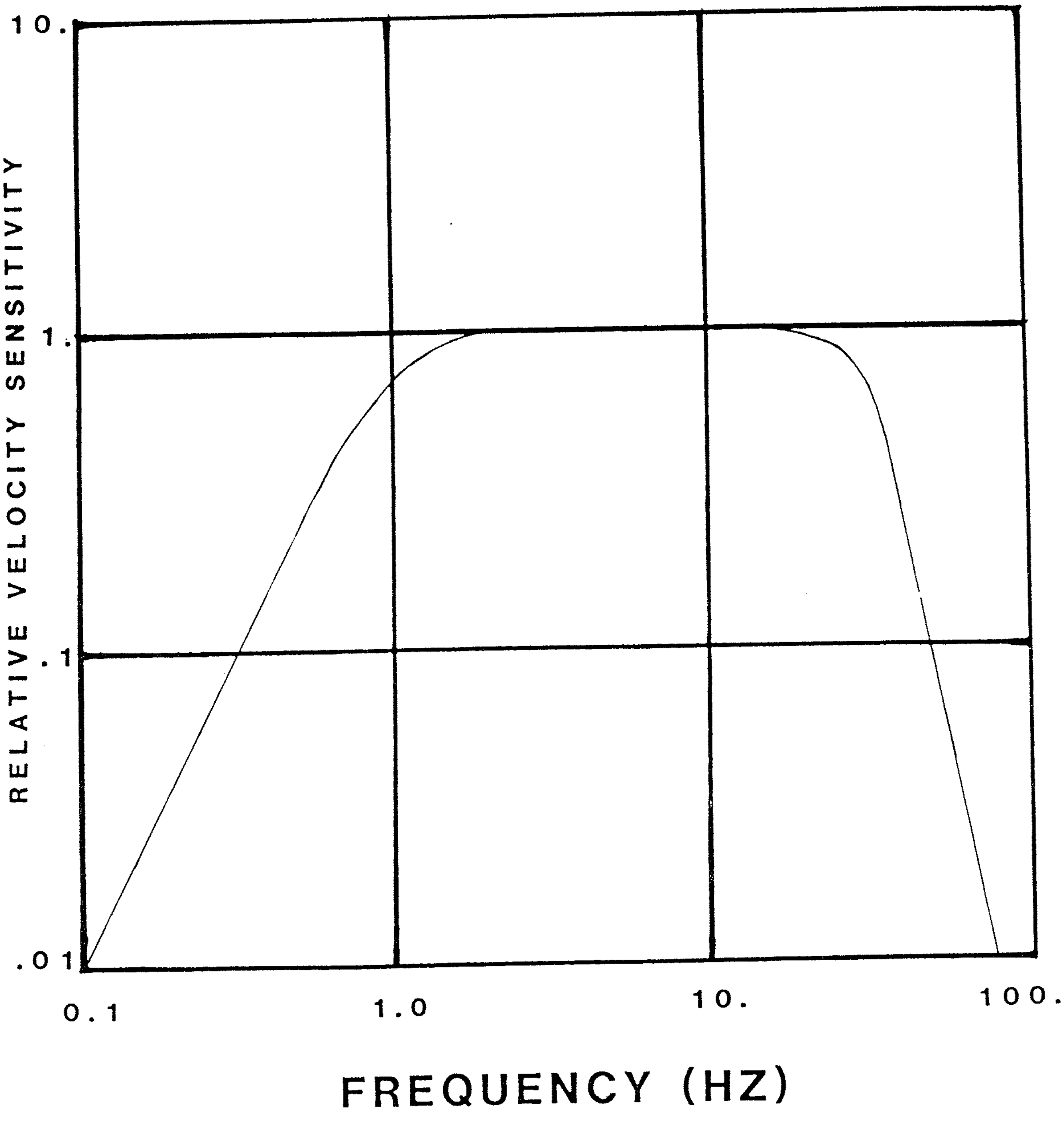

Figure 9. Relative velocity sensitivity of the Sprengnether DR-100 based seismographs.

Seismic Data. The data, consisting of 1142 seismic traces, are presented as time series on digital magnetic tape. To convert these data, recorded on different instruments and at different gain settings, to a common ground velocity requires application of the numerical factor GAIN to each time series. GAIN, contained in the record header, is defined as the number by which each time series must be divided to obtain units of 10^{-8} m/s at a frequency of 5 Hz.

The complete data set is on two magnetic tapes in a modified version of the 'CO-CRUST[1] format' (*cf.* Ellis and Clowes, 1981). (The data can also be made available in SEGY format.) Tape 1 contains the seismic traces in 23 separate files, one for each of the shots listed in Table 3. The number of traces per file varies from 22 to a maximum of 56 (see Table 5) and are arranged within each file numerically by site number. Each trace consists of 14400 data points contained in 12 records. The first three points of the first record are a three word header:

1st sample - Site no. (*e.g.* 304)

2nd sample - Shot no. (*e.g.* 1)

3rd sample - Seismometer orientation (*e.g.* 1 = vertical)

As indicated above, the sampling frequency for all traces is 60 Hz. All traces have been corrected to the same time base. The 14400 data points consist of the three word header and 14397 samples of the seismic data which start 59.95 s before the shot and continue for 180.00 s after the shots; *i.e.*, the 3601th sample corresponds to the shot time to within one-half sample interval (0.0083 s). If insufficient data were recorded/provided to span the 59.95 s before or the three minutes after the shot, the trace was padded with zeros.

Tape 2 contains the detailed record headers corresponding to the seismic traces on Tape 1 and are also contained in 23 separate files arranged numerically by site number. Each header consists of ten formatted records (see Appendix D for an example):

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1 CO-CRUST . . . Consortium for Crustal Reconnaissance Using Seismic Techniques

Table 5: Number of traces/headers in data tapes

File	No. of Traces/ Headers
1	27
2	22
3	23
4	31
5	55
6	56
7	53
8	53
9	53
10	51
11	55
12	55
13	55
14	55
15	56
16	56
17	56
18	56
19	56
20	56
21	56
22	53
23	53

Record 1. title of experiment

2. line, date, shot time, shot size

3. shot location, shot number, shot latitude and longitude

4. shot elevation, shot depth, receiver elevation

5. site number, receiver latitude and longitude

6. seismometer type, natural frequency, seismometer orientation

   (in this experiment only vertical seismometers were used.)

7. recorder type, sampling frequency, GAIN

   (Note: recorder type 'Geotech MCR 600-1' refers to those with 0.8 Hz low cut filter, 'Geotech MCR-600-2' refers to those with 0.2 Hz low cut filter.)

8. site number, shot number, seismometer orientation in the form of a six digit integer number (*e.g.* 304011 corresponds to site number 304, shot number 01, and a vertical seismometer)

9. shot/receiver distance and time after the shot of the first data sample

10. time of first data sample (UTC)

The subroutine WRITIT used to produce the 10 record headers is shown along with an example of the header from the PRASE experiment in Appendix D.

Each tape is unlabelled, 6250 bpi, in IBM byte packing mode, and unblocked (*i.e.* 1 logical record = 1 block). Tape 1 is written with a logical record length of 4800 bytes and can be read using the format statement

FORMAT(12(100A4))

into a REAL*4 array of length 1200. Tape 2 is formatted (see Appendix D) and has a logical record length of 80 bytes.

Seismic Sections. For all shots, preliminary seismic sections are plotted in Figures 10 to 27 with a reduction velocity of 8 km/s. No filtering has been performed and no corrections have been made for shot and receiver elevations, sediment thickness, or shot size. For purposes of presentation all traces within a particular section have been scaled to a common maximum amplitude and all traces on the data tape have been included (except for Site 334, Shot 1, and Site 251, Shot 18 where instrument problems clearly exist).

Additional Notes:

(i) For the 200 kg partial misfires at C1 and C2, only limited data are available, all from the Geotech MCR 600, Sprengnether DR 100, and UWO FM systems.

(ii) All missing traces except those indicated above are not on the data tape due to instrument failure.

(iii) Recording failures occurred at sites 324 and 343 for Shot 5 and at sites 331 and 343 for Shot 6. To provide more complete sections, traces from these sites from the 200 kg shots have been included in the sections for Shots 5 and 6. Amplitude ratios between the large and small shots recorded at adjacent sites have been used to obtain appropriate GAIN values for these traces.

(iv) Preliminary despiking has been perfomed on all traces although in some cases only in the 60 s following shot time.

(v) The following traces have excessive high frequency signal which in most cases is suspected to be due to seismometer malfunction; however, the traces do contain usable information.

Site	Shot
345	5
353	5
345	6
353	6
635	15
635	16
635	17
239	19
239	20
239	21

(vi) As yet, true amplitude sections have not been plotted. However, the following traces are believed to have unreasonably low amplitudes which are likely related to recording system problems:

Site	Shot
333	5
337	5
333	6

337	6
537	7
537	8
537	9
537	10
634	15
634	16
634	17
426	22
426	23

(vii) Short intervals in a few traces have been zeroed to eliminate very large amplitude noise.

(viii) The following traces appear to have unresolved timing problems:

Site	Shot
333	5
205	18
207	18
245	19

(ix) The following traces have been assigned negative shot/receiver distances as in each case the shot/receiver azimuth differs from that of the rest of the line by more than 90 degrees

Site	Shot
356	1
356	4
501	11
502	11
556	12
656	17
255	19
200	21
201	21
400	22

(x) Sites 355 and 356 were moved to different locations following Shot 4. Correct distances for each location are in the record headers.

(xi) Site 101 may be mislocated as the arrival from Shot 9 is ~0.5 s early and the arrival from Shot 7 is ~1.5 s late.

(xii) For Line B fan (Shot 18) some of the site locations differ slightly from the corresponding in-line locations.

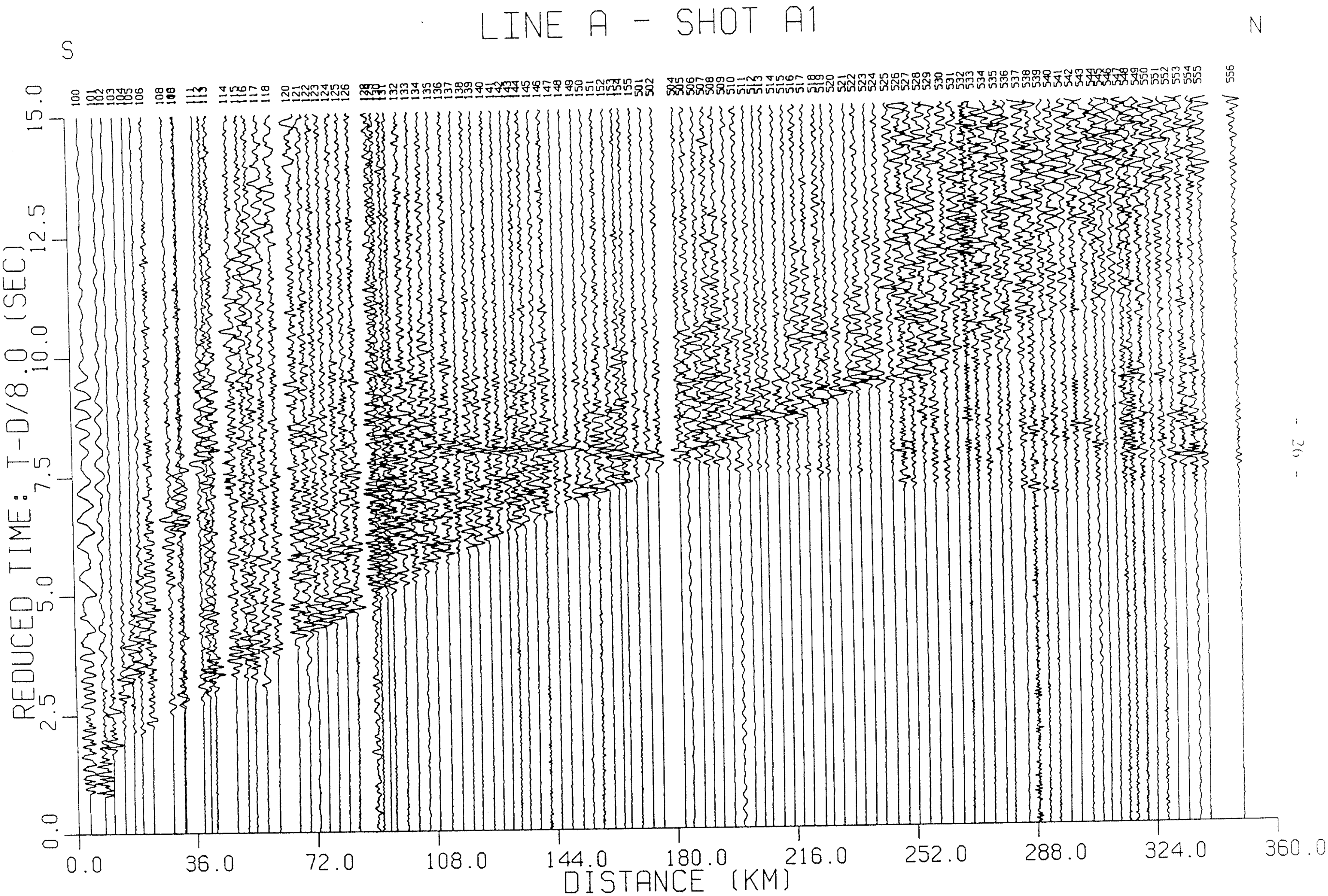

Figure 10. Record section from shot point A1 (Shots 9 and 13) recorded

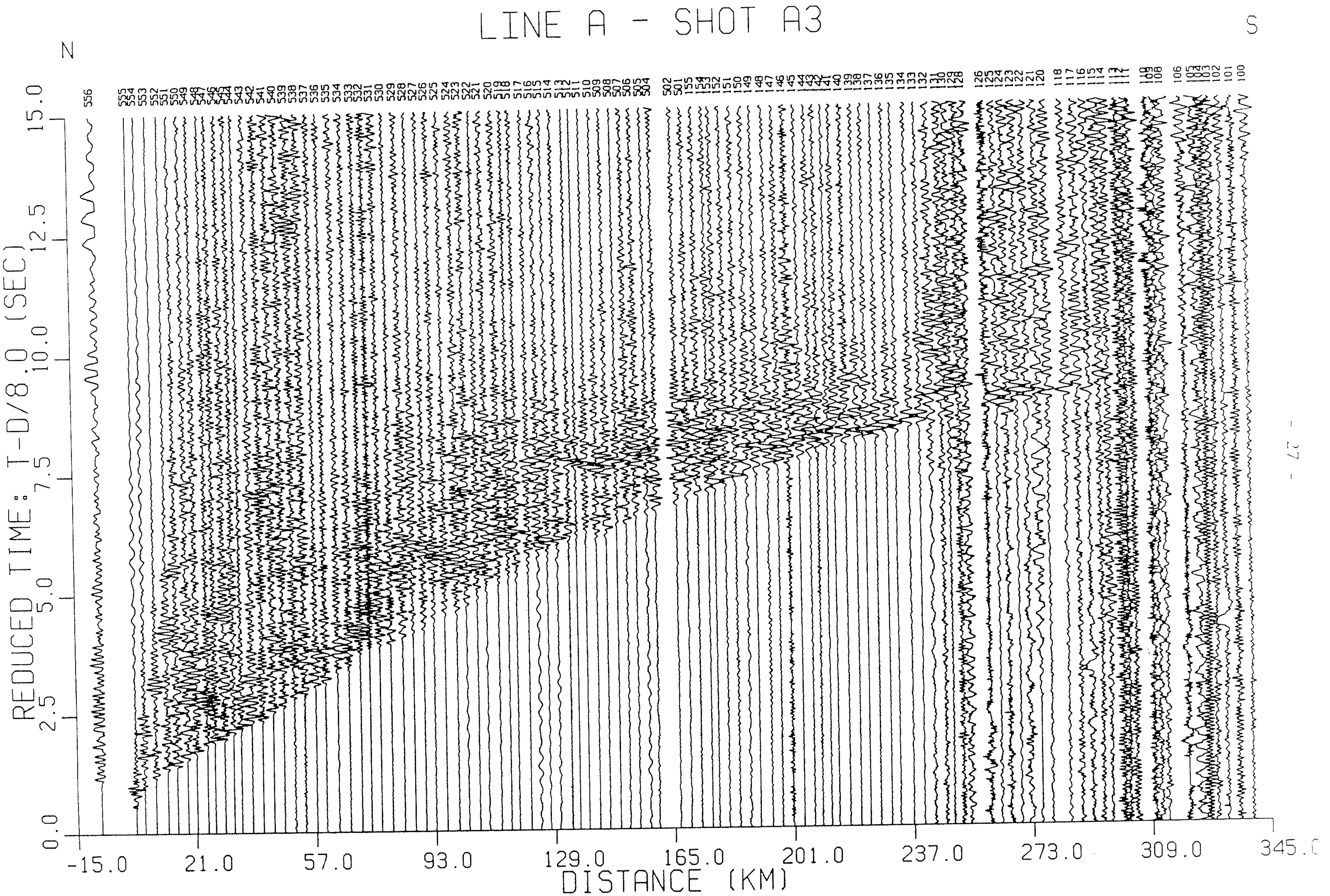

Figure 11. Record section from shot point A3 (Shots 8 and 12) recorded

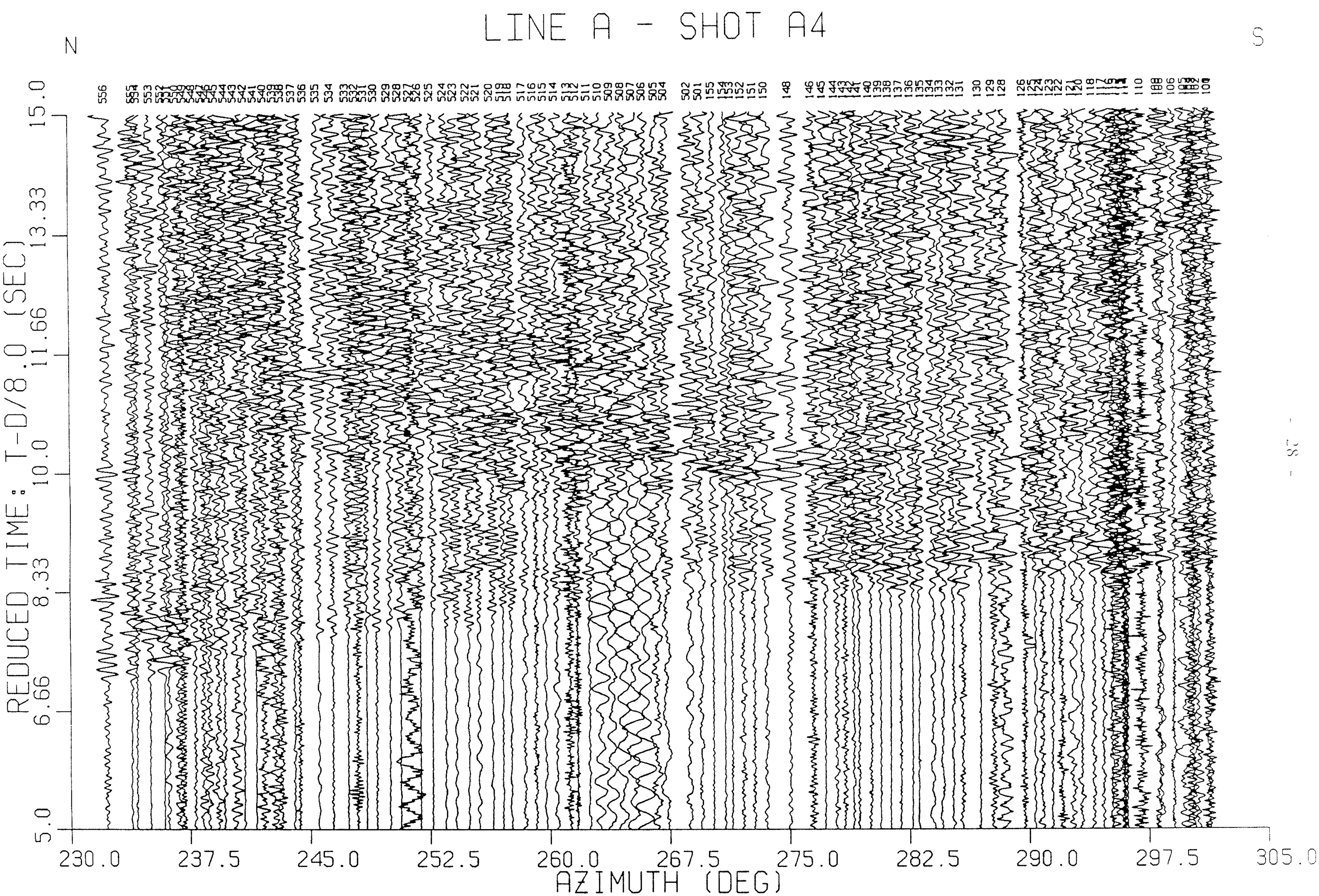

Figure 12. Broadside record section from shot point A4 (Shots 10 and 14)

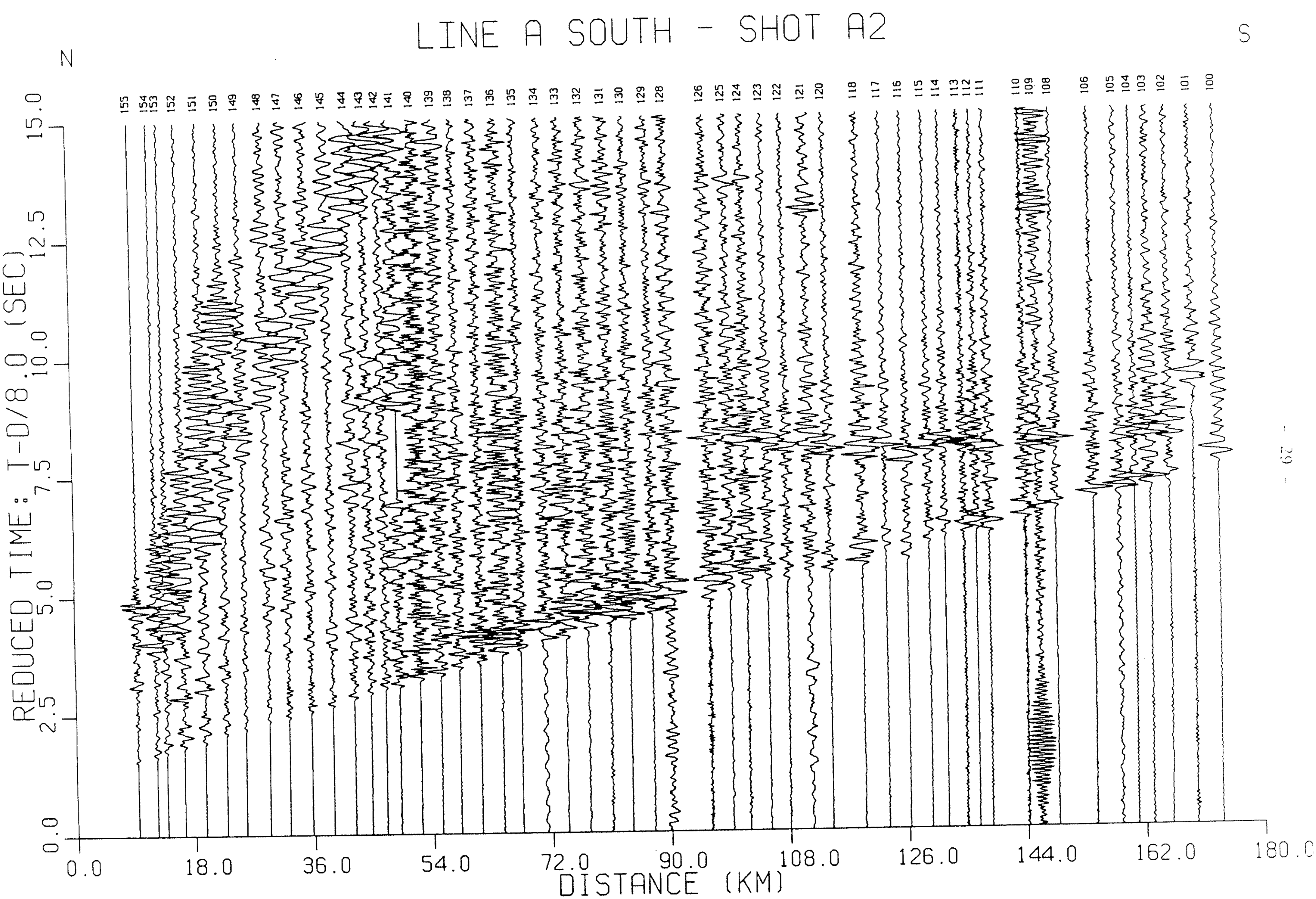

Figure 13. Record section from shot point A2 (Shot 7) recorded along Line A

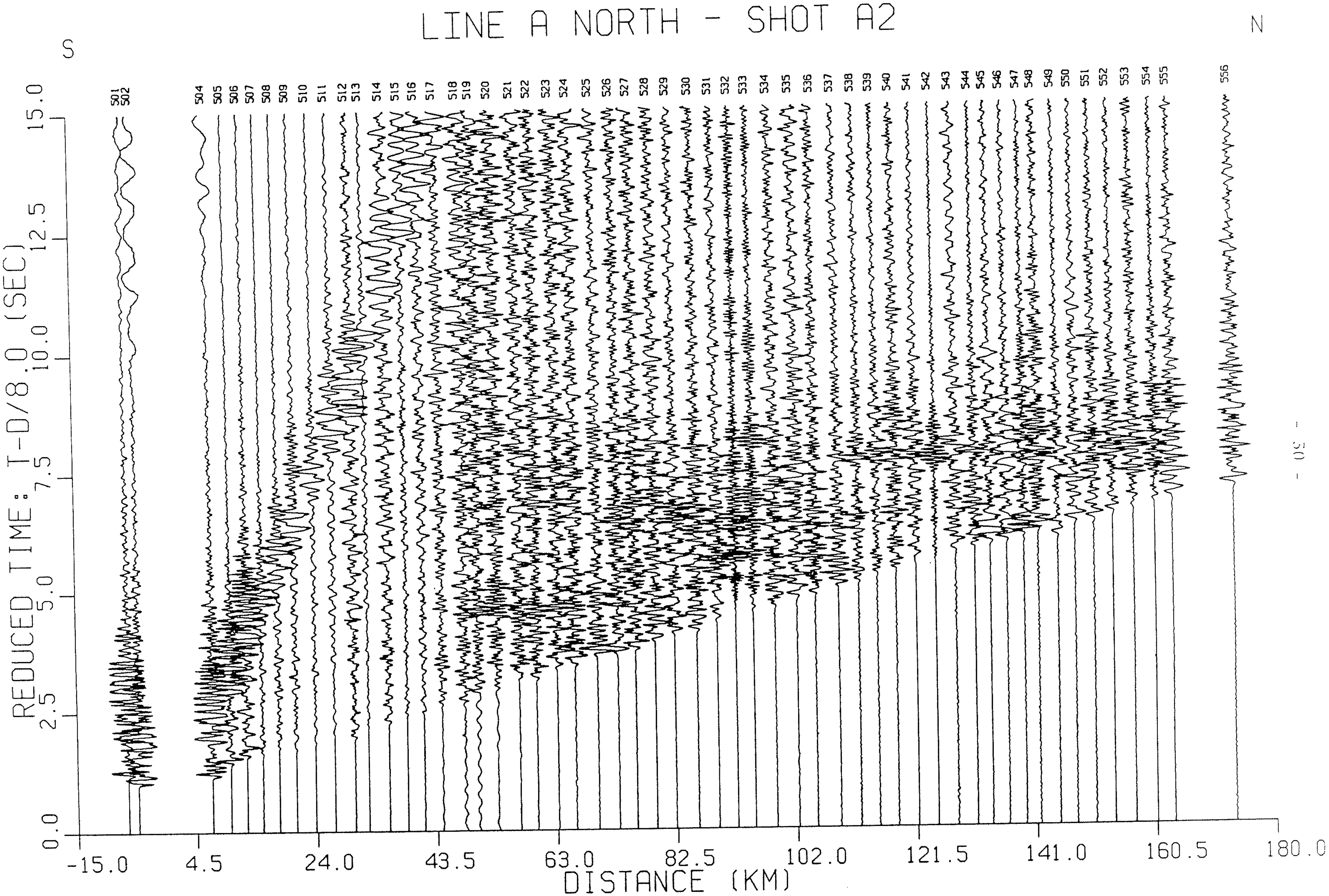

Figure 14 Record section from shot point A2 (Shot 11) recorded along Line A

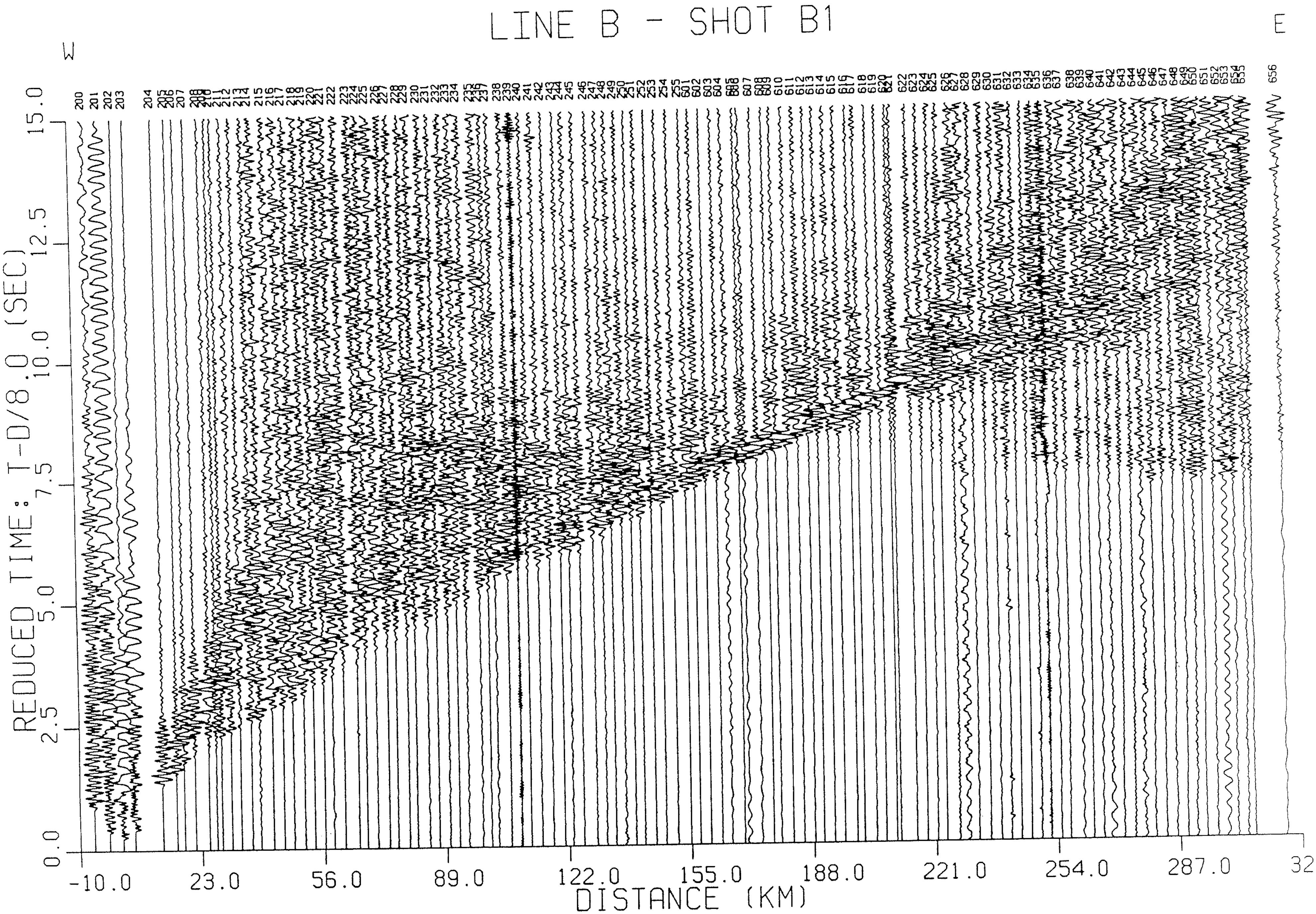

Figure 15. Record section from shot point B1 (Shots 15 and 21) recorded

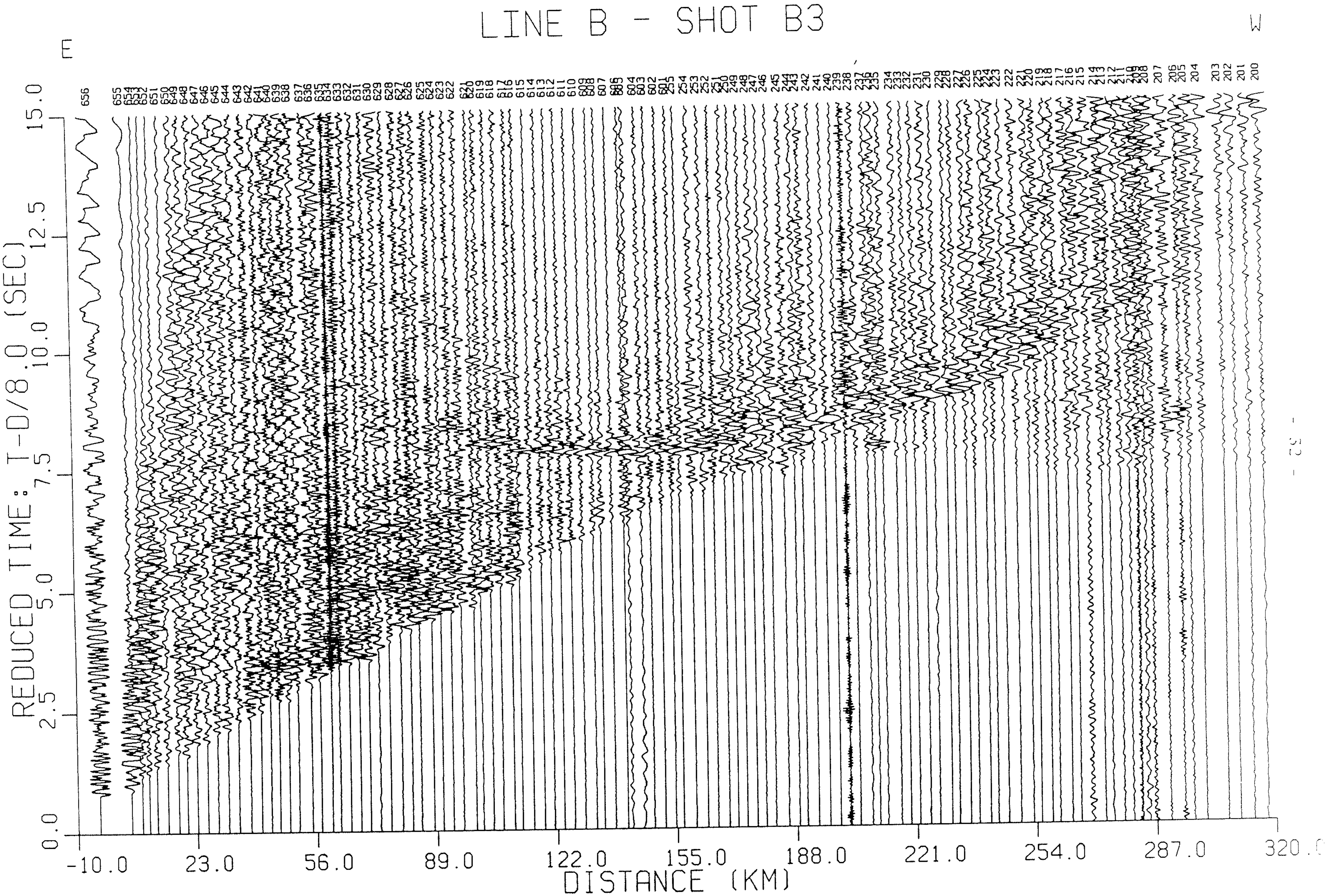

Figure 16. Record section from shot point B3 (Shots 17 and 20) recorded

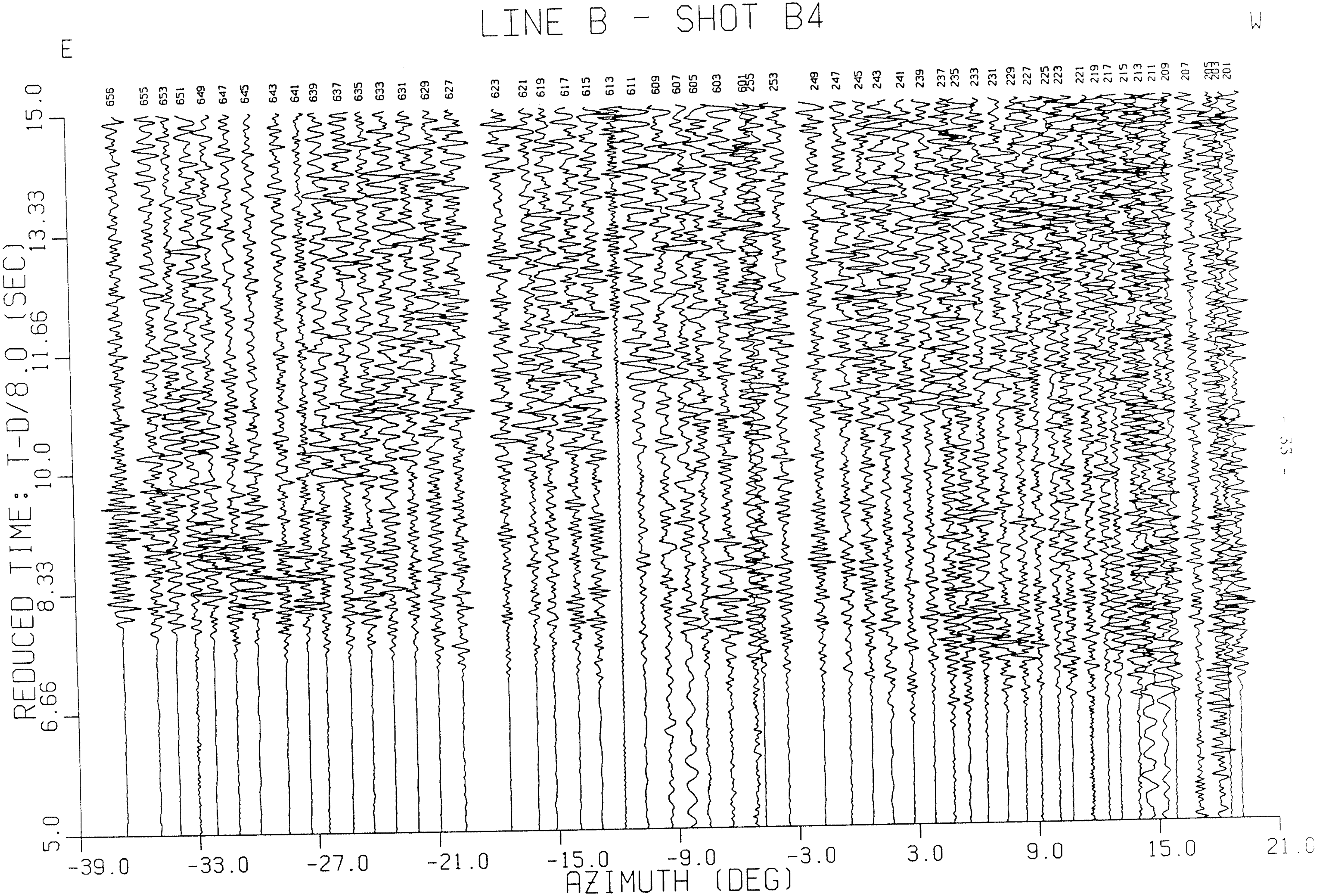

Figure 17. Broadside record section from shot point B4 (Shot 18) recorded along

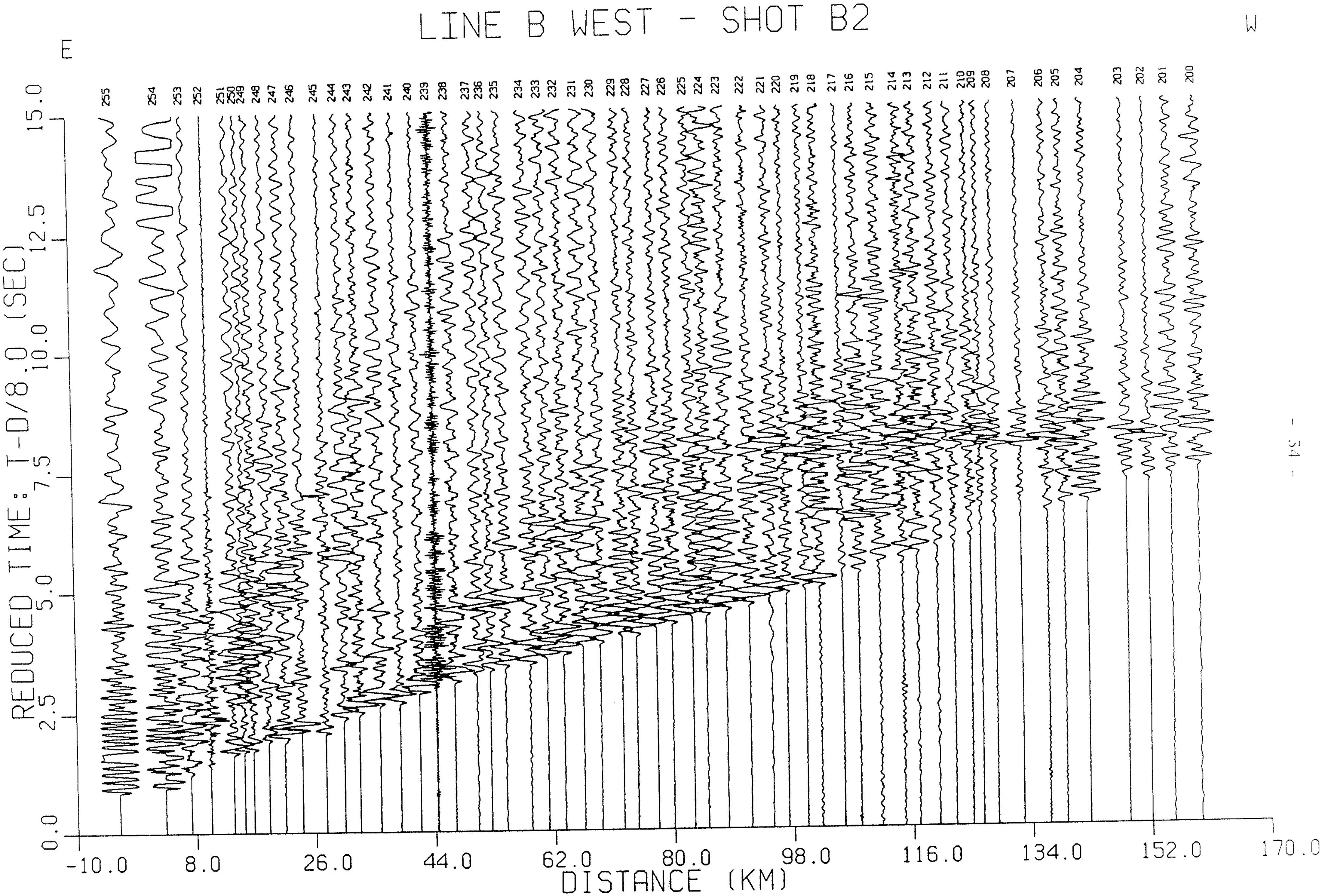

Figure 18. Record section from shot point B2 (Shot 19) recorded westward along

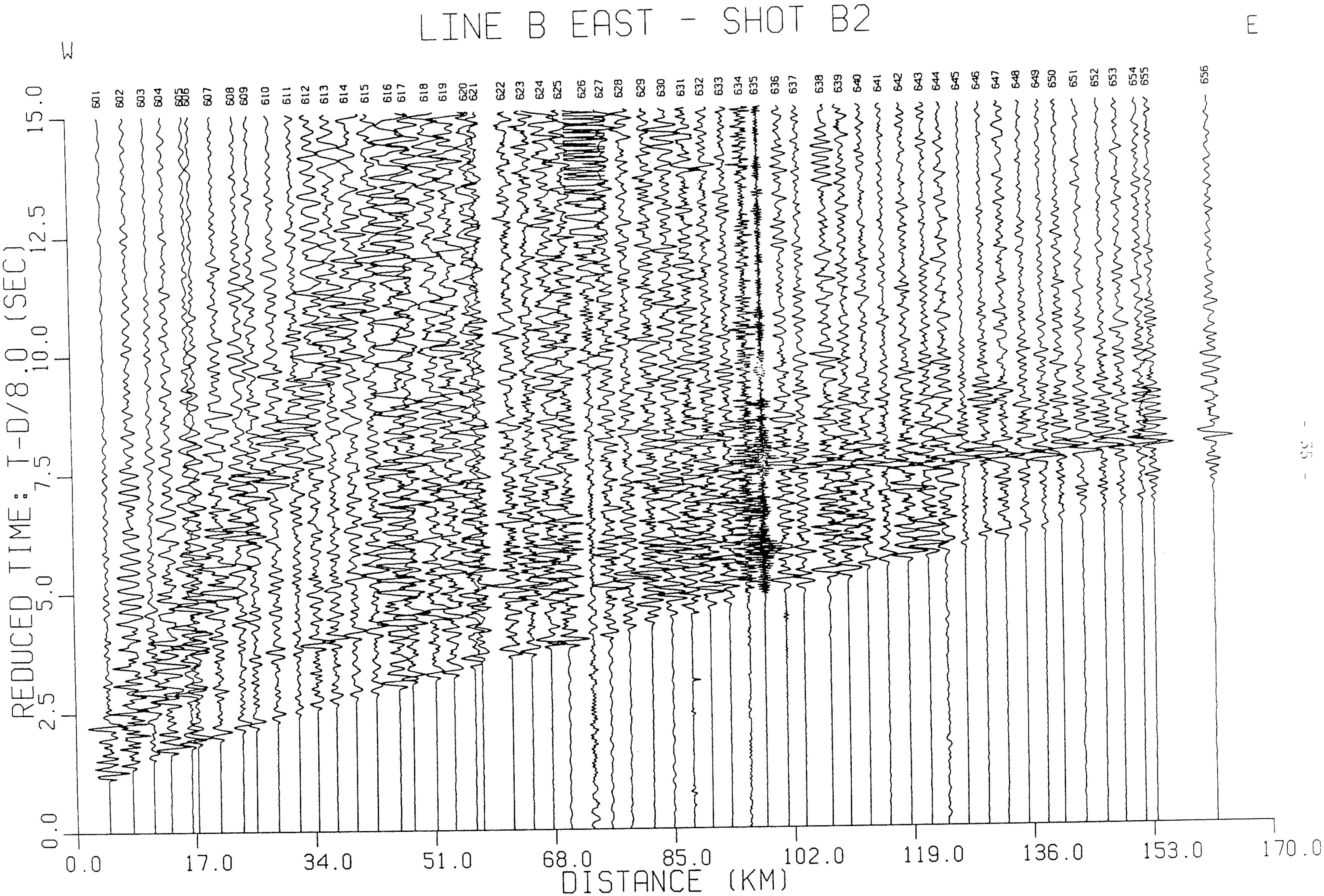

Figure 19. Record section from shot point B2 (Shot 16) recorded eastward along

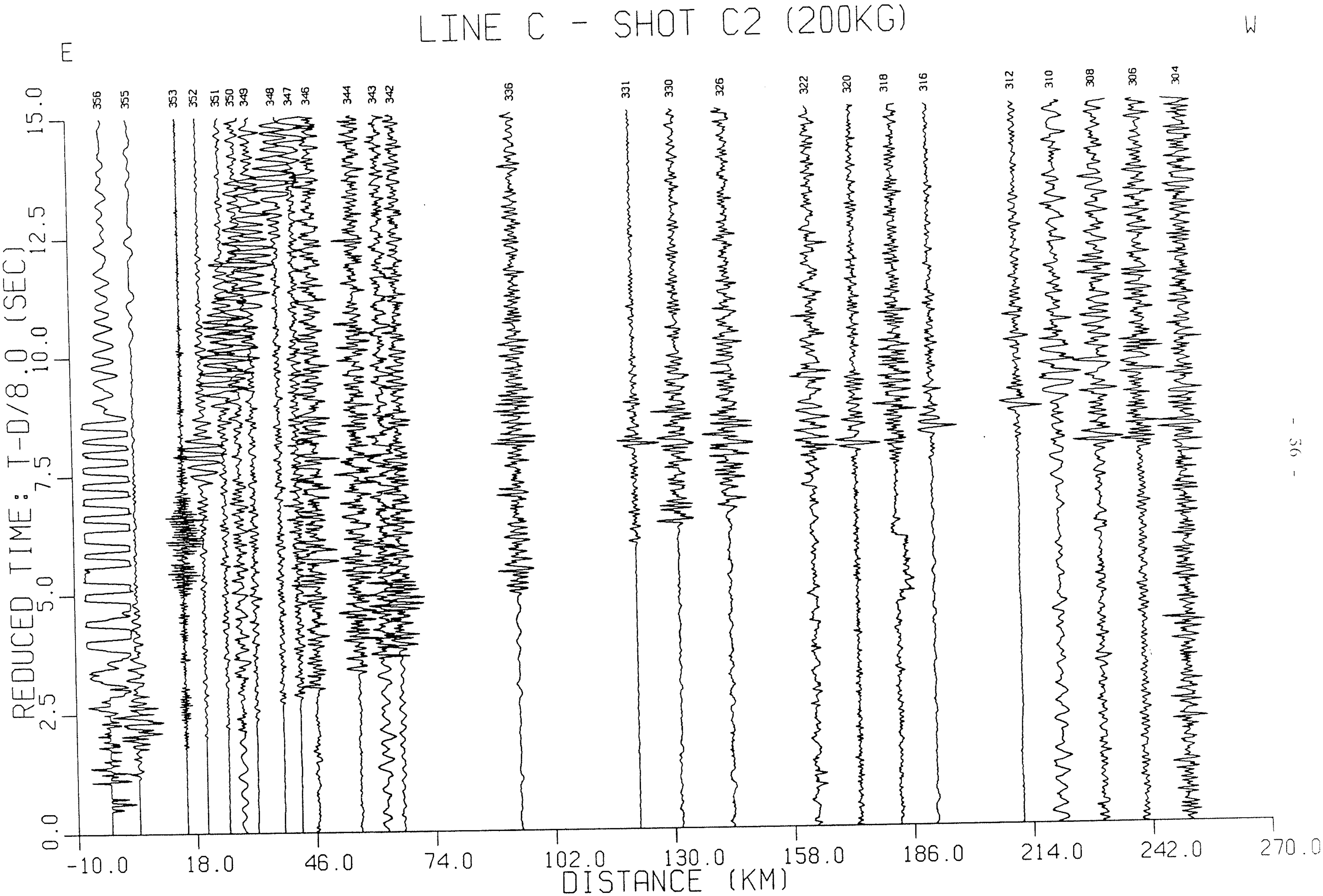

Figure 20. Record section from shot point C2 (Shot 1) recorded westward along

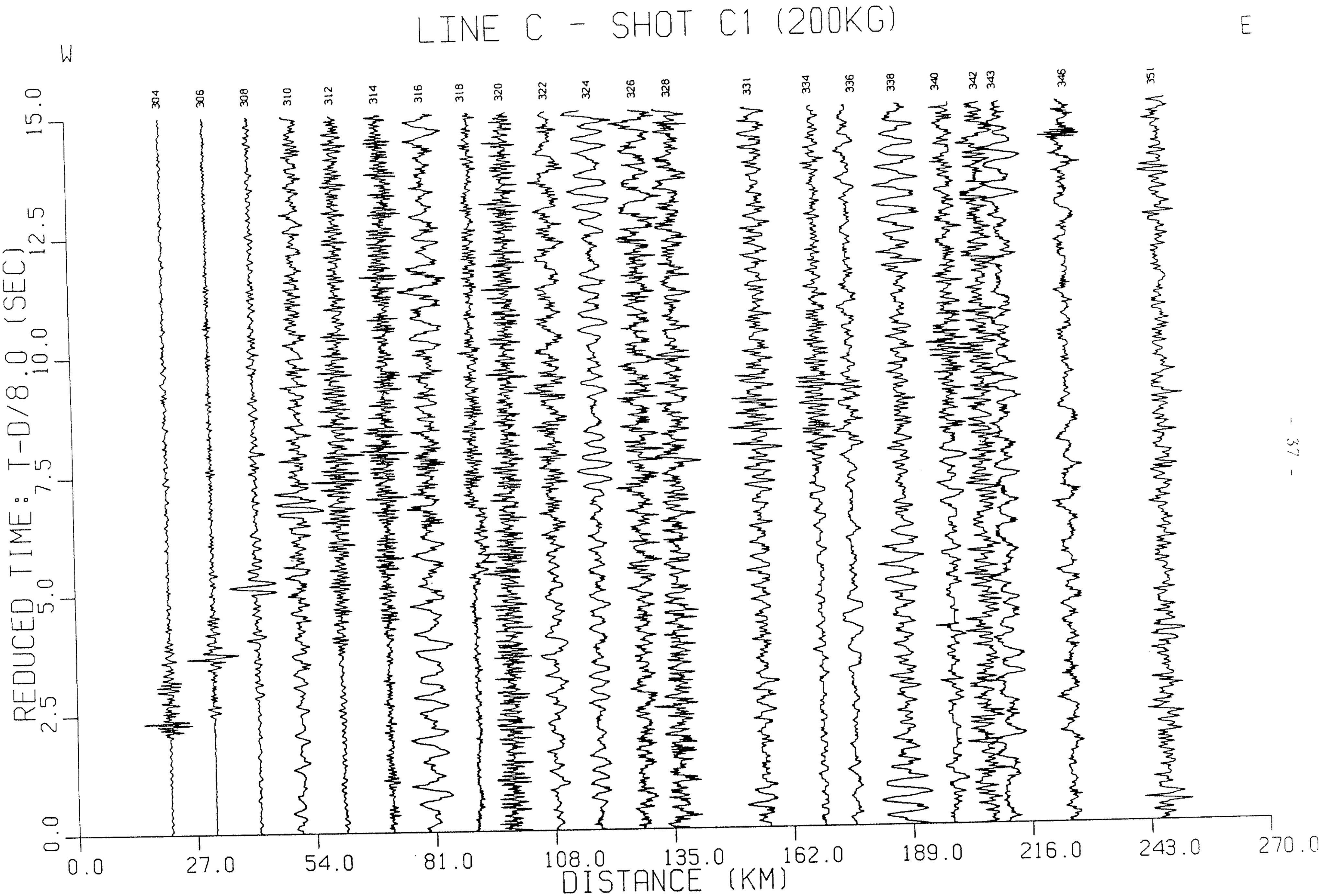

Figure 21. Record section from shot point C1 (Shot 2) recorded eastward along

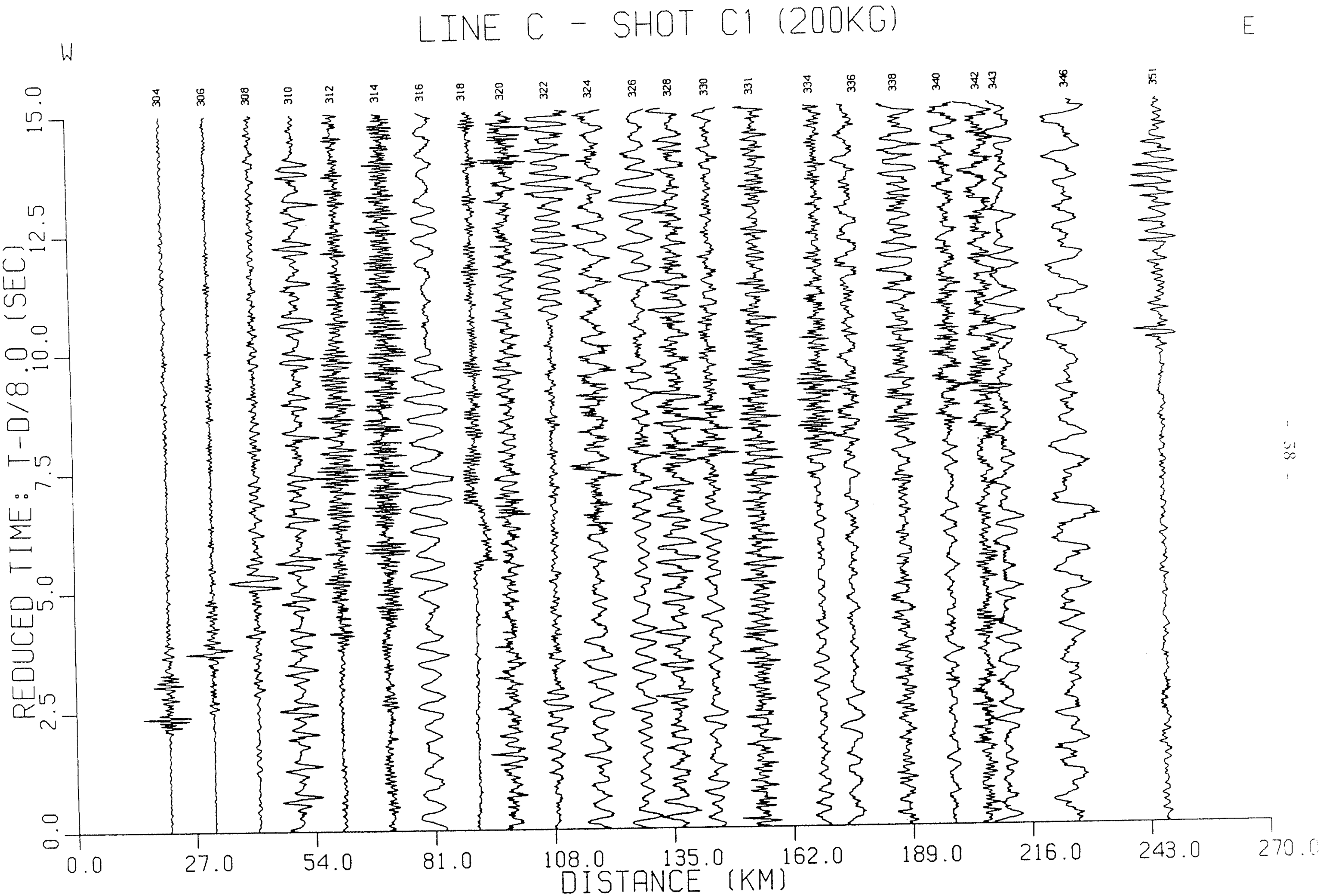

Figure 22. Record section from shot point C1 (Shot 3) recorded eastward along

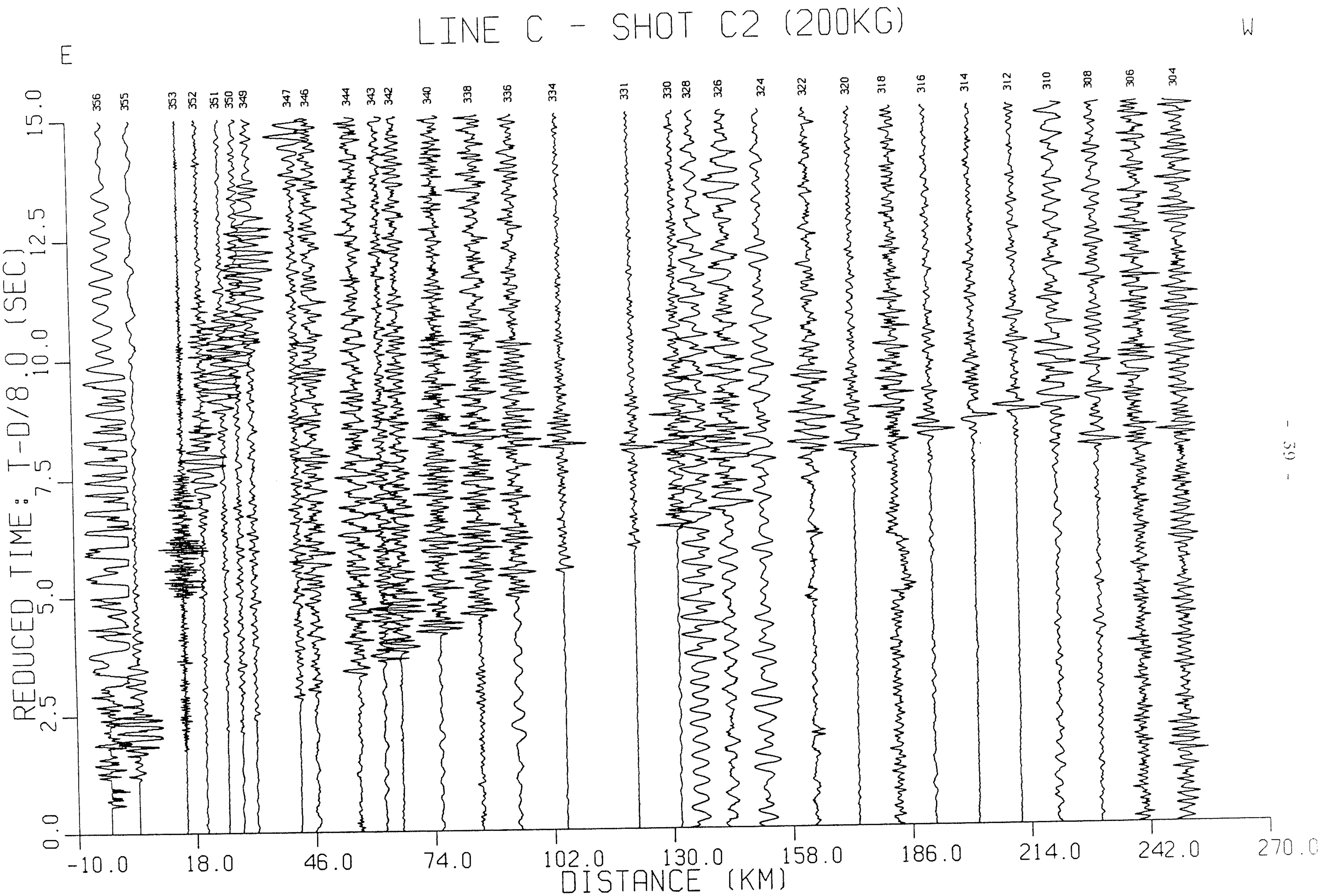

Figure 23. Record section from shot point C2 (Shot 4) recorded westward along

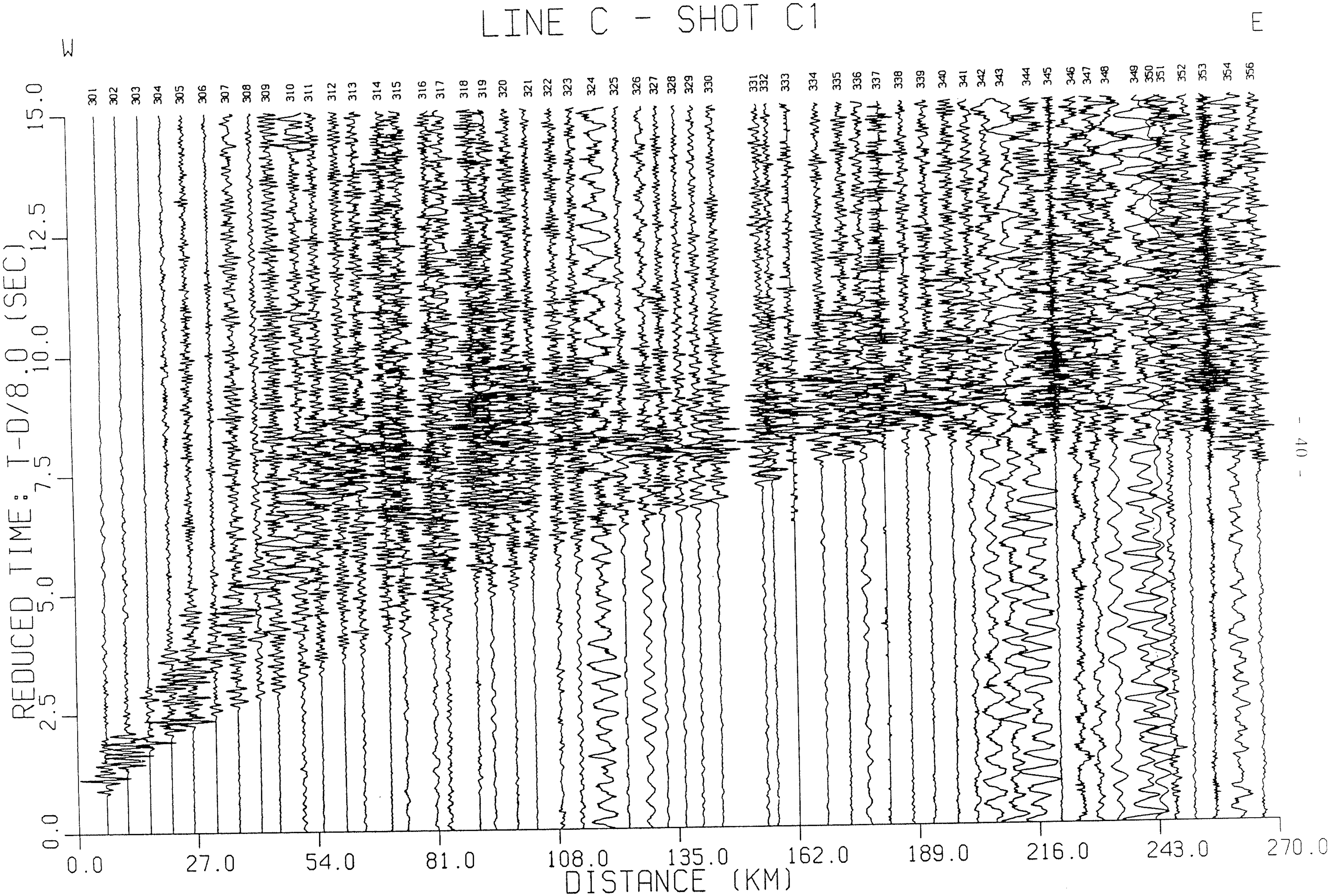

Figure 24. Record section from shot point C1 (Shot 5) recorded eastward along

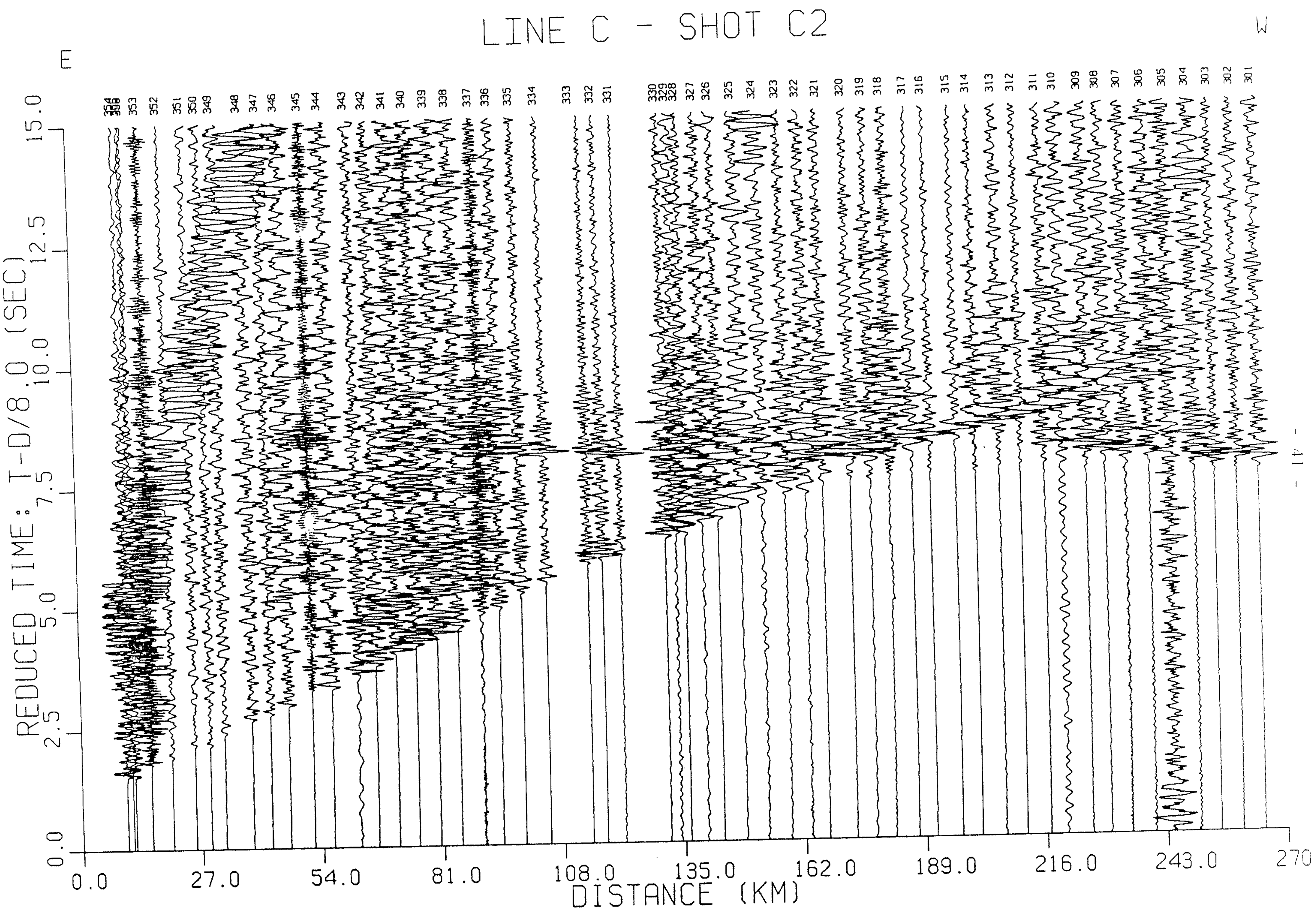

Figure 25. Record section From shot point C2 (Shot 6) recorded westward along

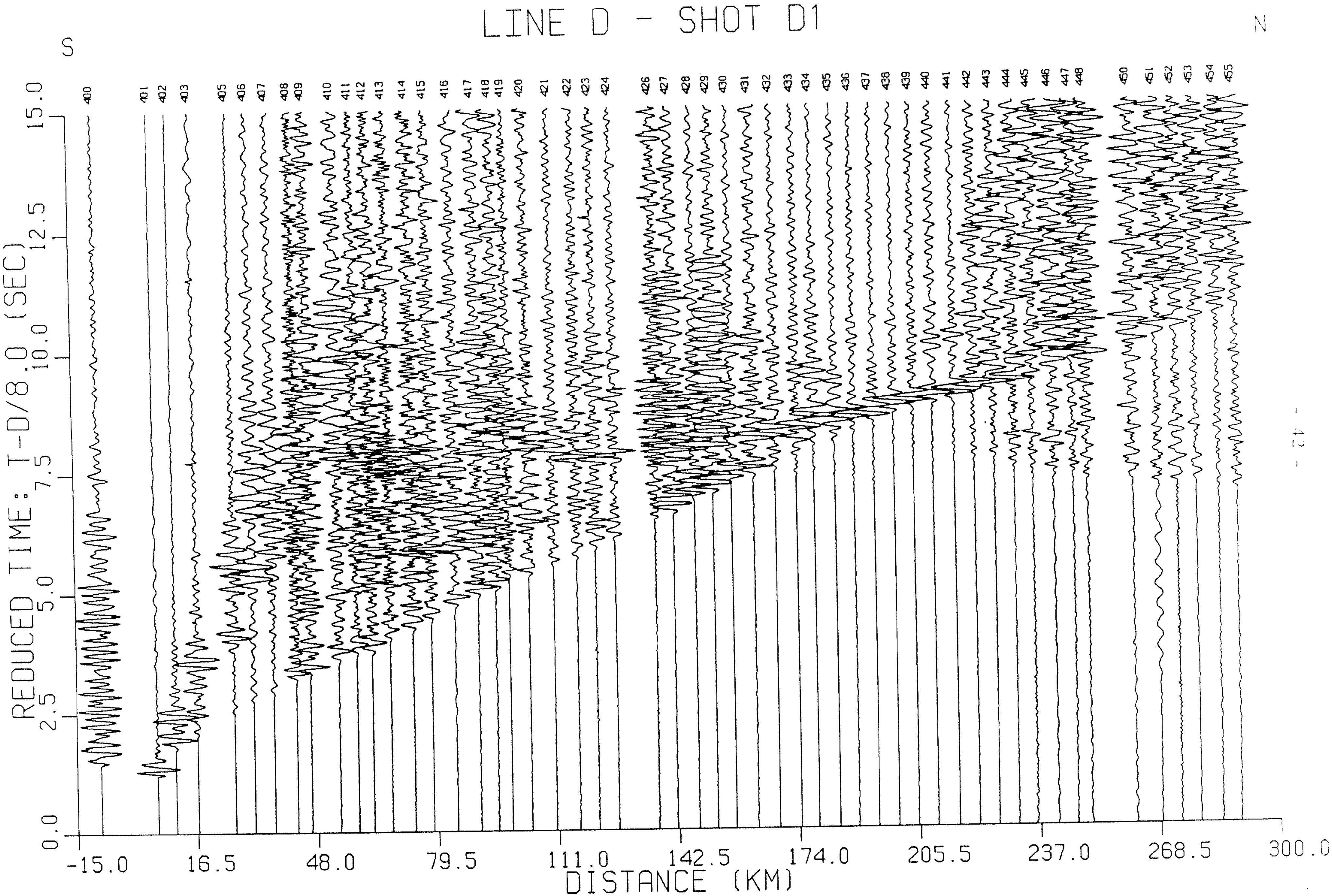

Figure 26. Record section from shot point D1 (Shot 22) recorded northward along

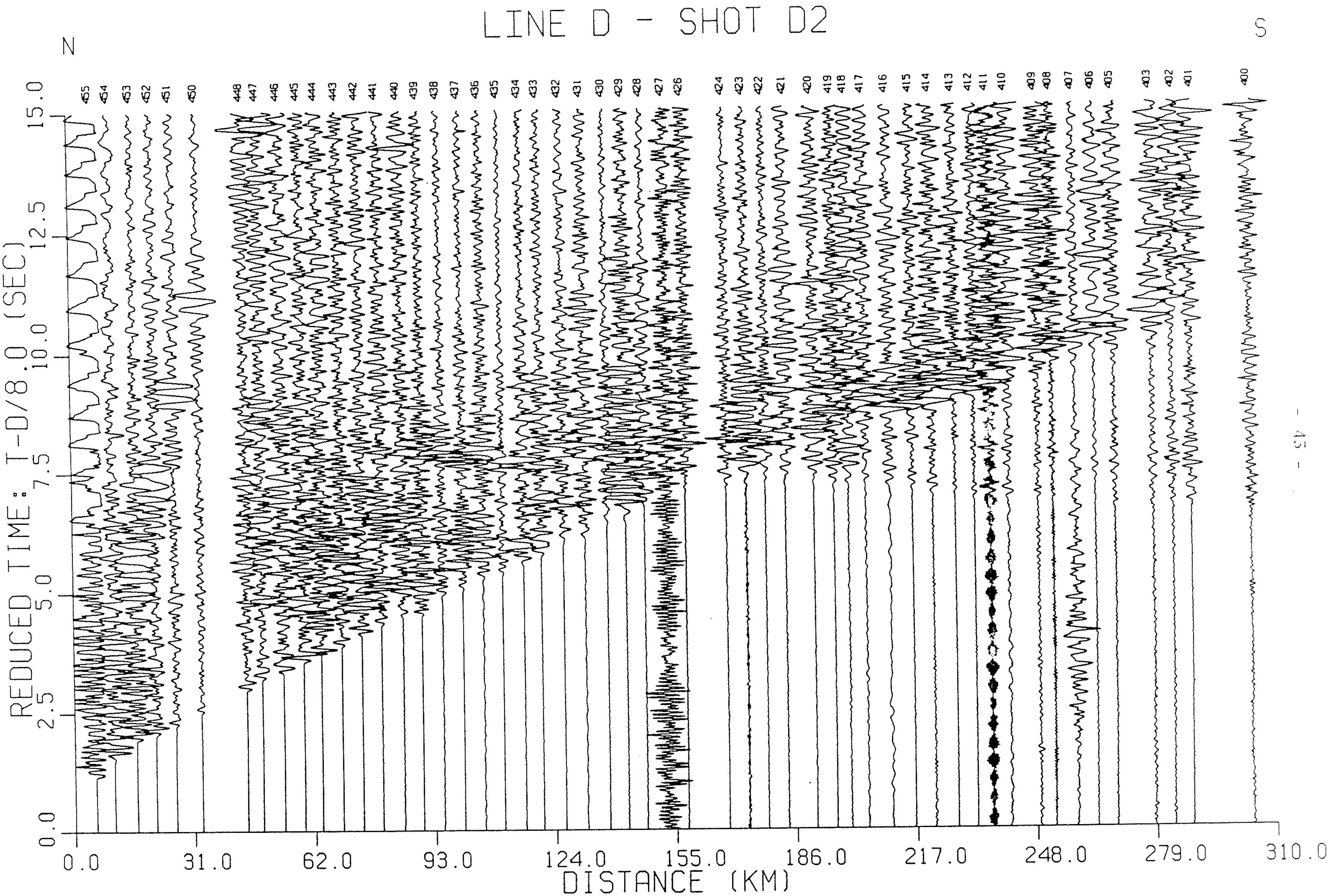

Figure 27. Record section from shot point D2 (Shot 23) recorded southward along

Summary

The field operations of the Institute of Sedimentary and Petroleum Geology's Peace River Arch deep seismic refraction survey, part of the ISPG's multidisciplinary Peace River Arch project, were successfully carried out through contracts to the Universities of British Columbia and Saskatchewan from May to July 1985. Twenty-seven scientists, technicians, and students from seven institutions and equipment from nine institutions were involved in the field programme. Four reversed refraction profiles as well as two fan profiles, each of approximately 300-350 km with seismometer spacings of 3-6 km, were established along and across the axis and flanks of the Paleozoic geological structure known as the Peace River Arch. The refraction data have been compiled and assembled into documented files now available on magnetic type. Preliminary seismic sections show the data to be of excellent quality. The Universities of British Columbia and Saskatchewan, with the financial support and cooperation of the ISPG, are currently undertaking further processing and interpretation of the data set in order to elucidate the relationship between the crustal structure and the Phanerozoic history of the Peace River Arch.

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Acknowledgements

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Canterra Energy Limited and Chevron Canada Resources Limited made substantial financial contributions to PRASE '85. These allowed a significantly enhanced data acquisition programme with the addition of both Line D and fan shots.

N.J. McMillan and Kirk Osadetz of the ISPG provided much encouragement and assistance during the planning stages of PRASE '85. Jim Barclay of the ISPG is thanked for his enthusiastic interest and his considerable time devoted to helping us better understand the tectonic history of the Peace River Arch Area.

Doug Lyons of the Forest Land Use Branch, Alberta Forest Service, Alberta Energy and Natural Resources in Edmonton and Don Johnson, Engineering Branch, Petroleum Resources Division, British Columbia Ministry of Energy, Mines, and Petroleum Resources in Fort St. John and their respective staffs and colleagues are gratefully acknowledged for their considerable cooperation and willingness to accommodate the quite unusual demands of our deep seismic refraction field operations.

Finally, Bob Meldrum of UBC, Doug Cant of the Alberta Geological Survey, and various ISPG colleagues have all read parts or all of earlier versions of this report and have suggested changes which have improved its clarity.

Appendix A

"Statement of work" DSS Contract O1SG-23294-5-0572

Objective: To explore the nature of the crust and upper mantle by conducting a seismic refraction survey on and in the vicinity of the geological structure known as the Peace River Arch in northwestern Alberta and northeastern British Columbia.

1. The refraction survey will comprise

   a. a N-S profile known as line A running from the vicinity of Tp95-R22, W5 in the north to the vicinity of Tp60-R18,W5 in the south, a total length of approximately 350 km, set out in two approximately 175 km segments in each case recording seismic arrivals from two 600 kg shots, at each end of the 175 km array, a 2000 kg shot at the distal end of the profile, and a 2000 kg broadside shot from the vicinity of Lone Prairie, B.C.
   b. an E-W profile known as line B running from the vicinity of Tp86-R14, W5 in the east to the vicinity of Lone Prairie, B.C. in the west, a total length of approximately 350 km, set out in two approximately 175 km segments, in each case recording seismic arrivals from two 600 kg shots, at each end of the 175 km array, and a 2000 kg shot at the distal end of the profile. In addition, the recording instruments should be redeployed along the whole of line B so as to record seismic arrivals from a single 2000 kg broadside shot from the vicinity of Tp110-R6, W6;
   c. an E-W profile known as line C running from the vicinity of Tp73-R10, W5 in the east to the vicinity of Tp69/70-R13/14, W6 in the west, a total length of apprxoimately 300 km, recording seismic arrivals from 2000 kg shots situated at either end;
   d. a N-S profile known as line D running from the vicinity of Tp96-R4, W6 in the north to the vicinity of Tp65-R5, W6 in the south, a total length of approximately 300 km, recording seismic arrivals from 2000 kg shots situated at either end.

2. The specified detonation of explosives will be provided by Z. Hajnal, University of Saskatchewan, according to the requirements of the contractor.

3. Recorder spacing should be approximately 3.2 km for each segment of lines A and B, except for the broadside shot into B for which a spacing of approximately 6.4 is sufficient, and approximately 5.6 km for lines C and D.

4. The contractor is responsible for arranging all-terrain vehicular and/or helicopter support in order to satisfy the spacing requirements specified in paragraph 3 or to the satisfaction of the Scientific Authority.

5. Instrumentation capable of recording the shots over a bandwidth of 1 to 20 Hz is required.

6. At least 60 seconds of data, after first arrivals, are to be recorded.

7. The absolute timing of recording channels should be accurate to within 10 milliseconds. The horizontal and vertical positions of shot points should be accurate to within 50 and 15 m respectively. The horizontal positions should be stated in terms of latitude and longitude.

8. Field recording may be digital, AM or FM tape but must finally be available on 9-track, 1/2" magnetic tape, 10 millisecond digital sampling, and in a standarized format specified by the ISPG.

9. Recording shall begin on or about 20 June 1985 and take place every other day thereafter, other circumstances permitting, until complete.

10. The ISPG bears no responsibility for losses, damages, or liabilities incurred by the contractor, his sub-contractors, and/or employees, associates, etc.

Appendix B

"Statement of work" DSS Contract O1SG-23294-5-0573

Objective: To explore the nature of the crust and upper mantle by conducting a seismic refraction survey on and in the vicinity of the geological structure known as the Peace River Arch in northwestern Alberta and northeastern British Columbia; specifically, to provide seismic energy for the seismic refraction survey by placing and detonating explosives provided by the ISPG and the University of British Columbia.

1. Shot sizes and their approximate locations are as follows:

   a. for the N-S refraction profile known as line A: one shot of 2000 kg, with recording site offsets of 175 to 350 km, and one shot of 600 kg, with recording site offsets of 3 to 175 km, in the vicinity of Tp95-R22, W5; two shots of 600 kg, with offsets of 3 to 17 km, in the vicinity of Tp78-R20, W5; one shot of 2000 kg, etc, and one shot of 600 kg etc., in the vicinity of Tp60-R18, W5; and two broadside shots of 2000 kg, with recording site offsets of approximately 300 km, in the vicinity of Lone Prairie, B.C.;
   b. for the E-W refraction profile known as line B: one shot of 2000 kg, etc., and one of 600 kg, etc., in the vicinity of Lone Prairie, B.C.; two shots of 600 kg, etc., in the vicinity of Tp83-R5, W6; one shot of 2000 kg, etc., and one of 600 kg, etc., in the vicinity of Tp86-R14, W5; and one broadside shot of 2000 kg, etc., in the vicinity of Tp100-R6, W6;
   c. for the E-W refraction profile known as line C: one shot of 2000 kg, with recording site offsets of 5 to 300 km, in the vicinity of Tp69/70-R13/14, W6; and one shot of 2000 kg, etc., in the vicinity of Tp73-R10, W5.
   d. for the N-S refraction profile known as line D: one shot of 2000 kg, etc., in the vicinity of Tp96-R4, W6; and one shot of 2000 kg., etc., in the vicinity of Tp65-R5, W6.

2. Explosives are to be detonated in holes drilled to properly contain the charges, with approximately 200 kg of explosive in each drilled hole.

3. Shooting of the explosives is to be coordinated with the seismic recording requirements of R.M. Ellis, University of British Columbia. Shots should be prepared for firing on or about 20 June 1985, with additional shots taking place every other day thereafter, other circumstances permitting, until complete.

4. Absolute timing of shots should be accurate to within 10 milliseconds. The horizontal and vertical positions of shot points should be accurate to within 50 and 15 m respectively. The horizontal positions should be stated in terms of latitude and longitude.

5. The contracter shall take possession of the provided explosives, Geogel 60%, at Explosives Ltd., Grande Prairie, no earlier than 13 May, 1985.

6. The contractor and his sub-contractors shall operate under Alberta Exploration Permit and Licence held by the ISPG.

7. The operations of the contractor and his sub-contractors are expected to conform with all relevant provincial and federal laws and regulations.

8. After-shot inspections, clean-up, repair of damage (flowing wells etc.) and settlement of damage claims are the contractor's responsibility.

9. The ISPG bears no responsibility for losses, damages, or liabilities incurred by the contractor, his sub-contractors, and/or employees, associates, etc.

Appendix C

Extract from letter, 11 July 1985

I.C. Ross, Technical Manager-Seismic,
C-I-L Inc., Calgary:
Z. Hajnal, University of Saskatchewan, Saskatoon

Unusual Occurrence

The unexpected fire in hole #4 of the original 10 hole pattern at East Pine [British Columbia], which was 30 metres distant from the end hole in the pattern shot on June 28th, must have been related to unusual ground conditions between these holes. The pattern was shot at 4:05 a.m. (B.C. time). Hole #4 was observed burning at 4:07 a.m. as evidence by emission of nitrogen dioxide (brown fumes), and the charge detonated at 4:09 a.m.. The GEOGEL in hole #4 possibly started burning by contact with hot gases from hole #5 through fissures already existing in the ground and/or opened up by the blast. Frictional effects of shock-induced shear on the shale layers may also have played a role in the ignition process. On the other hand, there was evidence of narrow coal seams on the sedimentary patterns of the mountain road-cuts, so the holes may have been interconnected by coal seams, which of course might be associated with pockets of methane gas. The coal seam theory is compatible with the observation that the original pattern ran into current leakage problems. (Coal is associated with low impedance.) Once combustion was started, detonation was inevitable as the charge contained two seismic detonators which are activated by heat (normally provided by passage of current through the bridge wire). With the benefit of hindsight, 30 metres was perhaps too close to shoot holes containing 200 kg. However, I must concede that I regarded this as easily adequate to preclude sympathetic detonation. I did not foresee the possibility of an ignition by burning. I still feel that this was a very unusual occurrence . . .

Appendix D

(a) Example of PRASE Header

```
PEACE RIVER ARCH SEISMIC EXPERIMENT (PRASE)  1985
LINE -    C  DATE - 171D 85Y     SHOT TIME - 11HR 15MIN  0.000S  SIZE -  200KG
SHOT LOCATION -  C2   SHOT NUMB -   1  LAT -  55.6492DEG  LONG - 115.8774DEG
SHOT ELEVATION -  715M   SHOT DEPTH -   30M   RECEIVER ELEVATION -  725M
RECEIVER LOCATION - NUMB 304  LAT -  55.0420DEG  LONG - 119.6778DEG
SEISMOMETER TYPE - MARK L4                    FREQUENCY -  1HZ  ORIENT - VERT
RECORDER TYPE - GEOTECH MCR 600   -   1    SAMPLING FREQ. 60HZ  GAIN    1.66000
304011
UBC CALCULATED: SHOT/RECEIVER DIST - 250.382  START TIME AFTER SHOT : -59.950S
TIME OF FIRST DATA SAMPLE     11HR 14MIN  0.050S
```

(b) Subroutine WRITIT used to Produce Record Headers

```
      SUBROUTINE WRITIT(LINE,IDAY,IMIN,ISIZE,SLOC,ISHOT,ALAT,
     1 ALONG,ISE,IRE,JTRACE,BLAT,BLONG,IFREQ,RNAME,RGAIN,
     2 DIST,IUNIT)
      CHARACTER*24 RNAME
      CHARACTER*4  LINE,SLOC
      REAL*8 ALAT,ALONG,BLAT,BLONG,DIST
      JMIN=IMIN-1
C
      WRITE(IUNIT,800)
      IF(IMIN.LT.10)THEN
        WRITE(IUNIT,811)LINE,IDAY,IMIN,ISIZE
      ELSE
        WRITE(IUNIT,801)LINE,IDAY,IMIN,ISIZE
      END IF
      WRITE(IUNIT,802)SLOC,ISHOT,ALAT,ALONG
      WRITE(IUNIT,803)ISE,IRE
      WRITE(IUNIT,804)JTRACE,BLAT,BLONG
      WRITE(IUNIT,805)IFREQ
      WRITE(IUNIT,806)RNAME,RGAIN
      IF(ISHOT.LT.10)THEN
        WRITE(IUNIT,817)JTRACE,ISHOT
      ELSE
        WRITE(IUNIT,807)JTRACE,ISHOT
      END IF
      WRITE(IUNIT,808)DIST
      IF(JMIN.LT.10)THEN
        WRITE(IUNIT,819)JMIN
      ELSE
        WRITE(IUNIT,809)JMIN
      END IF
C
800   FORMAT('  PEACE RIVER ARCH SEISMIC EXPERIMENT (PRASE)  1985')
811   FORMAT('  LINE - ',A4,' DATE - ',I3,'D 85Y     SHOT TIME - 11HR 0'
     #,I1,'MIN  0.000S  SIZE - ',I4,'KG')
801   FORMAT('  LINE - ',A4,' DATE - ',I3,'D 85Y     SHOT TIME - 11HR '
     #,I2,'MIN  0.000S  SIZE - ',I4,'KG')
802   FORMAT('  SHOT LOCATION - ',A4,'  SHOT NUMB - ',I2,'  LAT - ',
     #F8.4,'DEG  LONG - ',F8.4,'DEG')
803   FORMAT('  SHOT ELEVATION - ',I4,'M   SHOT DEPTH -  30M',
     # '   RECEIVER ELEVATION - ',I4,'M')
804   FORMAT('  RECEIVER LOCATION - NUMB ',I3,'  LAT - ',F8.4,
     # 'DEG  LONG - ',F8.4,'DEG')
805   FORMAT('  SEISMOMETER TYPE - MARK L4                   FREQUENCY - '
     #,I2,'HZ  ORIENT - VERT')
806   FORMAT('  RECORDER TYPE - ',A24,' SAMPLING FREQ. 60HZ  GAIN',
     # F11.5)
817   FORMAT('  ',I3,'0',I1,'1')
807   FORMAT('  ',I3,I2,'1')
808   FORMAT('  UBC CALCULATED: SHOT/RECEIVER DIST -',F8.3,
     # '  START TIME AFTER SHOT : -59.950S')
819   FORMAT('  TIME OF FIRST DATA SAMPLE    11HR 0',I1,'MIN  0.050S')
809   FORMAT('  TIME OF FIRST DATA SAMPLE    11HR ',I2,'MIN  0.050S')
C
      RETURN
      END
```