

ISBN 0-315-61807-8

MIGRATION BY THE DIFFRACTION STACK METHOD

CENTRE FOR NEWFOUNDLAND STUDIES

**TOTAL OF 10 PAGES ONLY
MAY BE XEROXED**

(Without Author's Permission)

PRIYA RANJAN MOHANTY



National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service

Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

MIGRATION BY THE DIFFRACTION STACK METHOD

by



Priya Ranjan Mohanty, M. Phil.

A thesis submitted in partial fulfilment
of the requirements for the degree of
Master of Science

Department of Earth Sciences (Geophysics)

Memorial University of Newfoundland

April 1984

St. John's

Newfoundland



National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-61807-8

Canada

ABSTRACT

Computer programmes were developed to implement the diffraction stack migration scheme. In order to test the above technique, zero offset synthetic seismograms were generated for two simple models; a dipping layer and an anticline. Later the diffraction stack algorithm was applied to the field seismic data for the Adolphus structure.

The general structure of the subsurface reflectors were better clarified in the migrated sections than the unmigrated sections for both synthetic and field seismic data. The anticline breadth was reduced in both synthetic and field migrated sections after collapsing the diffraction patterns generated at the sharp boundaries. The salt flank in Adolphus structure was delineated better than the original stacked section. It is also observed from migrated sections on the two synthetic models that the diffraction stack method works efficiently for steep dip reflectors up to dip angle 40 degrees.

TABLE OF CONTENTS

CHAPTER		PAGE
1.0	INTRODUCTION	
1.1	Objective	1
1.2	Regional Geology	1
1.3	Previous Geophysical Work	3
1.4	Present Survey	4
		8
2.0	MIGRATION	
2.1	Methods of Migration	11
2.1.1	Maximum Convexity Curves	11
2.1.2	Diffraction Stack Method	13
2.1.3	Finite - Difference Method	15
2.1.4	Frequency - Wavenumber Method	16
2.2	Mathematical Formulation of Diffraction Stack Method	18
2.3	Diffraction Summation	18
		20
3.0	APPLICATION OF DIFFRACTION STACK METHOD TO SYNTHETIC MODELS	23
3.1	Generation of Zero offset Synthetic Seismic Data	23
3.1.1	An Inclined Reflector	25
3.1.2	An Anticline	27
3.2	Migration of Synthetic Sections	28
3.2.1	Parameters for Migration of Synthetic Data	30
3.2.2	Implementation of Migration by Computer	33
3.3	Results of Migrated Sections	36
3.3.1	An Inclined Reflector	36
3.3.2	An Anticline	52
		52
4.0	APPLICATION OF DIFFRACTION STACK METHOD TO FIELD DATA	78
4.1	Local Geology of the Adolphus Structure	79
4.2	Data Translation form Consul Staked Reel	81
4.3	Parameters for Migration of Field Data	83
4.4	Results of Migrated Sections	86
		86
5.0	CONCLUSIONS	90
5.1	Limitations and Suggestions for Further Work	93
		93
	APPENDIX 1	95
		95
	APPENDIX 2	106
		106

(ii)

TABLE OF CONTENTS (cont'd)

	PAGE
ACKNOWLEDGEMENTS	107
REFERENCES	108

LIST OF FIGURES

FIGURE		PAGE
1.1	Index map for basins in Grand Banks (south), East Newfoundland Shelf and East Newfoundland Basin. Contours indicate depth to basement from seafloor	2
1.2	Composite stratigraphic section, Grand Banks	5
1.3	Well location map	7
1.4	Seismic data processing sequence	10
2.1	Use of curve of maximum convexity and wavefront for migrating reflection from apparent position at Q to actual position at P	12
2.1.1	Surface of maximum convexity for reflecting point at P. Positions along curve are shown for six shot points with coincident geophones	14
2.1.2	Diffraction stacking illustrating the principle of migration	17
2.2	The diffraction front and its construction	19
2.3	Diffraction summation migration as seen by the output trace.	22
3.1	Raypaths for coincident source-receiver locations	24
3.1.1	An inclined reflector model	26
3.1.2	An anticline model	29

LIST OF FIGURES (cont'd)

FIGURE	PAGE
3.2.1 The reflection patterns due to different apertures	31
3.2.2 Principle of computer migration using curve of maximum convexity with an aperture of 5 input traces	34
3.1.1 Unmigrated section	37
3.3.1.2 Unmigrated section	38
3.3.1.3 Unmigrated section	39
3.3.1.4 Unmigrated section	40
3.3.1.5 Unmigrated section	41
3.3.1.6 Unmigrated section	42
3.3.1.7 Migrated section	43
3.3.1.8 Migrated section	44
3.3.1.9 Migrated section	45
3.3.1.10 Migrated section	46
3.3.1.11 Migrated section	47
3.3.1.12 Migrated section	48
3.3.1.13 Time shift - offset distance curve	50
3.3.1.14 Least-squares fit curve	53
3.3.1.15 Migrated section	54
3.3.1.16 Migrated section	55
3.3.1.17 Migrated section	56
3.3.1.18 Migrated section	57
3.3.1.19 Migrated section	58
3.3.1.20 Migrated section	59

LIST OF FIGURES (cont'd)

FIGURE	PAGE
3.3.1.21 Migrated section	60
3.3.1.22 Migrated section	61
3.3.1.23 Migrated section	62
3.3.1.24 Migrated section	63
3.3.1.25 Migrated section	64
3.3.2.1 Unmigrated section	66
3.3.2.2 Unmigrated section	67
3.3.2.3 Unmigrated section	68
3.3.2.4 Unmigrated section	69
3.3.2.5 Unmigrated section	70
3.3.2.6 Unmigrated section	71
3.3.2.7 Migrated section	72
3.3.2.8 Migrated section	73
3.3.2.9 Migrated section	74
3.3.2.10 Migrated section	75
3.3.2.11 Migrated section	76
3.3.2.12 Migrated section	77
4.1 Map showing the Adolphus structure	80
4.2 Recommended demultiplexed format	84
4.4.1 Seismic section before migration (in pocket)	
4.4.2 Seismic section after migration (in pocket)	
4.4.3 Seismic section after migration (in pocket)	
4.4.4 Seismic section after migration (in pocket)	
A.2.1 An inclined reflector model	106
A.2.2 An anticline model	106

LIST OF TABLES

TABLE		PAGE
3.2.1	Different apertures values for different set of synthetic model data	32
3.3.1	Effect of dip angle on phase is shown	51
4.1	Details of geological formations penetrated by Adolphus wells	82
4.3	Different apertures values for different set of velocities for field stacked data	85

CHAPTER 1

1.0 INTRODUCTION

The present study was undertaken to investigate the diffraction stack migration technique and apply it to the stacked seismic data for the Adolphus structure on the Grand Banks. The Grand Banks basins are located approximately 315 km southeast of St. John's, Newfoundland and cover an offshore area of 17000 square kilometers (Fig. 1.1). Economic interest in the basins of the area arises from hydrocarbon occurrences of the Heron (H-73) well drilled on a flank of a salt diapir in the South Whale Subbasin (Procter et al., 1983), from the tested flow at the Adolphus 2K-41 well, from the major discoveries on the Hibernia structure, and other discoveries in the same area of the Jeanne d'Arc Subbasin.

1.1 Objective

The aim of the present study was to apply the diffraction stack migration technique to aid in the interpretation of seismic time sections. Computer programmes were developed to implement the migration technique. The application of the diffraction stack migration method was investigated for zero offset (stacked) synthetic seismic data generated by considering

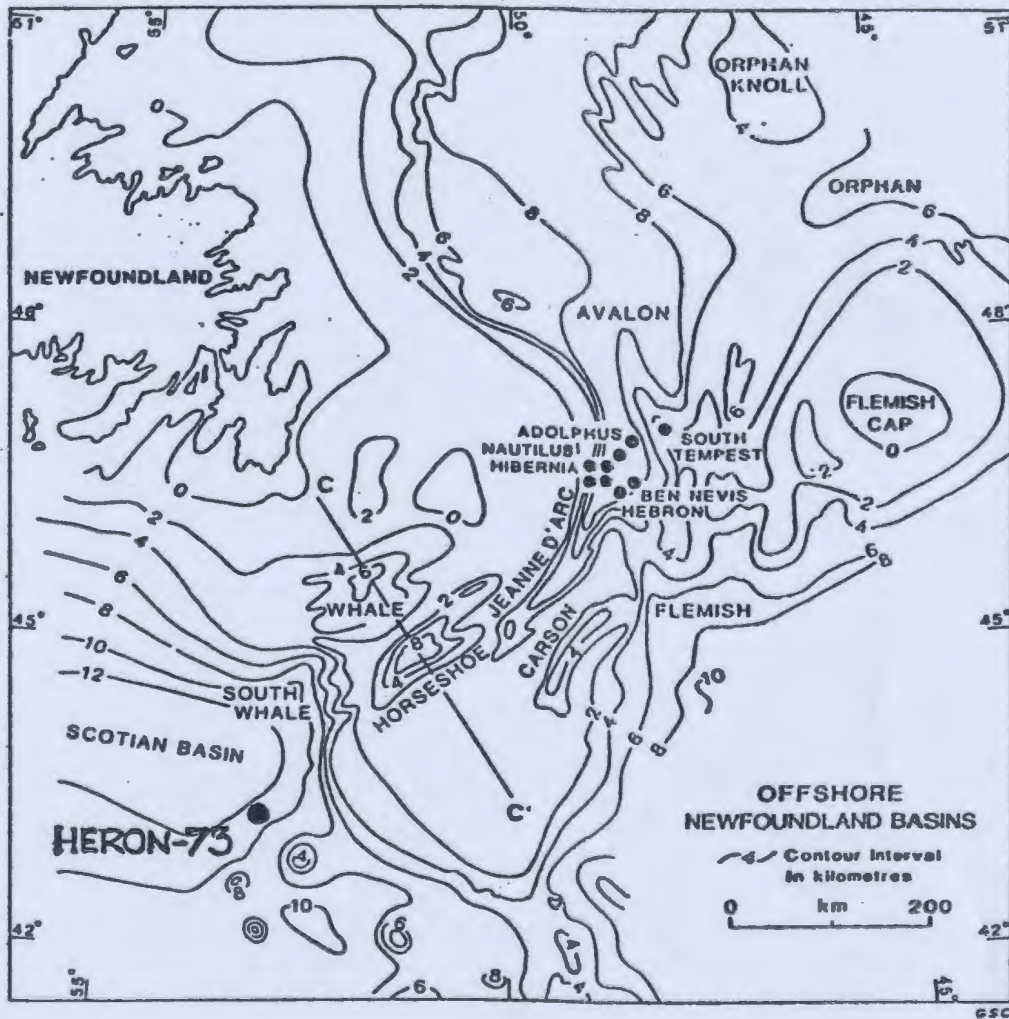


Figure 1.1 Index map for basins in Grand Banks (south), East Newfoundland Shelf and East Newfoundland Basin. Contours indicate depth from seafloor. (After McMillan, 1982).

two different simple models. The effects of migration velocity and dip angle on the application of the above technique were studied. After testing the method on synthetic data the programmes were applied to the existing seismic data for the Adolphus structure. The results from model and real data were analysed in terms of subsurface reflectors.

1.2 Regional Geology

The Grand Banks (Figure 1.1) are located east of Newfoundland. Extensive geophysical and drilling operations within the area of the Grand Banks have established the presence of a thick sedimentary section suitable for petroleum accumulations (Amoco and Imperial, 1973). The major sedimentary section in the area under study comprises Tertiary, Mesozoic and Paleozoic strata. There are two distinct geological units separated by an angular unconformity of early Cretaceous age. The "upper wedge" is mainly composed of Tertiary and Cretaceous strata. The other unit "Subunconformity basins" contains Jurassic and older rocks. The "upper wedge" is relatively simple with gentle dip, disturbed locally by salt-dome and rollover fault controlled structures. The "Subunconformity basins" contain different structural traps, including salt domes, salt ridges, faults, drape folds over basement rocks and major sedimentary truncations at the unconformity. The general stratigraphic sequence of the Grand Banks is shown in Figure 1.2.

Upper Cretaceous and Tertiary shales overlying the unconformity have potential as source rocks but are thermally immature (Procter et al., 1983). The lower and middle Jurassic are considered as poor, gas prone source rocks. The major potential reservoir rocks constitute basal transgressive porous sand and upper Cretaceous limestone units. The Verrill Canyon shale constitutes the major source rock found in the west flank of the Avalon Uplift.

1.3 Previous Geophysical Work

The first refraction seismic measurements were taken in the Grand Banks area by a group from Woods Hole Oceanographic Institution in 1951. Subsequently Press and Beckmann (1954) reported the sedimentary layers thickness range from 700m to 3300m on the basis of previous refraction data. Additional data collected by Bently and Worzel (1956) indicated low-velocity sedimentary layers beneath the western Grand Banks and Laurentian Fan deep-water area. Ewing and Ewing (1959) reported the results of a refraction study indicating the sedimentary layers thickness of Grand Banks as 4900m.

In the same year the Geological Survey of Canada and the Canadian Hydrographic Service conducted sea-magnetometer surveys covering a part of the Grand Banks (Bower, 1962). The results show the depths to magnetic basement varied from 76m below the seafloor in the Virgin Rocks-Eastern Shoals area to 2300m on the northern Grand Banks. Hood and Godby (1965) reported the sedimentary thicknesses in Grand Banks to be 2400m from their

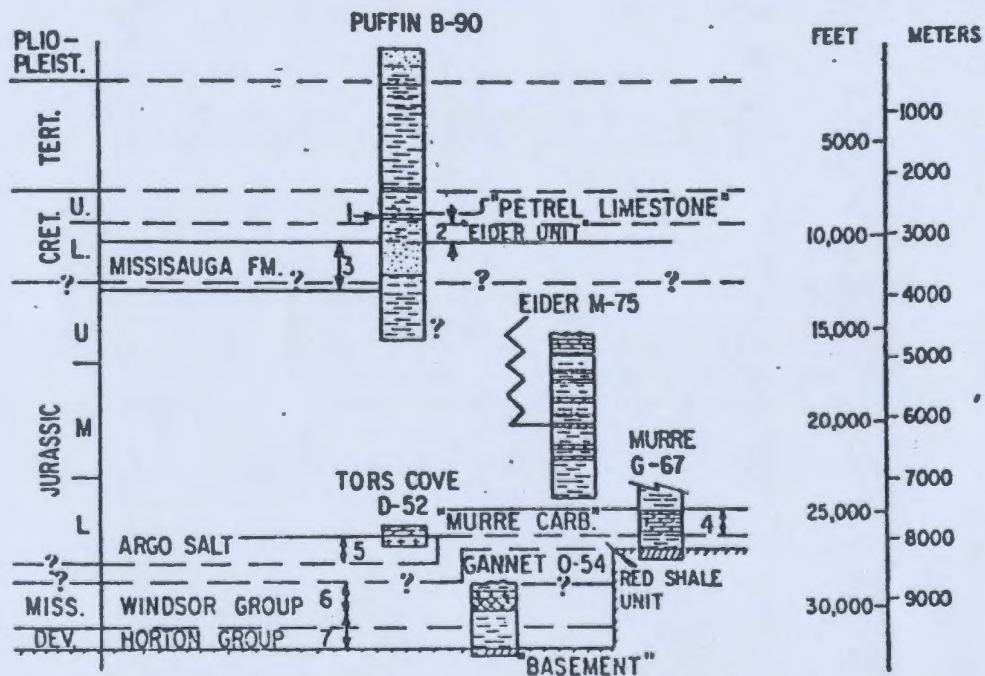


Figure 1.2 Composite stratigraphic section, Grand Banks (After Amoco and Imperial Oil, 1973).

long aeromagnetic profile running from Prince Edward Island, through the Cabot Strait to the trail of the Grand Banks of Newfoundland and subsequently over the Flemish Cap.

Direct geological information about the sedimentary rocks beneath the Grand Banks came from Lilly (1965). Lilly also reported the outcropping Precambrian basement-rock on the Eastern Shoals and Ballard Banks. Pelletier (1971) reported on the basement rock confirming the earlier result from a core of granodiorite in Flemish Cap area of the eastern Canadian continental margin located 500 km east of St. John's, Newfoundland (Figure 1.1).

In 1964, Amoco conducted both aeromagnetic and shallow seismic reflection surveys in the Grand Banks area (Figure 1.3). The basin shape (southern Grand Banks) was first delineated from the aeromagnetic interpretation whereas shallow seismic indicated the major structures associated with salt domes. Between 1964 to 1965, 15,300 km of gas-exploder seismic surveys were conducted. These surveys indicated two major structural features of the area - namely, a mid-Cretaceous angular unconformity, and salt piercement structures. In 1965, multifold seismic data were collected for the first time with dynamite as energy source. This led to the locations of two exploratory wells Tors Cove and Grand Falls in the Grand Banks area (Figure 1.3). Since 1967, approximately 32,000 km of 12 and 24 fold seismic data have been acquired, with dynamite, Flexotir, and airgun as energy sources. By the end of 1974 40 dry wells had been drilled on the Grand Banks. Between 1974 and 1976 three wells were

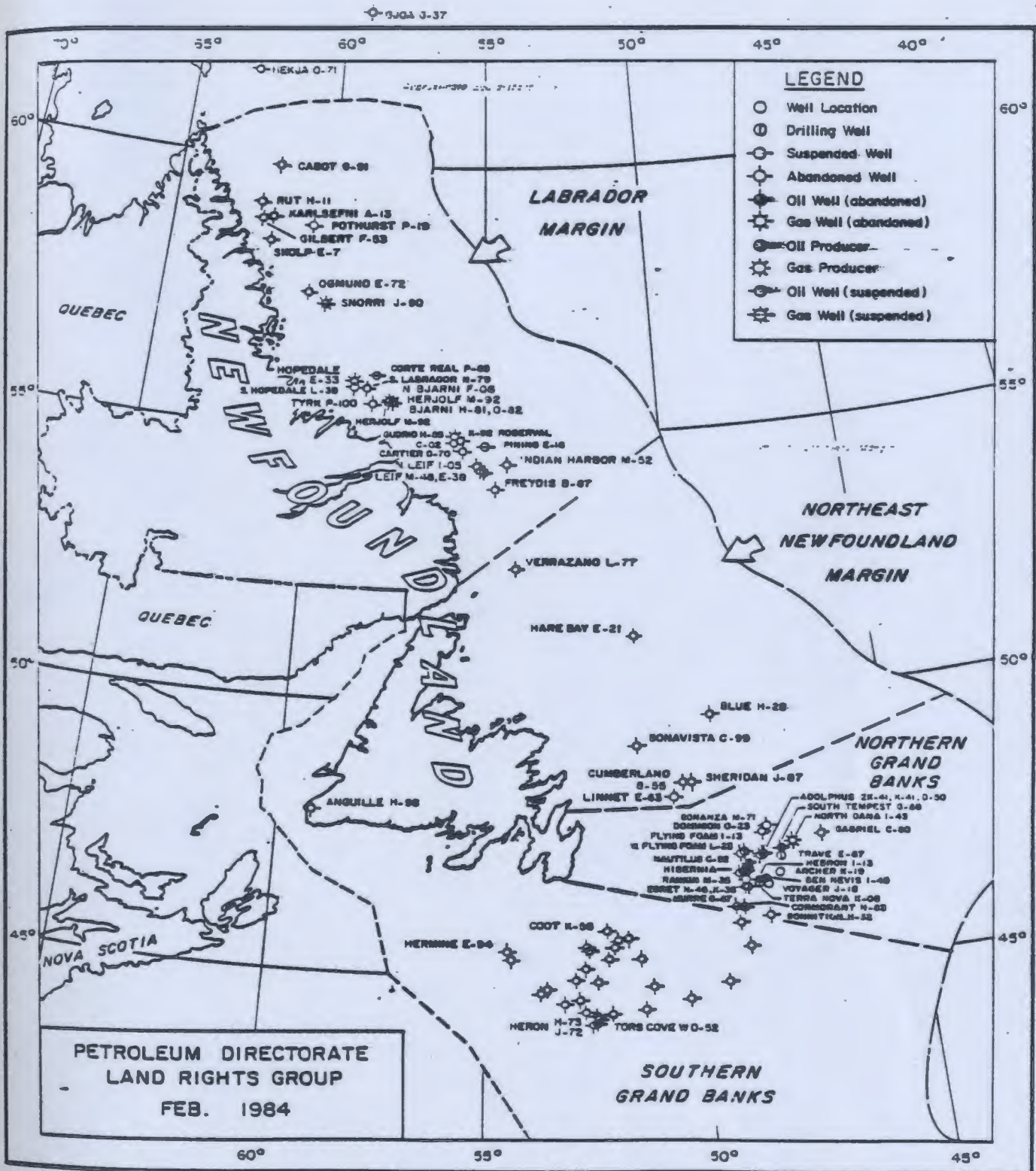


Figure 1.3 Well location map.

drilled on the northeast Newfoundland shelf area: Bonavists C-99, Cumberland B-55 and Verrazano L-77.

Geophysical investigations from Mobil's survey indicated the presence of various structures - salt diapirs, basement highs and tilted fault blocks in the northern Grand Banks area. Up to the end of 1974, no commercial hydrocarbon reserves were found in the above area. However, minor flows of oil and gas from the upper Cretaceous sandstones were noticed from the Adolphus 2K-41 well (Figure 1.3) on a salt piercement structure drilled by Mobil Oil Limited. Drilling again resumed in 1979 on the Grand Banks area and Gabriel C-60 well was spudded. This well indicated the presence of noncommercial amounts of oil in a lower Cretaceous core (Petroleum Directorate Information Kit, 1984). In September 1979, Chevron tested the Hibernia P-15 well and made a significant discovery of hydrocarbon accumulations in the Hibernia structure. The total flow rate was 20,000 barrels of oil per day which is thought to be viable for commercial production. Later it was established as a commercial oilfield on the basis of further exploratory drilling on the Hibernia structure (Petroleum Directorate Information Kit, 1984).

1.4 Present Survey

The present seismic survey was conducted during December 1975 by Geophysical Services Incorporated (GSI), Calgary with Mobil Oil Canada Limited as operator. Forty eight fold seismic data were collected on seismic line G-583B on the Adolphus structure in the Grand Banks,

Newfoundland (Fig. 1.3) with 9 track DFS III recording system. The direction of seismic line was south-east. Tuned airgun arrays were used as energy source with air pressure of 1600 psi. Hydrophone groups with group interval of 50m and 30 hydrophones per group were arranged in the streamer cable with a hydrophone spacing of 1.1m. A spread length of 2350m was used for the entire data acquisition process. Shots were fired at every 25m to acquire the seismic data. All data were recorded digitally for 5 seconds using a 2ms sampling rate. Satellite navigation for position location in the offshore area was provided by GEONAV system.

The data were processed by GSI headquarters in Calgary. The data processing sequence applied to this data is presented in Fig. 1.4. The present analysis was carried out using the stacked seismic data (for line G-583B). The stacked data for the above seismic line was provided by Mobil Oil Canada Limited at Calgary in form of consul staked reels. In this thesis, migration (Chapter 2), and the application of diffraction stack method to synthetic models (Chapter 3) are discussed. Application of the above migration method to field data is described in the Chapter 4.

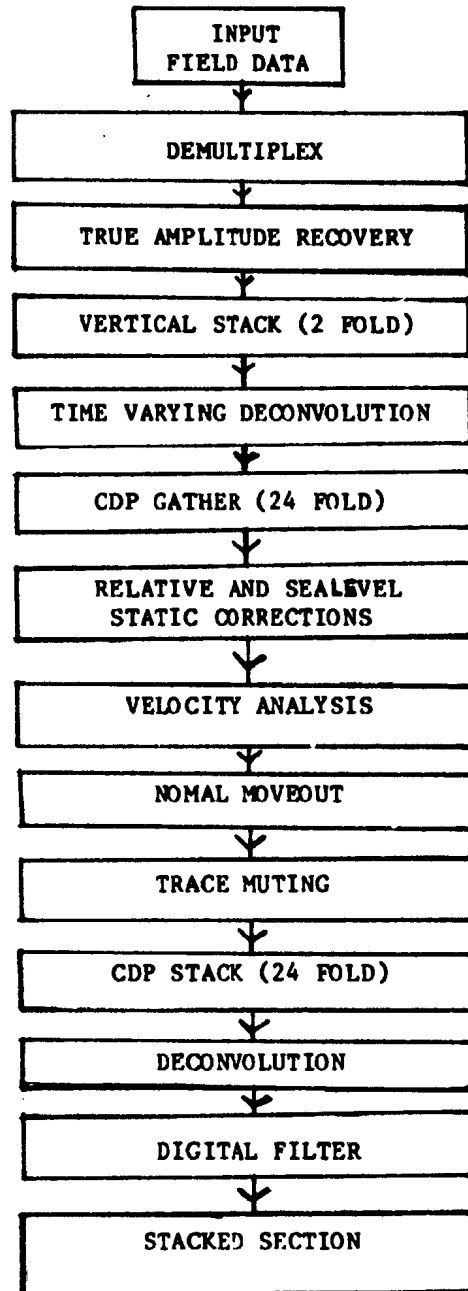


Figure 1.4 Seismic data processing sequence

CHAPTER 2

2.0 MIGRATION

Conventional time sections are often interpreted directly in terms of subsurface geometry. However, the interpretations can be misleading and are often hard to interpret geologically in areas of complex structure and high angles of dip. Unmigrated sections give an apparent subsurface picture which becomes increasingly distorted with increasing dip angle of the reflector. To overcome this problem migration of seismic traces is an essential aid in interpretation. The basic purpose of this technique is to plot the dipping reflections (apparent reflections) in the true spatial positions rather than plotting directly beneath the point midway between the shot point and centre of the geophone spread or vertically below the point (common reflection point) of coincident source and receiver position. Figure 2.1 shows the effect of migration in determining the position.

2.1 Methods of Migration

Up to the late 1960s migration was performed on a single stacked trace by graphical and mechanical methods using Hagedoorn's (1954) method. Rapid processing of multifold seismic data became possible with the rapid growth of digital computers in the 1960s. Automatic migration techniques were introduced around 1970 based on Hagedoorn's concept of the surface of

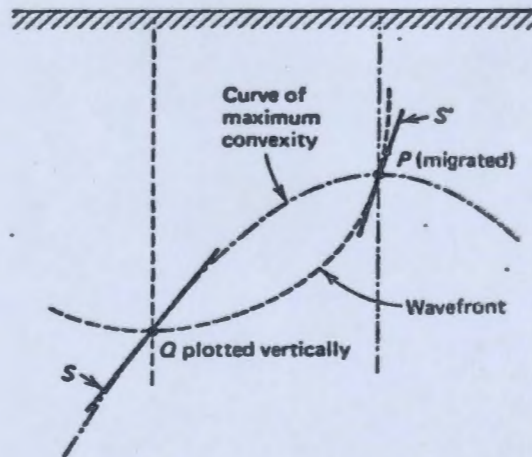


Figure 2.1 Use of curve of maximum convexity and wavefront for migrating reflection from apparent position at Q to actual position at P (After Hagedoorn, 1954).

maximum convexity. Later Rockwell (1971) introduced the diffraction stack migration method for steep-dip reflection data.

Several major developments have taken place in the late 1970s. For the first time, Hagedoorn's ray theory concept was replaced by wave theory in migration by Claerbout (1970) who developed the finite-difference method based on the scalar wave equation. Another development has taken place in implementing the diffraction stack method through Kirchhoff integral theory (French, 1975). Stolt (1978) suggested a new technique called frequency - wavenumber method based on wave theory concept. Each of these methods is summarised below.

2.1.1 Maximum Convexity Curves

Hagedoorn (1954) introduced migration using surfaces of maximum convexity (Figure 2.1.1) which he defined for a two-dimensional case. These surfaces represent the time along a slant path that would be due to a reflection or diffraction event from a given point in the subsurface to travel to a receiver as its horizontal distance from that point changes (Dobrin, 1976). This is also referred to as a diffraction curve. This is a ray tracing method which obeys Snell's Law. If the constant velocity assumption is used the wavefronts are arcs of circles with centre being at the shot point. Wavefronts will still be circles for velocity increasing linearly with depth. Maximum convexity charts are prepared by combining individual curves of maximum convexity for successive source depth over the required migration range.

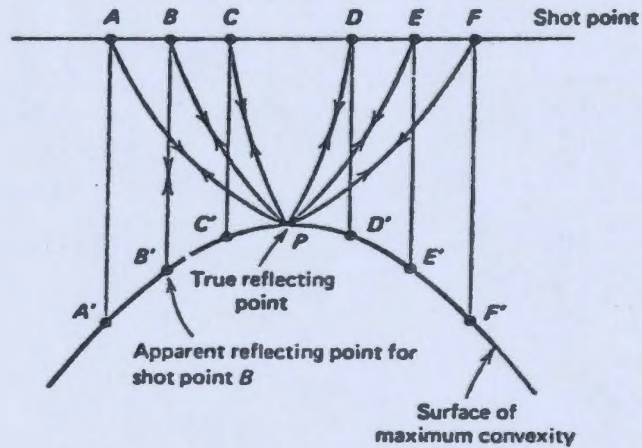


Figure 2.1.1 Surface of maximum convexity for reflecting point at P. Positions along curve are shown for six shot points with coincident geophones (After Dobrin, 1976).

To use Hagedoorn's technique, one requires two charts, a wavefront chart (chart of equal reflection times) and a chart containing curves of maximum convexity for closely spaced vertical two-way times. Initially the two curves are placed on each other with the zero depth positions coincident. The reflecting point is found along the curve on the wavefront chart corresponding to the time of the reflection along the central (vertical) axis of the chart. Then the maximum convexity curves are slid laterally until a line is found that is tangent to the apparent (unmigrated) dip at the depth of the reflecting point. The migrated position of the point is found at the vertex of this curve, and the dip of the migrated segment is found by drawing a line tangent to the wavefront circle corresponding to the reflection time where it intersects this vertex. Usually wavefront charts are prepared for a constant velocity function. For inhomogeneous media the charts are also constructed taking known velocity as a function of depth.

2.1.2 Diffraction Stack Method

This method is based on the assumption that a reflector consists of packed series of diffraction points or scatterers (Al-Sadi, 1980). This method can easily be implemented by doing addition along hyperbolic diffraction curves in the space-time domain. The basic object of this technique is to collapse diffracting events and reposition the reflections correctly. This technique is applied to the images caused by diffraction. A diffraction hyperbola is constructed for each point in the subsurface for different source and receiver positions along the horizontal axis considering a

constant velocity medium. During the diffraction stack process the diffraction curves of the true reflections will lie on the apex of the hyperbola forming a clear a reflection line whereas the diffracting events are eliminated statistically. This process is shown in Figure 2.1.2. This method can be applied both to common mid-point (CMP) or zero offset stacked seismic time sections.

2.1.3 Finite-Difference Method

Finite-difference or wave equation migration was introduced by Claerbout (1970). This technique uses the downward continuation process by solving the scalar wave equation using a differential form of solution. Wave-equation migration is based on the concept of separating the seismic wave into upgoing and downgoing waves by a mathematical procedure involving the use of a coordinate frame which moves downward at the speed of backward wave propagation. Basically the seismic section is reduced as if the time runs backward until it reaches the situation where the source-receiver common position is placed on the actual reflector. This method can be applied to stacked and unstacked data. It employs a grid of seismic data and works quite well up to true dip angles of 45° . It has the advantage over diffraction stack method while considering the factors such as computational cost, low noise from gently dipping events and lateral velocity variations. Diffraction stack migration can only handle lateral velocity variations if a raytracing technique is used.

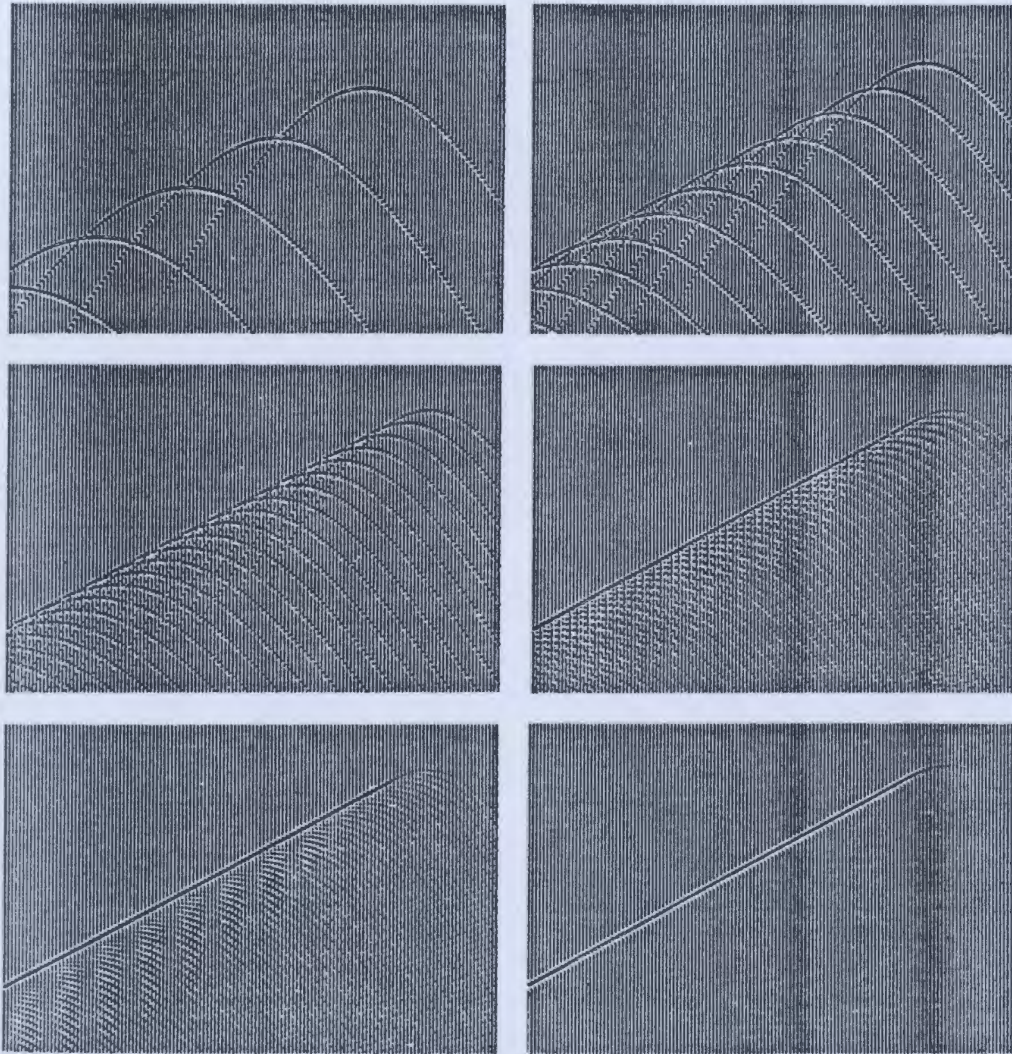


Figure 2.1.2 Diffraction stacking illustrating the principle of migration (After Dohr, 1981).

2.1.4 Frequency - Wavenumber Method

The last method called frequency-wavenumber method was developed by Stolt (1978). This method is computationally fast because it uses the fast Fourier transform algorithm. This technique is also based on the concept of downward continuation of seismic waves and works moderately well for steep dip reflectors. Stolt developed a frequency-wavenumber technique replacing the horizontal co-ordinate by their Fourier conjugates. This technique extends the Claerbout finite-difference concept, greatly reducing dispersion problems that are associated with higher dips and frequencies. Moreover, Stolt's method can be applied to three-dimensional migration and migration before stack. Generally this method considers a constant velocity medium but it can be extended to lateral variation in velocity under certain assumptions.

For our present analysis, the diffracton stack migration method in space-time domain was used to migrate the stacked seismic data over Adolphus structure on the Grand Banks area. The mathematical theory and summation technique are described in the next sections of this chapter.

2.2 Mathematical Formulation of Diffraction Stack Method

Consider the diffraction front due to point reflector at (x, z) as given in Figure 2.2. Assume coincident source-receiver placed at $(x_0, 0)$. The distance from $(x_0, 0)$ to the point reflector is $ct/2$, where c is the wave

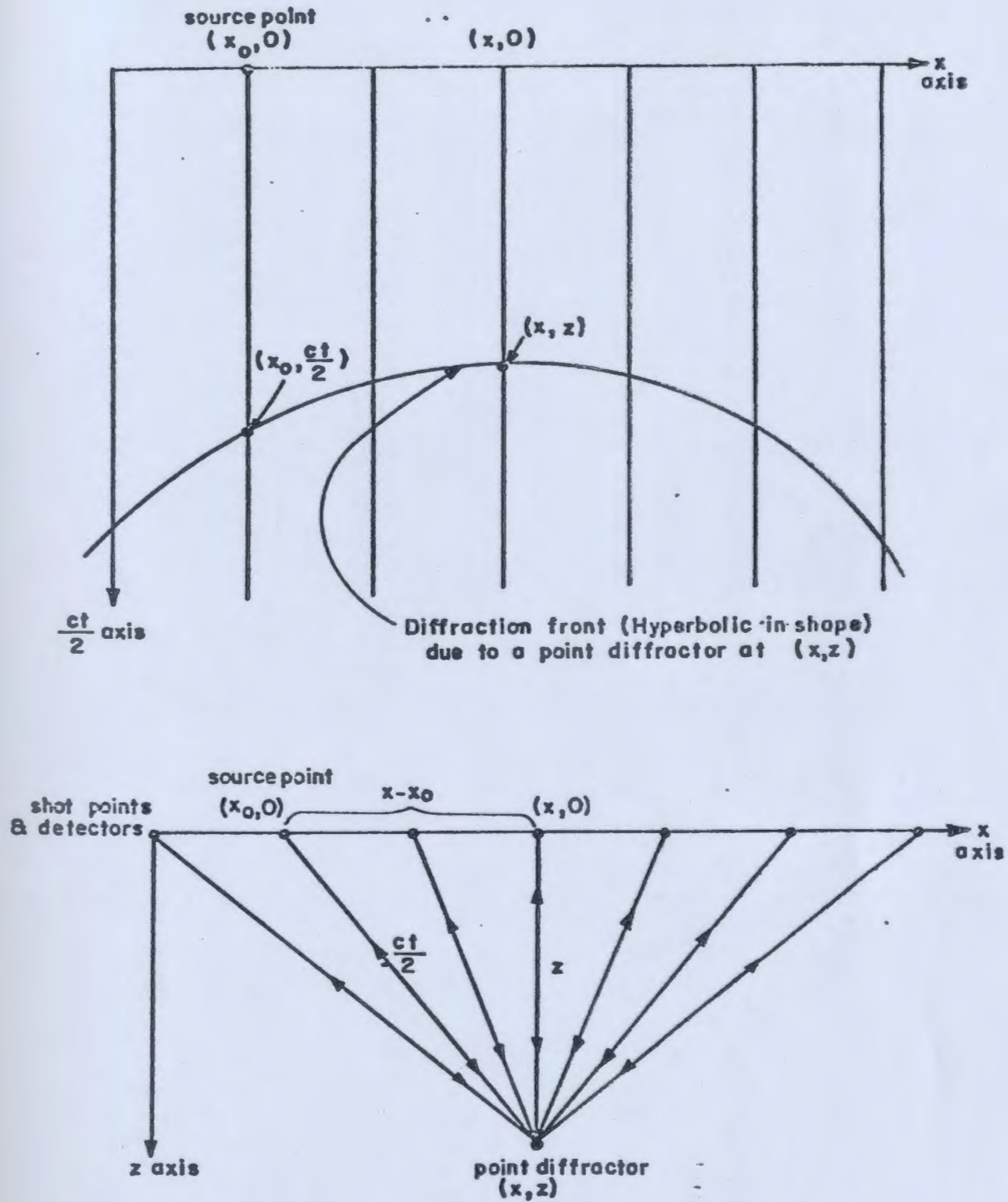


Figure 2.2 The diffraction front and its construction (After Robinson et al, 1977).

velocity and t is the two-way time.

Then,

$$\frac{ct}{2} = [(x-x_0)^2 + z^2]^{1/2} \quad 2.2.1$$

The event is plotted at time ' t ' i.e., two-way time directly under the source-receiver point at $(x_0, 0)$ that is, the event corresponding to the point reflector (x, z) is

$$(x_0, \frac{ct}{2}) = (x_0, [(x-x_0)^2 + z^2]^{1/2}) \quad 2.2.2$$

Now the diffraction front is defined as the event given by reflections from the point reflector for all source-receiver points $(x_0, 0)$. Hence, the diffraction front is the locus given by

$$\frac{ct}{2} = [(x-x_0)^2 + z^2]^{1/2} \quad 2.2.3$$

which is the semi-hyperbola in $x, ct/2$ space given by

$$(ct/2)^2 - (x-x_0)^2 = z^2 \quad 2.2.4$$

for a fixed depth.

2.3 Diffraction Summation

To reconstruct the energy due to a given true reflection point, the summation operation has to be carried out. Migration velocity depends on the shape of hyperbola along which the summation is to be carried out.

Migration velocity was considered the same as the material velocity in the synthetic stacked sections constructed for two simple models. In the field seismic stacked data, the migration velocity was determined through a trial and error method by examining the coherency energy at the apex of the diffraction hyperbola as follows:

First take the diffraction curve determined from the equation (2.2.4) using an assumed velocity and see where it intersects each trace. Then the amplitude value of each trace at the point of intersection is taken and all the values are summed together. The energy due to the given true reflection point adds inphase and is preserved. The extraneous energy adds out of phase and is cancelled. As a result of this summation the energy due to the true point reflector is positioned correctly and is plotted at the apex of the diffraction curve.

Three different constant migration velocities 2500 m/s, 3500 m/s and 4500 m/s were chosen to construct the diffraction hyperbola in order to get the maximum energy at the apex of the diffraction hyperbola. The migration velocity 3500 m/s was found best because it gave the maximum energy at the diffraction curve. The process is carried out for subsequent traces that are falling on the diffraction curve and the result is plotted at its apex. The process of doing such summations for all possible apexes is the migrated or true seismic section. This method of migration is called diffraction stack migration. Figure 2.3 shows the process of diffraction summation. A Fortran programme (Appendix 1) was developed using equation 2.2.4 to implement the diffraction stack migration technique.

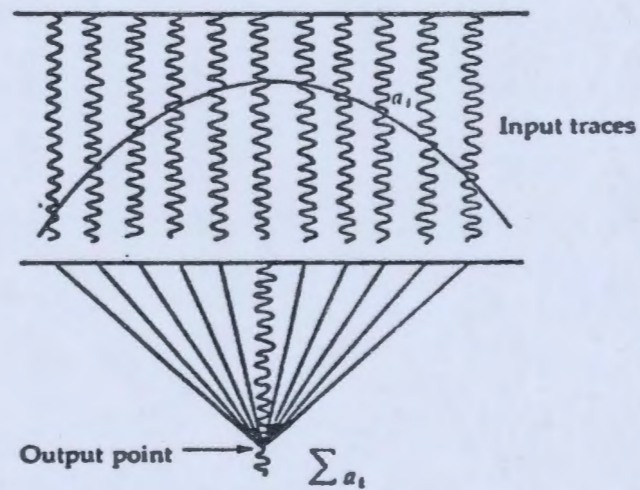


Figure 2.3 Diffraction summation migration as seen by the output trace (From Robinson, 1983).

CHAPTER 3

3.0 APPLICATION OF DIFFRACTION STACK METHOD TO SYNTHETIC MODELS

In practice, migration schemes are applied to zero offset seismic data to improve the lateral resolution and true amplitudes of the reflected events. The diffraction stack migration technique is very sensitive to velocity variation. One way to overcome this problem is to do conventional velocity analysis and take the correct stacking velocity for migrating the time section. The other alternative is to model the configuration of the subsurface by which a discrete velocity can be assigned. For our present analysis ideal synthetic seismograms using a fixed velocity were constructed for two geological models to test the above migration technique.

3.1 Generation of Zero Offset Synthetic Seismic Data

Conventional methods of migration make use of the zero offset (stacked) seismic record section which is based on coincident source-receiver geometry (Fig. 3.1). The coincident source-receiver geometry accomplishes the objective of the diffraction stack method considering only the diffraction effects while rejecting those refraction effects caused by lateral changes in velocity. The refraction effects are avoided as the rays travel to the reflector and back along the same path, with the rays normal to their final reflecting interface. Two synthetic models were

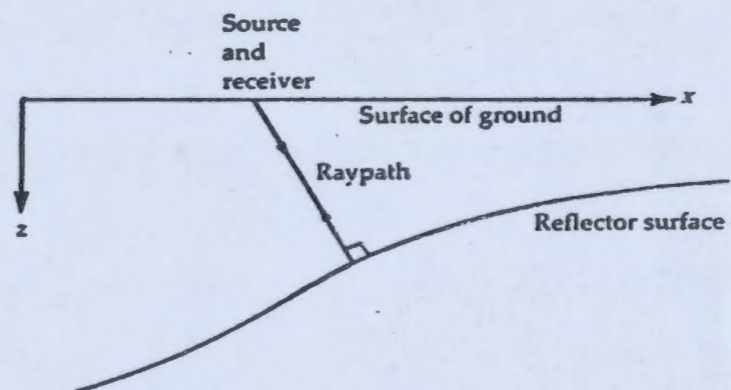


Figure 3.1 Ray paths for coincident source-receiver locations (After Robinson, 1983).

used to generate zero offset seismic data to implement the diffraction stack migration.

3.1.1 An Inclined Reflector

We consider straight ray paths constructed along perpendiculars to the beds from coincident source-receiver position (zero offset section) on the surface and the final seismic section is presented in vertical orientation. In areas of steep dip (more than ten degrees), the reflections from dipping beds emanate from depth points which are up dip from the surface source-receiver positions. In general plotted seismic time sections display these depth points directly beneath the surface source-receiver location depicting apparent subsurface structure. This introduces an error in interpreting the subsurface location of the reflector and in its geometry. Simple ray-path modelling at normal incidence is adequate to show the expected apparent interface caused due to an inclined reflector.

Synthetic seismograms can be constructed through manual, analog and digital methods. For our present analysis digital techniques are implemented to generate zero offset synthetic seismograms. Synthetic time data were generated for a zero offset section assuming a simple geologic model having depths, velocities and densities shown in (Fig. 3.1.1). To produce this zero offset synthetic section means to generate synthetic seismograms (Peterson et al, 1955) which are artificial reflection records

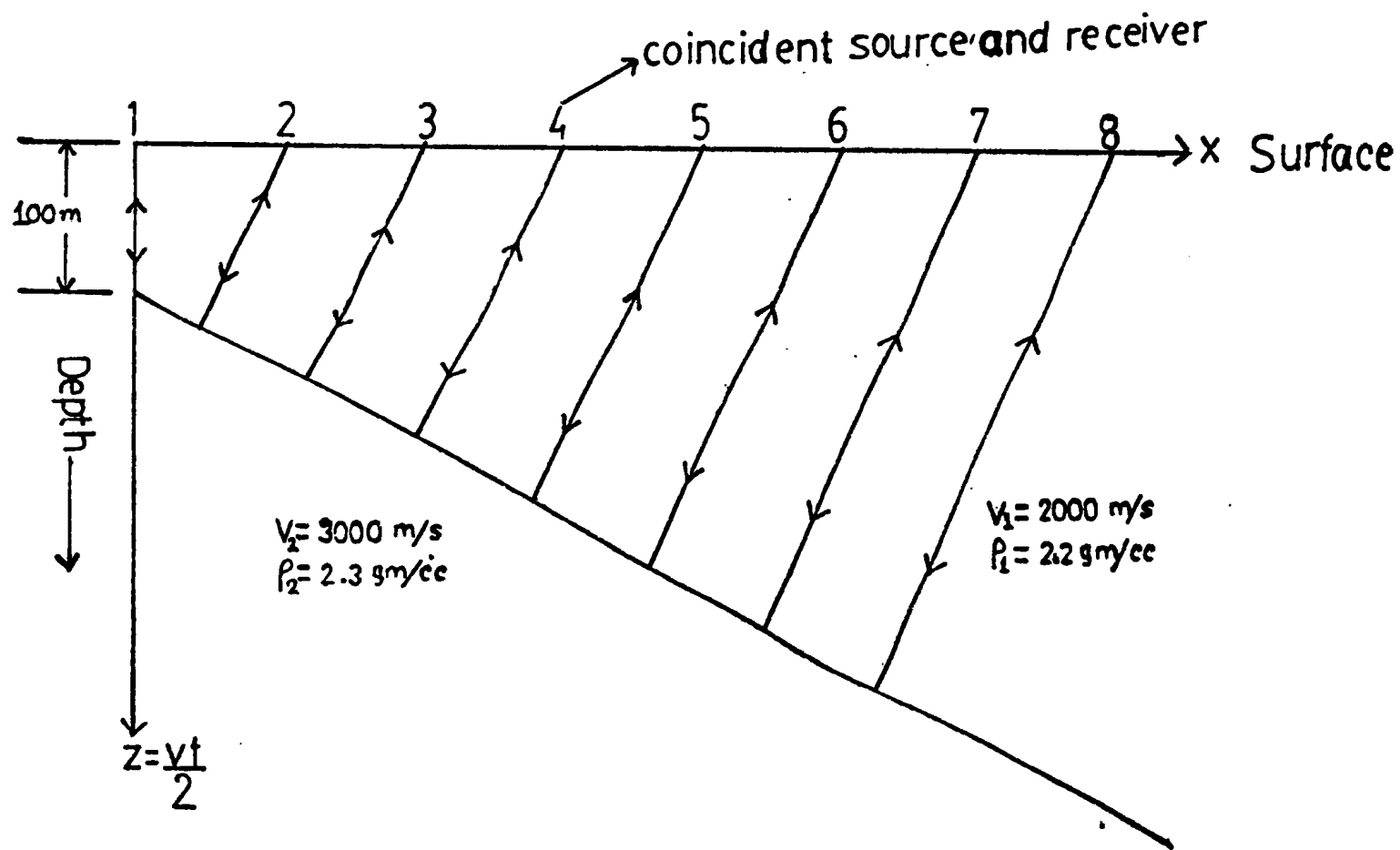


FIG.3.1.1 An inclined reflector model.

constructed by convolution of the reflectivity function with a source pulse.

First the two-way travel times from coincident source-receiver position to the inclined reflector were calculated for each offset distance. Then the seismic trace was digitised at 1 ms interval which is same as the sampling interval used for the migration process. Multiples were not included in generating the zero offset synthetic section to minimise migration noise in the implementation of the diffraction stack technique. The reflectivity was calculated (Appendix-2) assuming the above geological model (Figure 3.1.1). A 25HZ Ricker wavelet was chosen as the source pulse because good Ricker wavelets were observed in the unmigrated field data (Fig. 4.1.1). The chosen 25HZ frequency is within the seismic range.

3.1.2 An Anticline

In normal seismic sections, an anticline structure can easily be mapped by reflection if the data are of good quality. Normally we expect oil-bearing anticlinal structures associated with rising salt domes or other diapiric features. The time sections over such anticlines do not display a clear picture of the subsurface structure. Migration is applied to such cases to collapse the diffraction patterns generated at the sharp boundaries and to reduce the breadth of anticlines to their correct values. One can model the anticlinal structure and see its response before and after migration.

For our analysis an anticline model is chosen to generate zero offset the synthetic data implementing the concept described in earlier section 3.1.1. Figure 3.1.2 shows the anticline model to generate the zero offset synthetic data. The velocity and density parameters were kept constant with the earlier model discussed. Two computer programmes were developed to generate vertical travel time and zero offset synthetic seismogram respectively (Appendix-1).

3.2 Migration of Synthetic Sections

The migration is carried out in two stages:

- 1) The migration where the reflection segment is moved to its new position horizontally. The reflection time is kept as vertical axis.
- 2) Depth conversion, in which the vertical scale is changed to depth.

In time migration diffraction events only are considered but not those refraction events caused by lateral changes in velocity. The first stage of migration is preferred here for our present work because it accomplishes all the objectives concerned with the collapse of diffraction and general clarification of structure (Anstey, 1977). Depth conversion is not attempted in our analysis because of the nonavailability of velocity information for the field seismic data over the Grand Banks area.

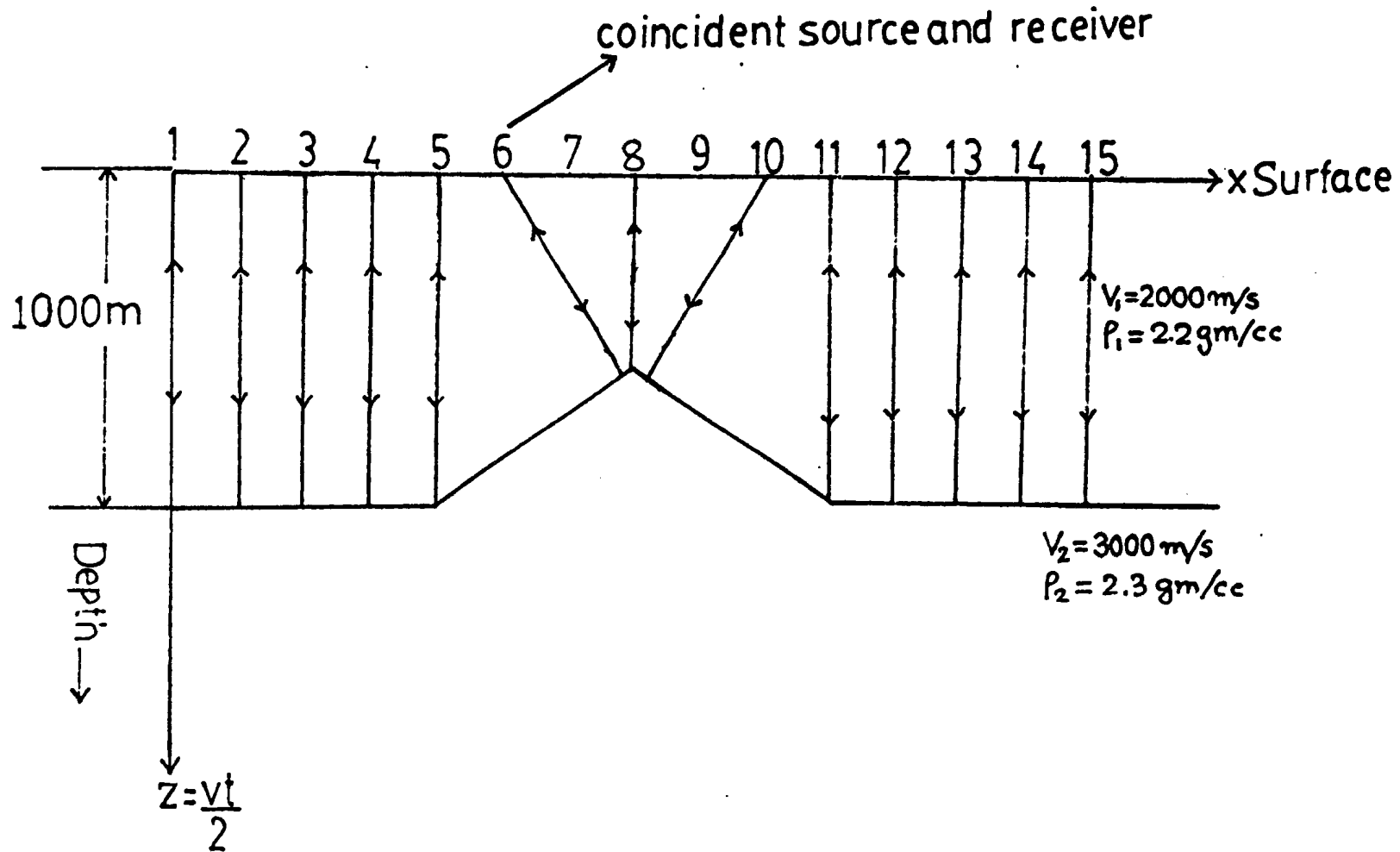


FIG. 3.12 An anticline model.

3.2.1 Parameters for Migration of Synthetic Data

The three basic parameters sampling interval, aperture and velocity should be fixed before applying the migration scheme. The first requirement, the input trace time sampling interval Δt must be chosen such that the highest frequency in the analog data f_h satisfies the sampling theorem given as

$$\Delta t \leq 1/2f_h \quad 3.2.1.1$$

where f_h is the highest frequency in the input trace, Δt is the sampling interval.

In our synthetic data, the sampling interval was taken as 1 ms while the f_h was 25 HZ. The output sampling interval is also taken as 1 ms to minimize the aliasing conditions during the migration process. The second requirement is to find the appropriate aperture for the migration method. Before implementing the migration programme, it is necessary to estimate the "aperture" (window) within which the input traces must be enclosed. The number of traces must be such as to include the horizontal zones which provide the final migrated reflection (Fig. 3.2.1). If too small an aperture is chosen, the migrated section will be distorted. Usually computer time increases proportionately with the increase of aperture size.

It is necessary to preselect the aperture from the unmigrated data by some calculative process. The aperture is related to the horizontal

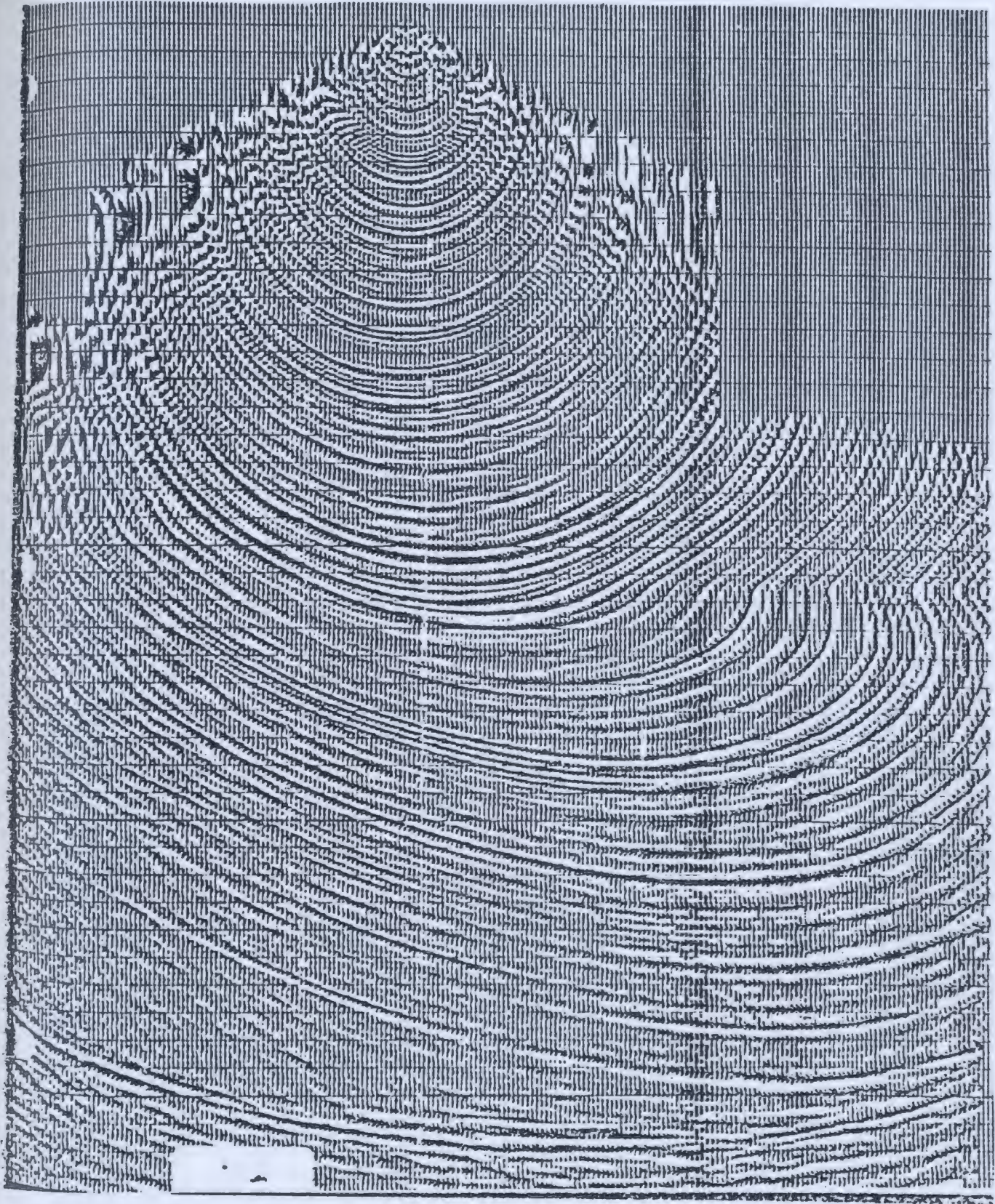


Figure 3.2.1 The reflection patterns due to different apertures
(After Anstey, 1977).

displacement of the reflection point and can be calculated from the time gradient on the unmigrated section and the velocity distribution (Anstey, 1977). For our present analysis the apertures were calculated using the relation (Owusu et al., 1981).

$$r = (vz/2f)^{1/2} \quad 3.2.1.2$$

where r is the migration aperture

v is the medium velocity

z is the depth of the reflector

and f is the frequency of the pulse

Table 3.2.1 gives the apertures used for different sets of synthetic data.

Reflector's Dip of the model 'degree'	Velocity of the medium 'm/s'	Frequency of the pulse 'HZ'	Maximum depth considered 'm'	Aperture value equivalent to no. of traces
10	2000	25	376	5
20	2000	25	564	6
30	2000	25	777	7
40	2000	25	1039	8
50	2000	25	1392	9
60	2000	25	1932	11

Table 3.2.1 Different apertures values for different sets of synthetic model data.

The third requirement is to assign a velocity for the migration scheme. The correct migration velocity can be obtained by generating migrated traces with a number of constant velocities. The velocity that gives the best migration stack will be taken as the correct migration velocity. This correct velocity used in migration defines the effective Huygens hyperbola on the assumption that all the Huygen's sources are in the plane of the section (Anstey, 1977). For our present analysis a constant velocity of 2000 m/s was used to migrate the synthetic data. The above velocity choice was suitable because the synthetic time sections were generated assuming a constant velocity which was the same as the migration velocity.

3.2.2 Implementation of Migration by Computer

A computer programme was developed (Appendix-1) to implement the diffraction stack migration on the VAX/VMS 11/780 computer system. The entire procedure is presented here in considering the aperture (5 traces) for the synthetic data generated with reflector dip equal to five degrees. First the input traces 1 through 11 were composited to obtain data for plotting on a single output trace (trace 6), which was printed out on the final record section (Fig. 3.2.2). This output trace (trace 6) gives the time at the vertex position for a particular curve of maximum convexity that crosses the input traces 1 to 11. The sampling time was used to determine trace amplitudes on each of the 11 input traces at the position where the trace was crossed by the curve of maximum convexity having its vertex at a time equals to T_0 (two-way vertical time) on the

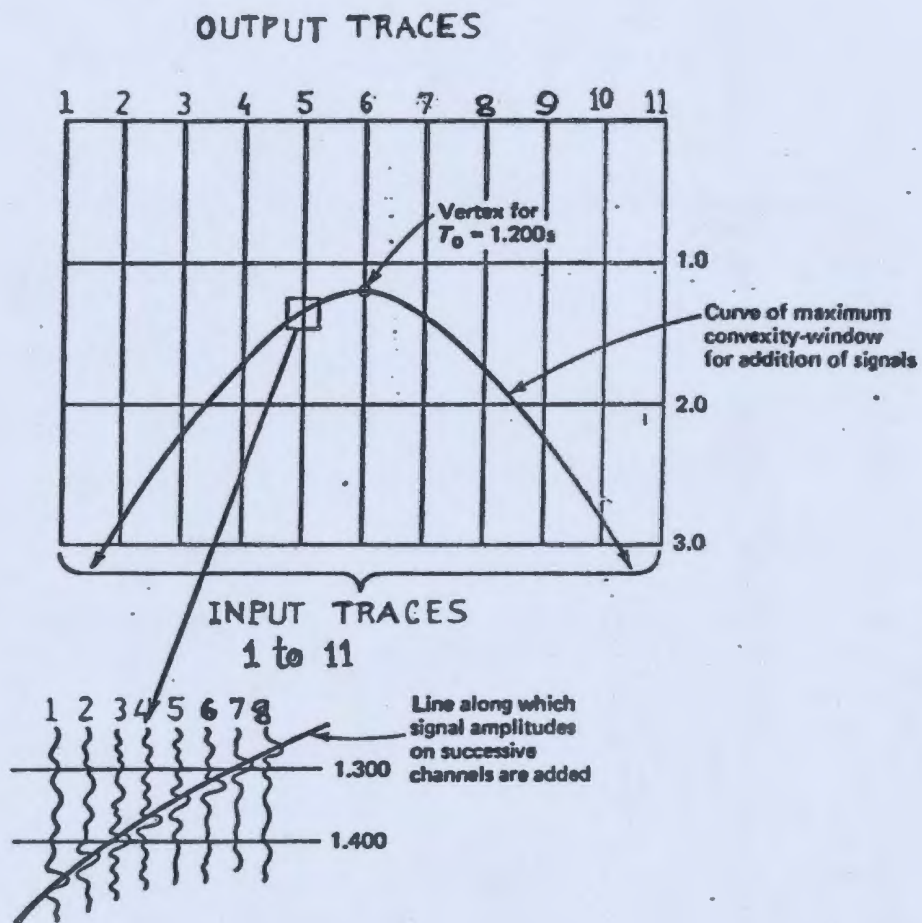


Figure 3.2.2 Principle of computer migration using curve of maximum convexity with an aperture of 5 input traces.

trace number 6. The amplitudes at these time were summed to obtain an output value which was plotted on the centre trace (6) at a time equal two-way vertical time T . Strong reflection or diffraction peaks were enhanced at the vertex position resulting in a large amplitude value in the output trace. The vertex position represents the true position of the event in space.

The vertex times for which amplitudes stored were separated by the next sampling interval for the subsequent summation process on trace number 6. Now this will generate a different curve of maximum convexity. A total of 1800 curves of maximum convexity were generated for summation of points for a 1.8 second synthetic section considering the sampling interval as 1 ms.

After completing all output values for the trace number 6, the computation was carried out in the similar fashion for the next trace number 7. Now the input window (aperture) was extended from traces 2 to 12. The whole process was continued up to the end of required migrated traces. Finally the migrated record sections were plotted using the computer programme developed (Appendix-1) for plotting the migrated sections. For our analysis each migration job took exactly one hour CPU time on the VAX/VMS 11/780 computer system.

3.3 Results of Migrated Sections

Two synthetic models were used - an inclined reflector and an anticline to implement the diffraction stack algorithm (Appendix-1). Both models consist of a single reflecting surface overlain by a material of constant velocity 2000 m/s (Fig. 3.1.1 and Fig. 3.1.2). Zero offset (stacked) single fold synthetic reflection data were generated over an area above the reflecting surface and are used as an input to the migration scheme. Both models were investigated for various dip angles of the subsurface reflector with dip values 10° , 20° , 30° , 40° , 50° and 60° . Finally, the models were tested with different migration velocities to implement the diffraction stack method. A record length of 1.8 sec equivalent to 1800 data samples were used for diffraction stack migration. A trace interval of 25m was used for all the migrated sections. The horizontal and vertical scales were kept constant for both migrated and unmigrated sections for plotting. The amplitude scale was also kept constant in both migrated and unmigrated sections.

3.3.1 An Inclined Reflector

Figures 3.3.1.1 to 3.3.1.6 represent the stacked (unmigrated) synthetic time sections generated for dip angles 10° , 20° , 30° , 40° , 50° and 60° respectively. The corresponding migrated sections are presented in Figures 3.3.1.7 to 3.3.1.12. These migrated sections were produced with a migration velocity 2000 m/s which was same as the material velocity considered for the synthetic model.

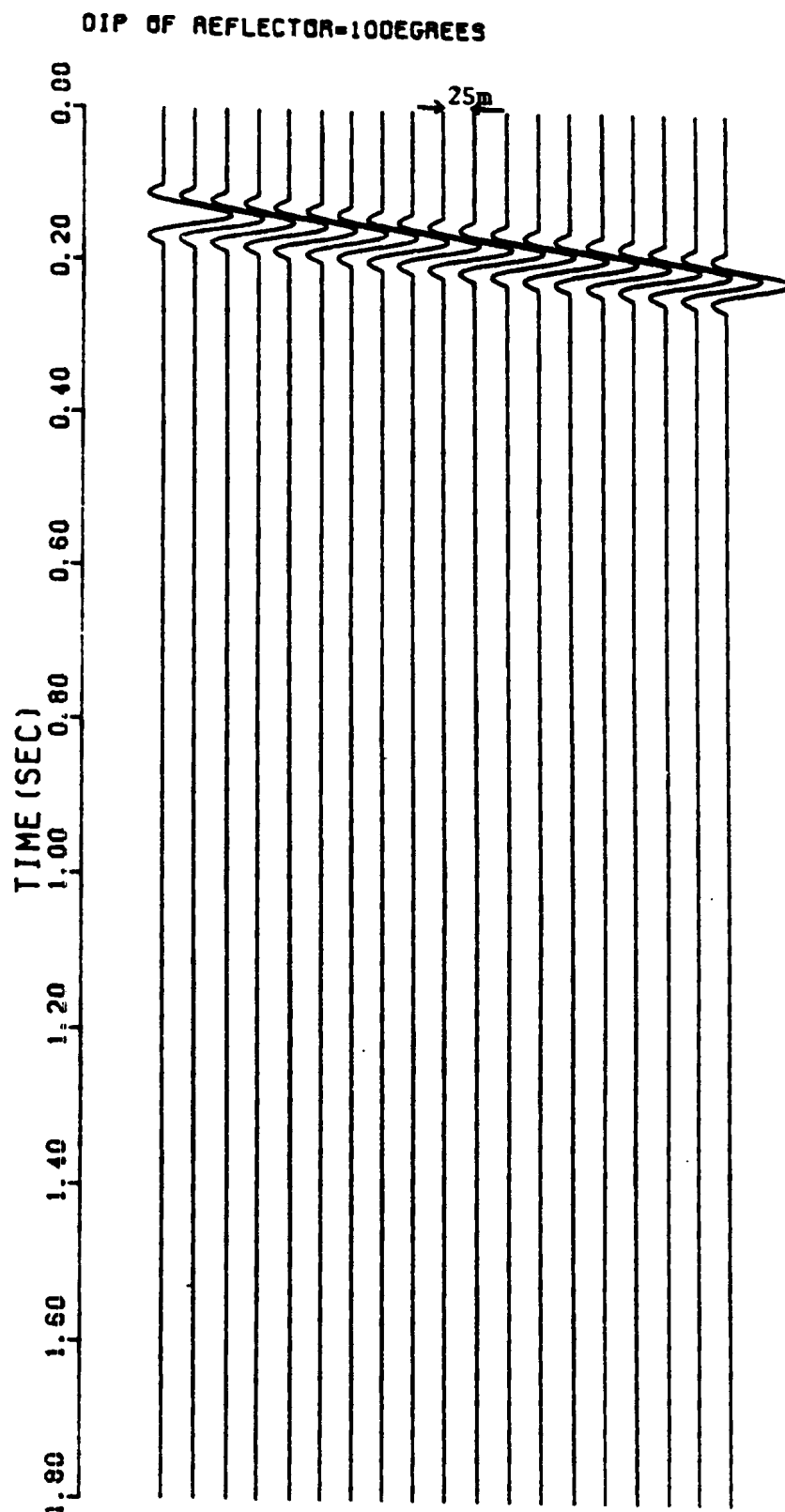


FIG.331 UNMIGRATED SECTION

DIP OF REFLECTOR=20DEGREES

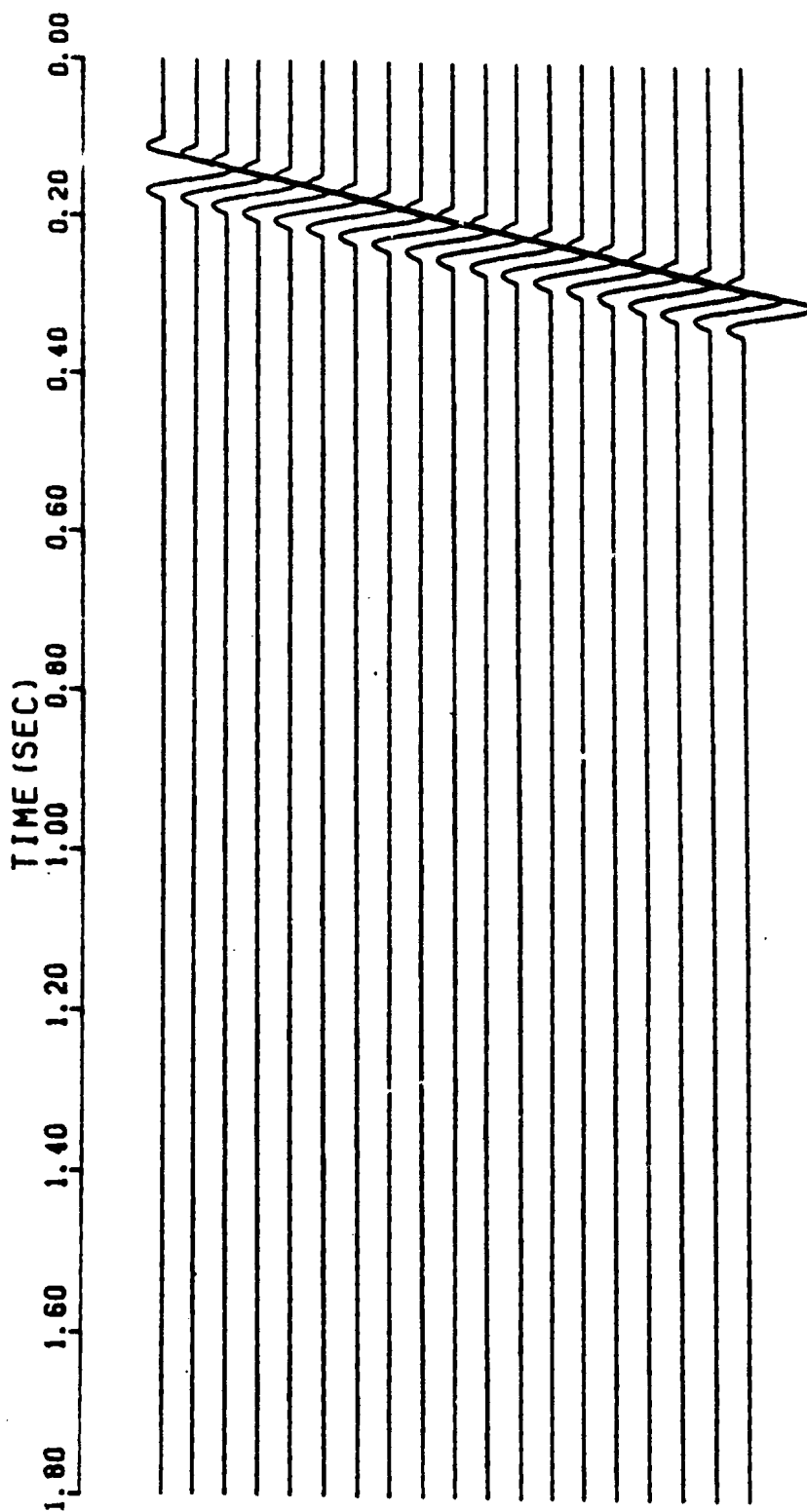


FIG.332 UNMIGRATED SECTION

DIP OF REFLECTOR=30DEGREES

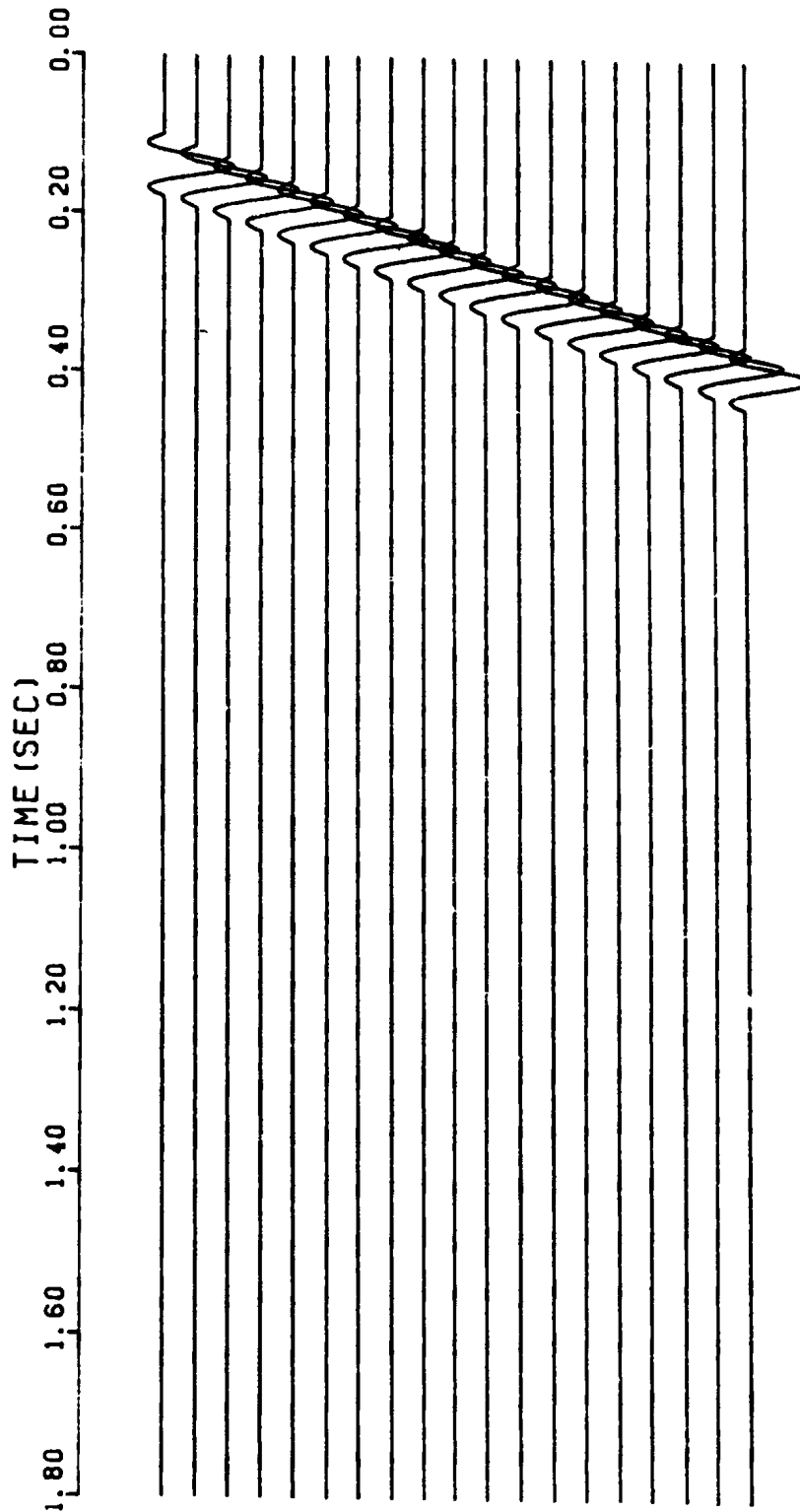


FIG.3313 UNMIGRATED SECTION

DIP OF REFLECTOR=40DEGREES

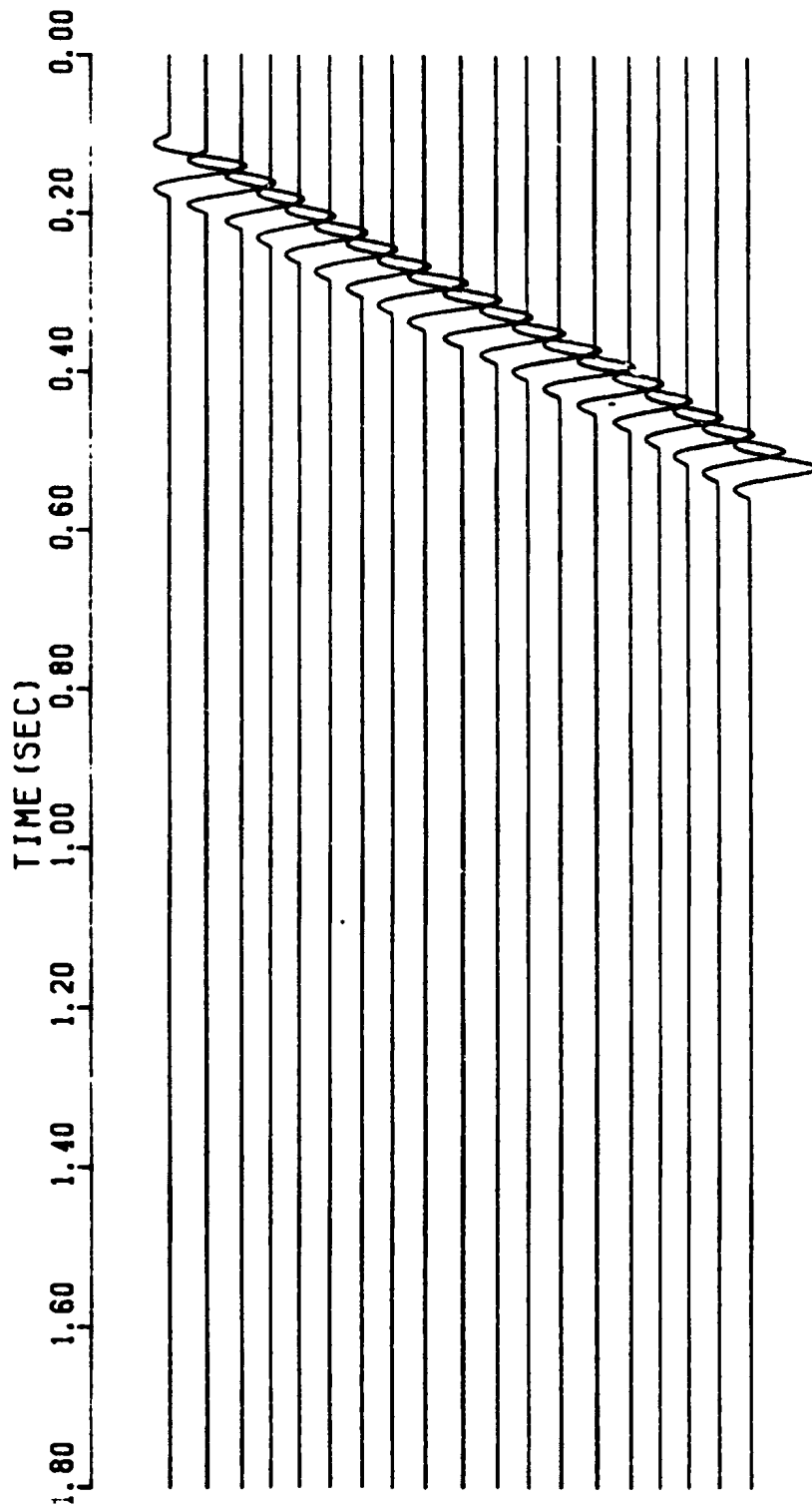


FIG.3.31.4 UNMIGRATED SECTION

DIP OF REFLECTOR=50DEGREES

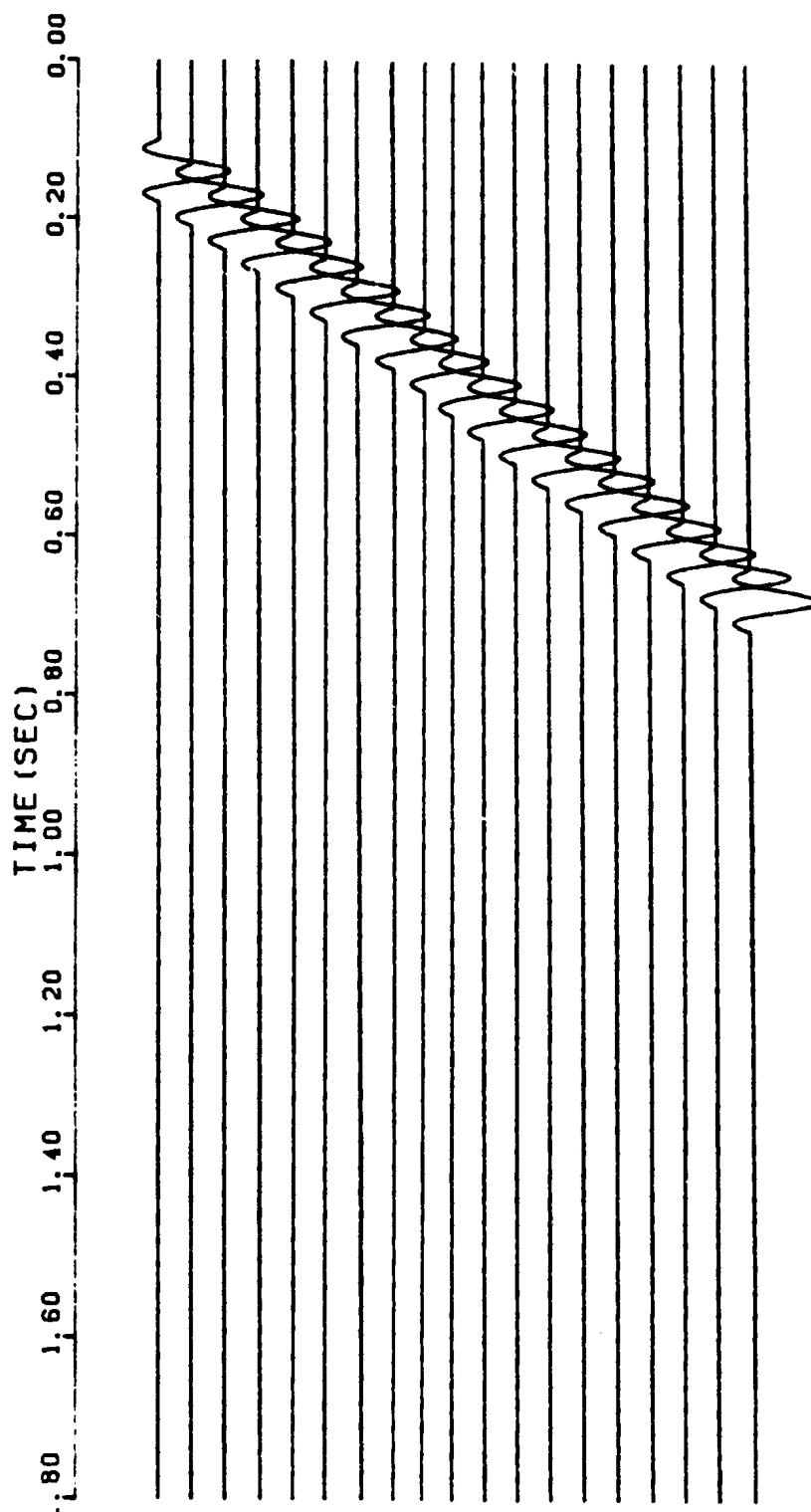


FIG.3315 UNMIGRATED SECTION

DIP OF REFLECTOR=60DEGREES

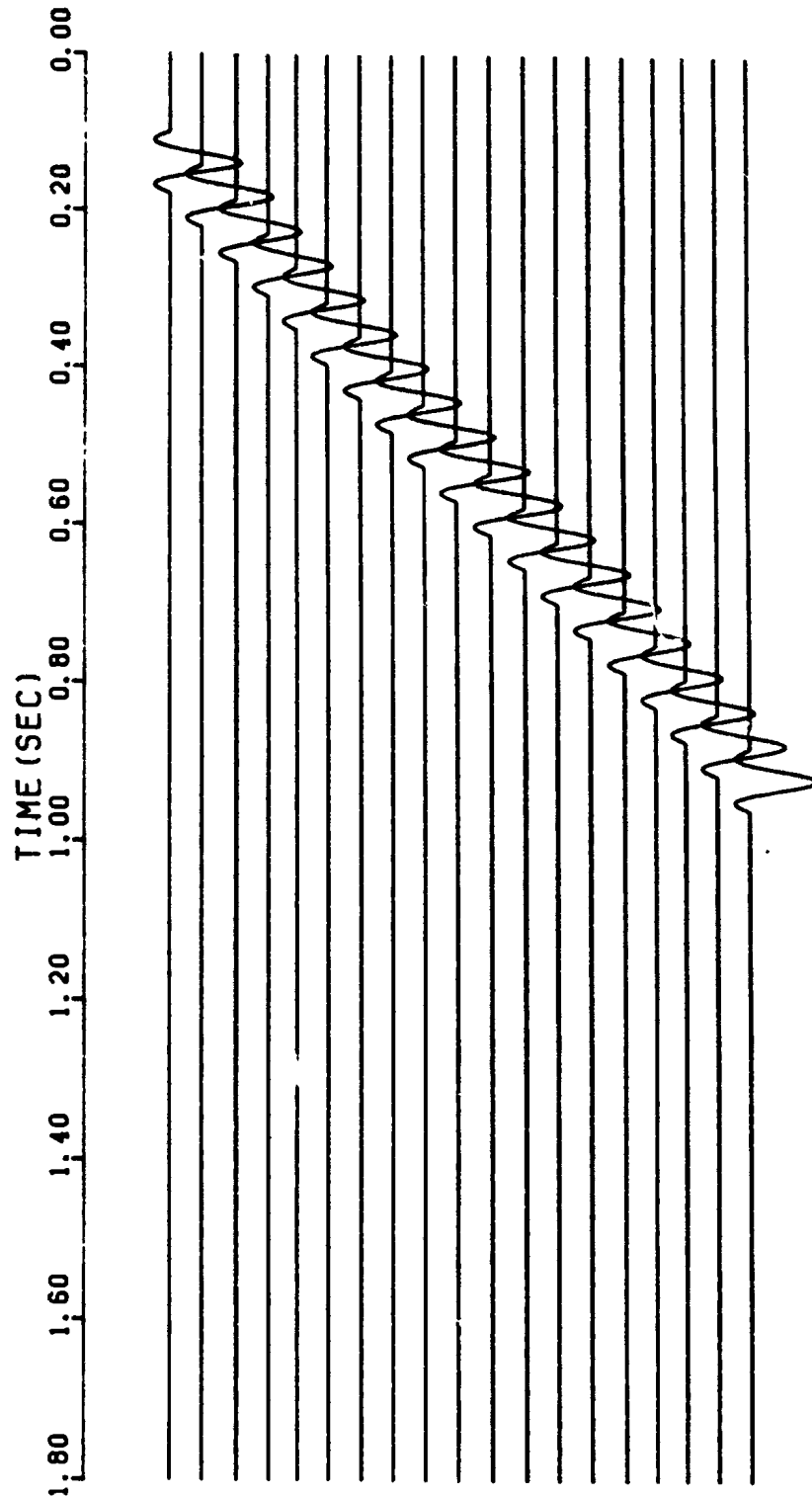


FIG.3316 UNMIGRATED SECTION

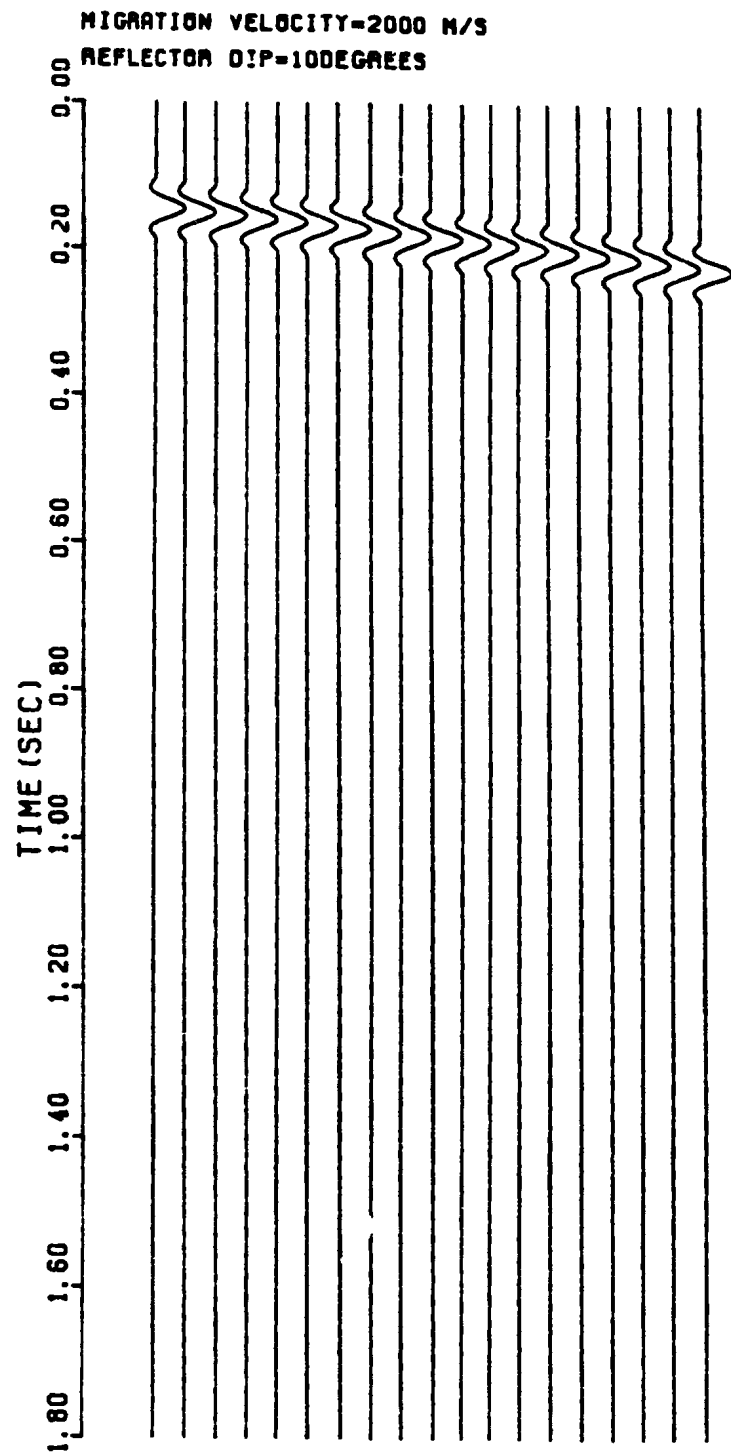


FIG.3.31.7 MIGRATED SECTION

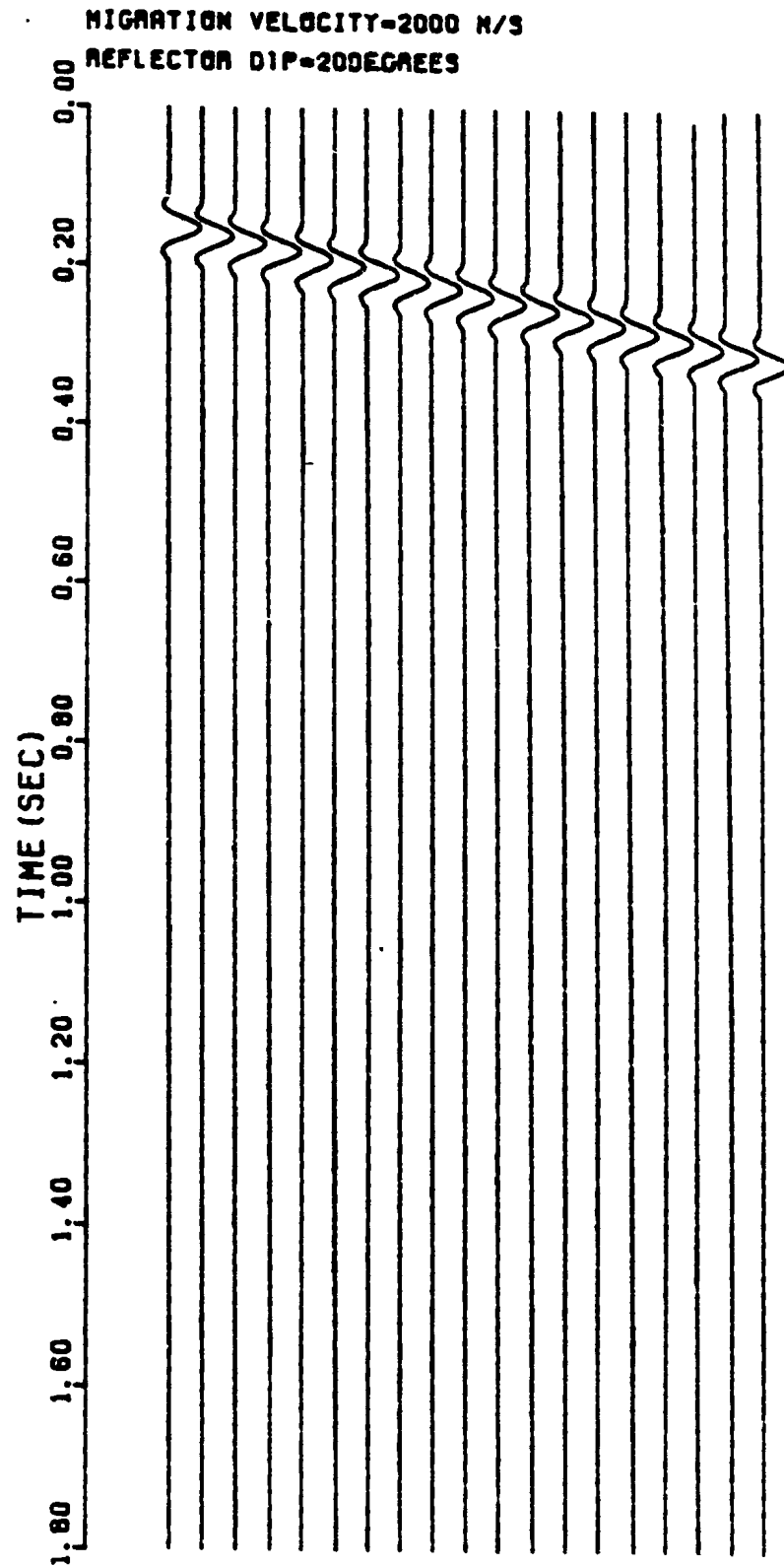


FIG. 318 MIGRATED SECTION

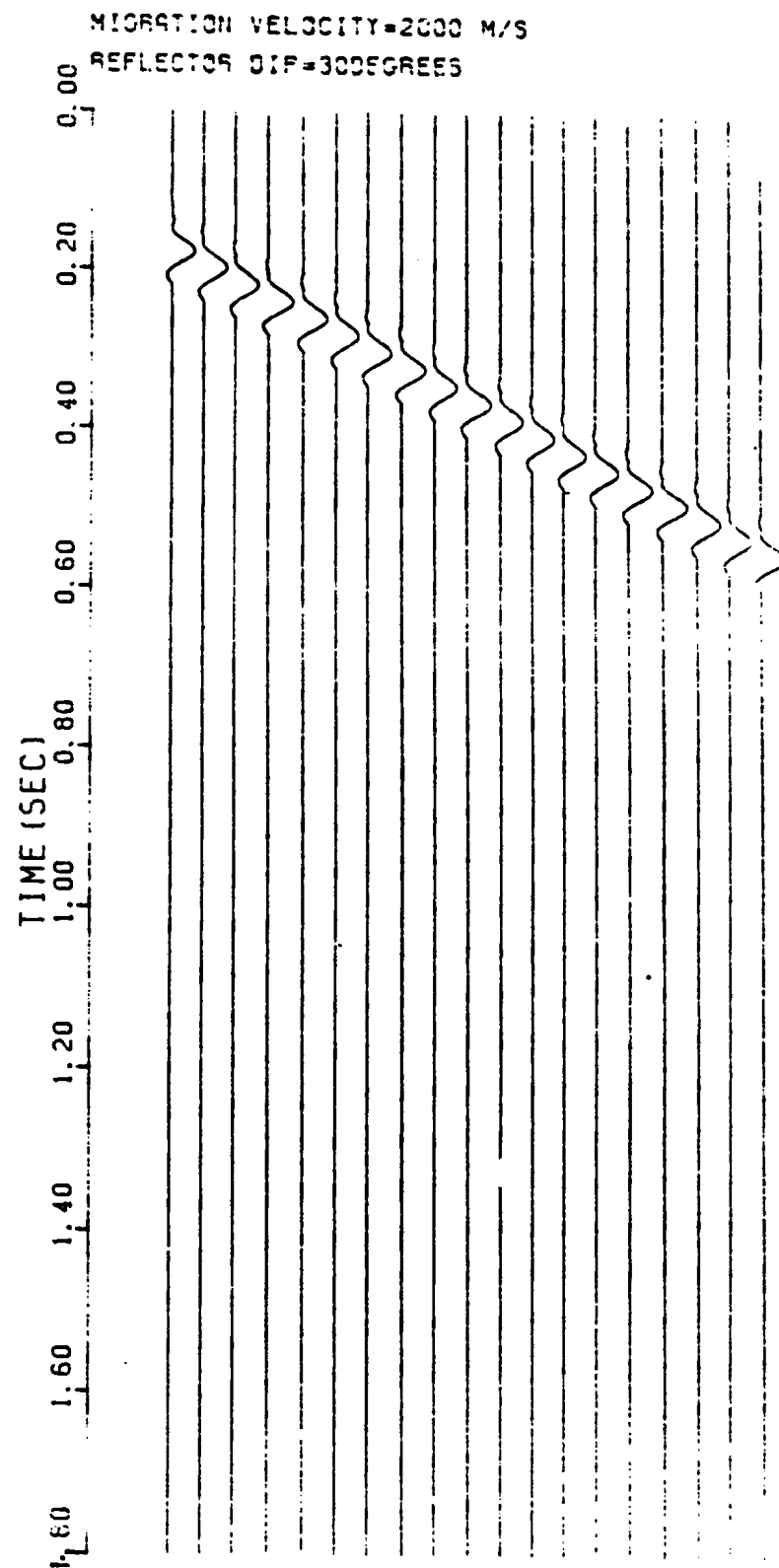


FIG. 3.3.19 MIGRATED SECTION

MIGRATION VELOCITY=2000 M/S
REFLECTOR DIP=400EGREES

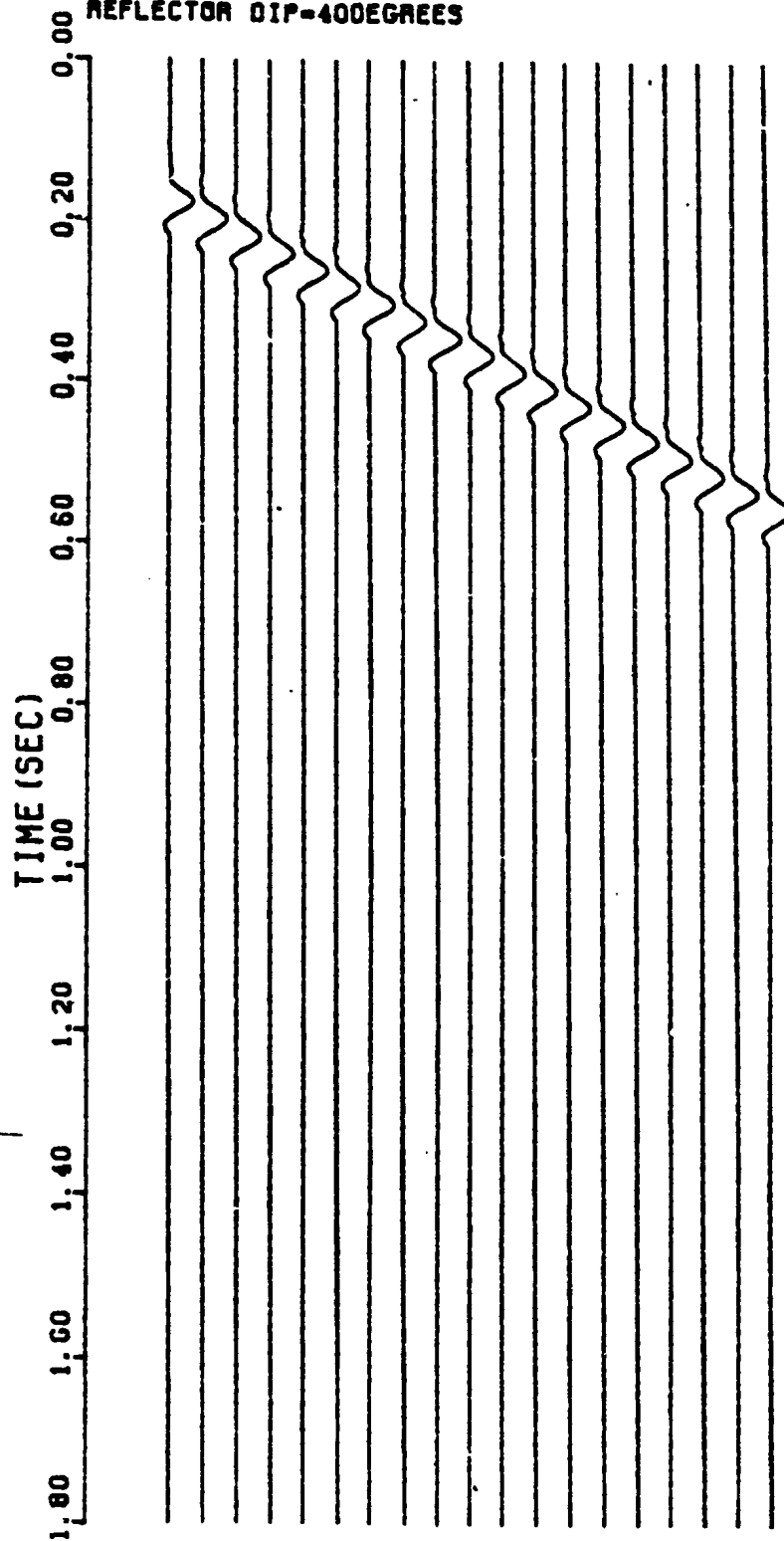


FIG.33.110 MIGRATED SECTION

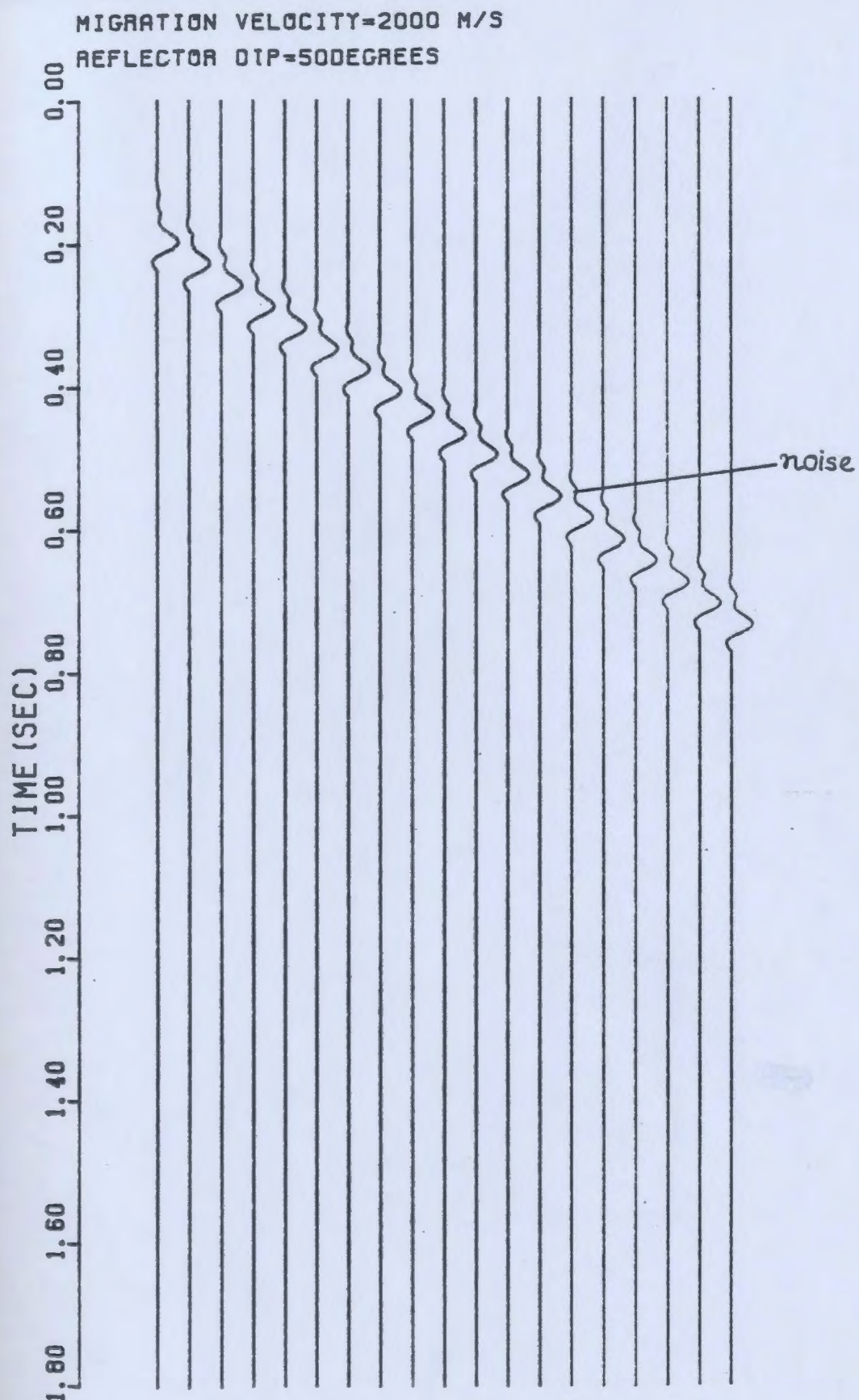


FIG.33111 MIGRATED SECTION

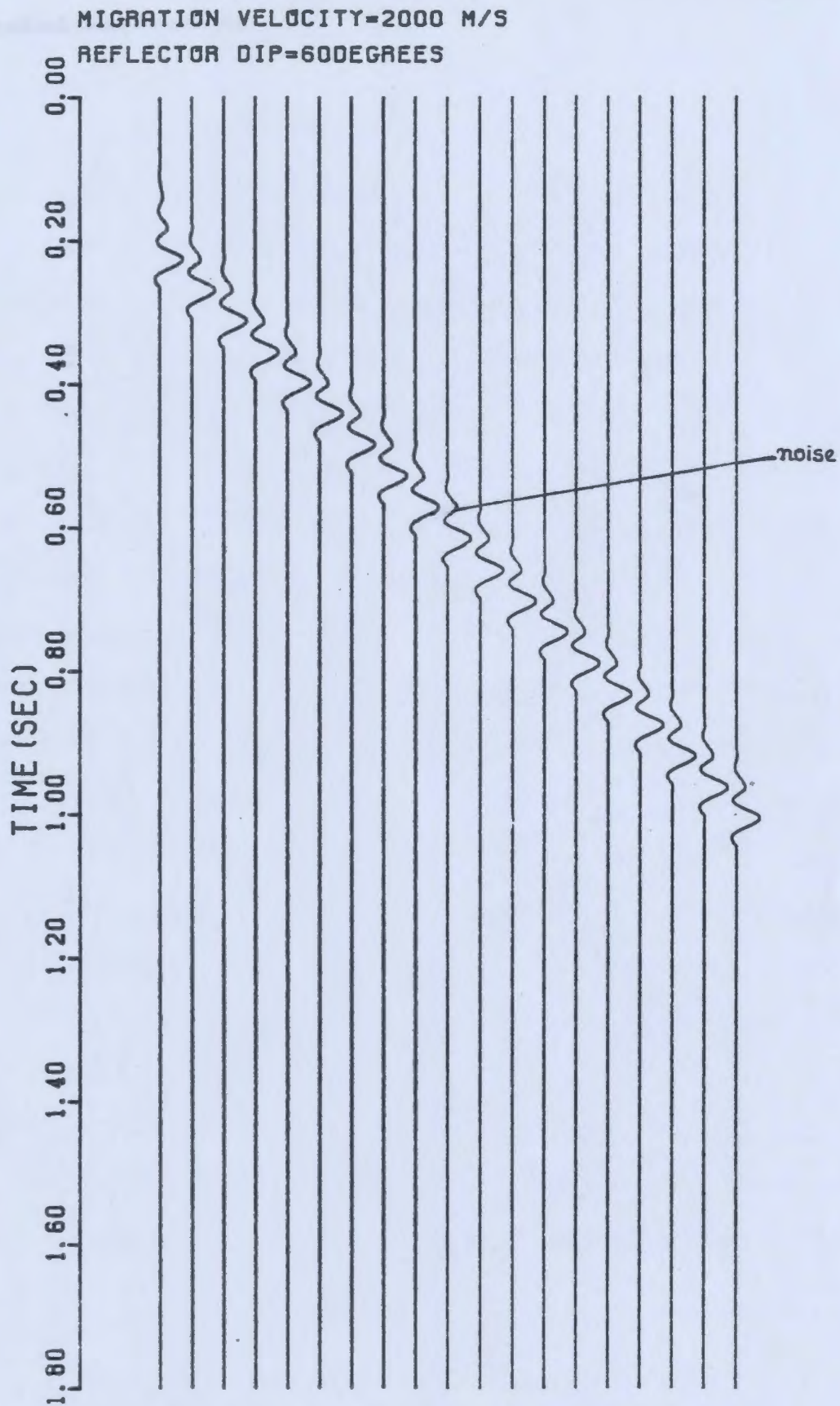


FIG.3.3.1.12 MIGRATED SECTION

The migrated sections (Figures 3.3.1.7 to 3.3.1.12) look better than the stacked (unmigrated) sections. Diffractions are migrated to their true positions. A reduction of amplitude by a factor 2.0 was observed in all the migrated sections and pulse shapes were broadened due to loss of high frequency content in the reflected pulse. The highest frequency content in the reflected pulse in the migrated sections was in the range of 10 to 15 HZ showing a frequency shift from the original signal. It is observed that noise was introduced into the migrated sections with reflector dip greater than 40° (Figures 3.3.1.11 and 3.3.1.12). During the migration process a phase change was noticed which is shown in the Figure 3.3.1.13. A graph was plotted (Fig. 3.3.1.13) between timeshift and offset distance taking different dip angles of the reflector. The time shift was calculated from the peak position of (considering the highest amplitude) the unmigrated and migrated pulse taking the same offset distance. It was evident from Figure 3.3.1.13 that phase change is independent of offset distance. The phase shift is constant for a particular dip angle of the reflector. There is a sudden jump in phase shift after the reflector dip equals to 30 degrees. This shows phase shift is dependent on increase of dip angle of the subsurface reflector. The data were fitted by a least-squares polynomial of the form $\Delta t = a\phi + b\phi^2 + c$. A Fortran subroutine for the least-squares fit of the polynomial was used to calculate the co-efficients (James et al., 1977). Figure 3.3.1.14 represents the least-square fit of the data obtained from the Table-3.3.1.

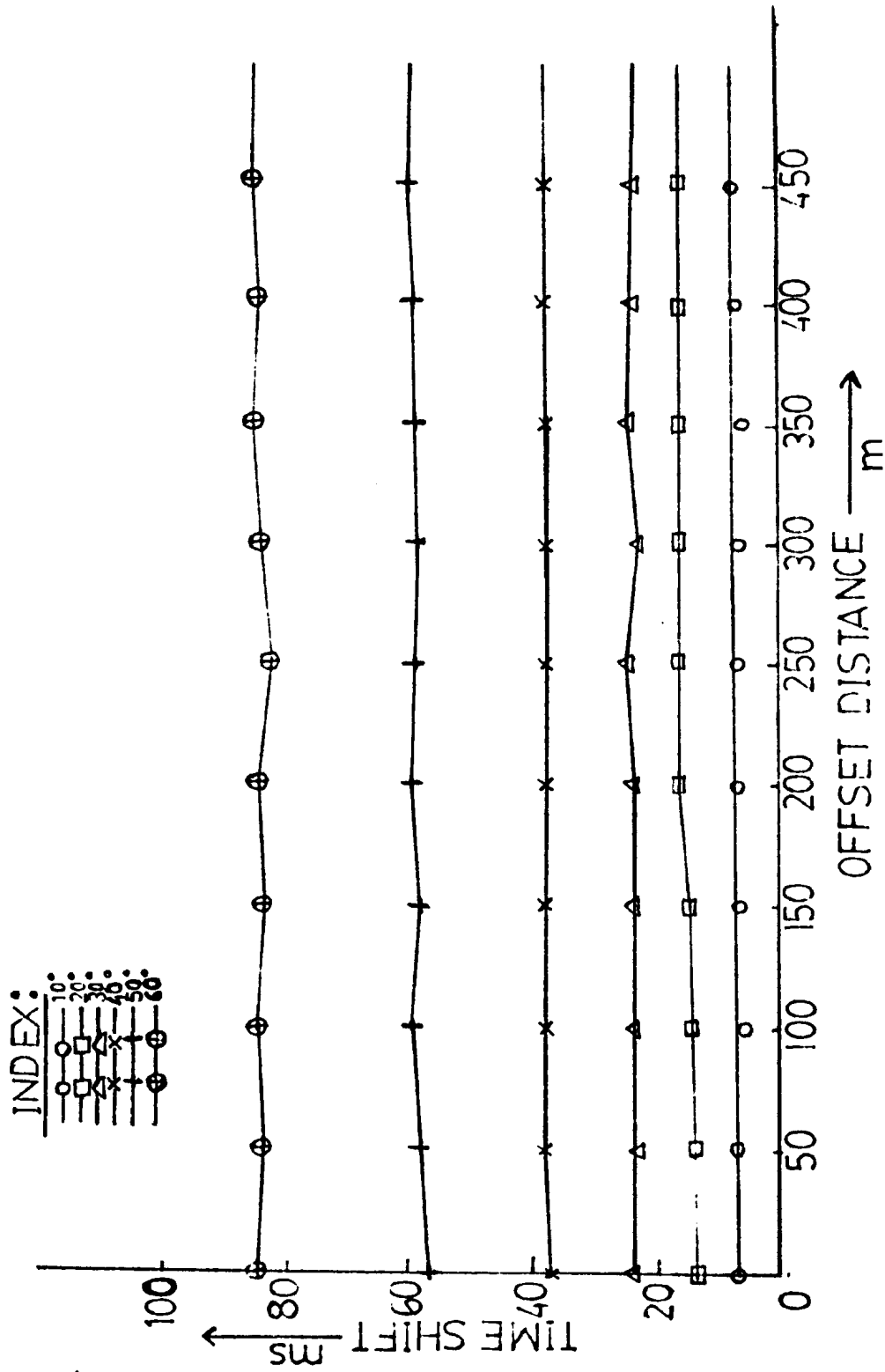


FIG. 3.3.113 TIME SHIFT-OFFSET DISTANCE CURVE

Serial Number	Angle of Dip ϕ in (Degrees)	Average Time shift Δt in (ns)	Remarks
1	10	6	A straight line relationship of the type $\Delta t = a\phi$ (where a is a constant quantity) can be obtained
2	20	14	
3	30	24	
4	40	38	A nonlinear relationship of the type, $\Delta t = a\phi + b\phi^2$ (where a and b are constant quantities) can be obtained
5	50	60	
6	60	85	

Table-3.3.1 Effect of dip angle on phase is shown.

The graph (Figure 3.3.1.14) was plotted between average time shift and dip angle. The average time shift was obtained from the individual time shift for different offset distances considering only one dip angle at a time. A linear straight line relationship can be obtained between angle of dip and average time shift up to reflector dip equals to 30 degrees (Table-3.3.1). As the dip increases, this linear relationship is no longer valid but replaced with a nonlinear relationship (Table-3.3.1). A break in the slope (Figure 3.3.1.14) indicates that the method is stable up to a reasonable amount of phase change i.e., up to dip angles equal to 30 degrees.

The effect of velocity on diffraction stack migration was examined on synthetic data generated for an inclined reflector dipping at an angle 30 degrees. The velocity was varied from 1500 m/s to 2500 m/s in steps of 100 m/s. The best migration velocity was 2000 m/s which was same as the material velocity considered for the inclined reflector model. Figures 3.3.1.15 to 3.3.1.25 represent the migrated time sections produced with different migration velocities for the above model. In general, the migrated time sections are much clarified than unmigrated synthetic section (Figure 3.3.1.9) generated for the above model with material velocity 2000 m/s. Two extreme cases were examined on taking two migration velocities 1500 m/s and 2500m/s. It is observed that a change in velocity of ± 500 m/s from the actual migration velocity 2000 m/s resulted a time shift in the order of ± 1 ms. It shows that change in velocity has an effect over phase shift in the migrated section. This error in phase can be detected if the sampling interval is 1 ms in the migrated section.

3.3.2 An Anticline

Figure 3.3.2.1 to 3.3.2.6 represent the stacked (unmigrated) synthetic time sections for the anticline model for which the flanks have dip angles 10° , 20° , 30° , 40° , 50° , and 60° respectively. The corresponding migrated sections are presented in figures 3.3.2.7 to 3.3.2.12. These synthetic sections were migrated with material velocity 2000 m/s which was used in constructing the above model. In the migrated

MIGRATION VELOCITY=1500 M/S

REFLECTOR DIP=30DEGREES

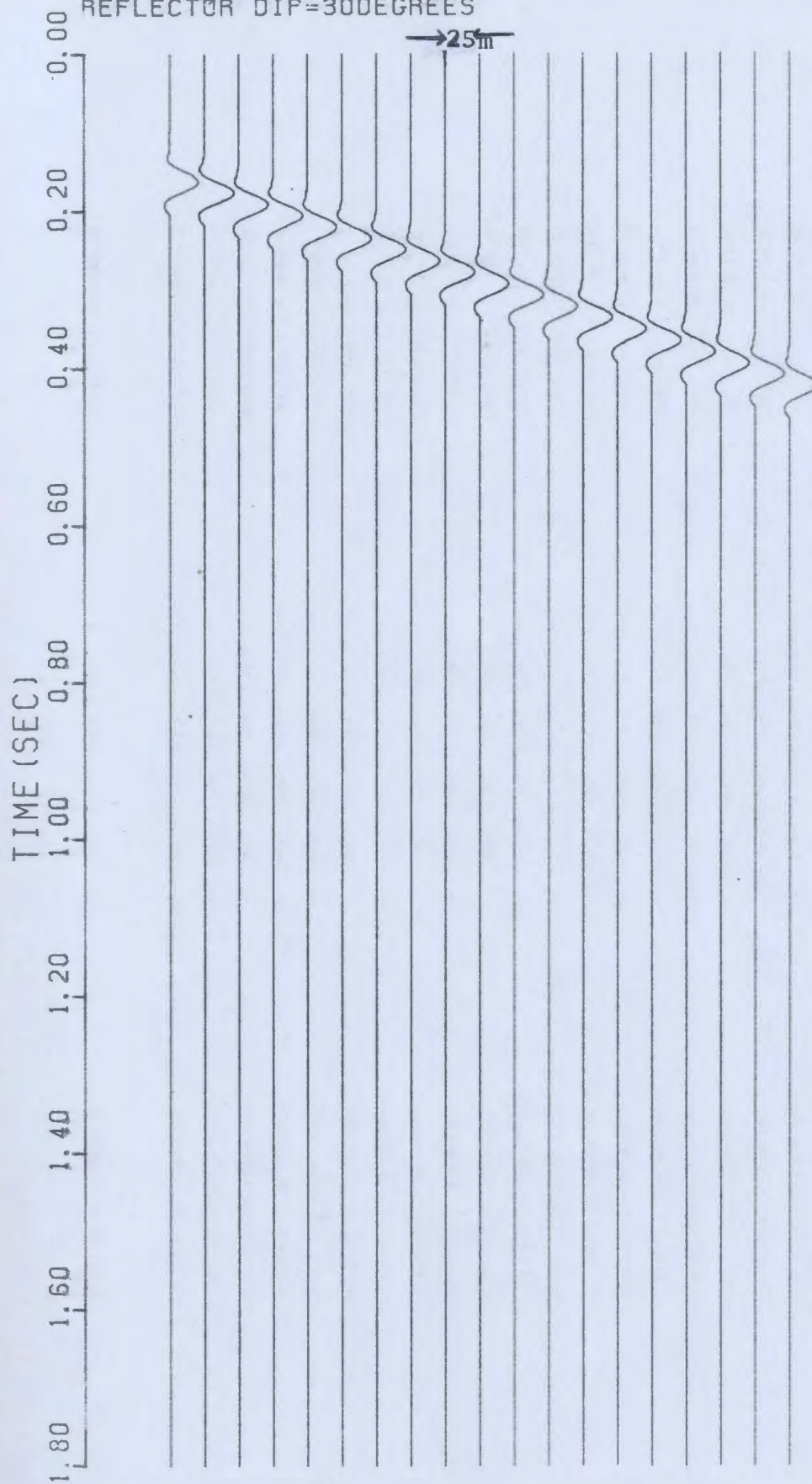


FIG.33.15 MIGRATED SECTION

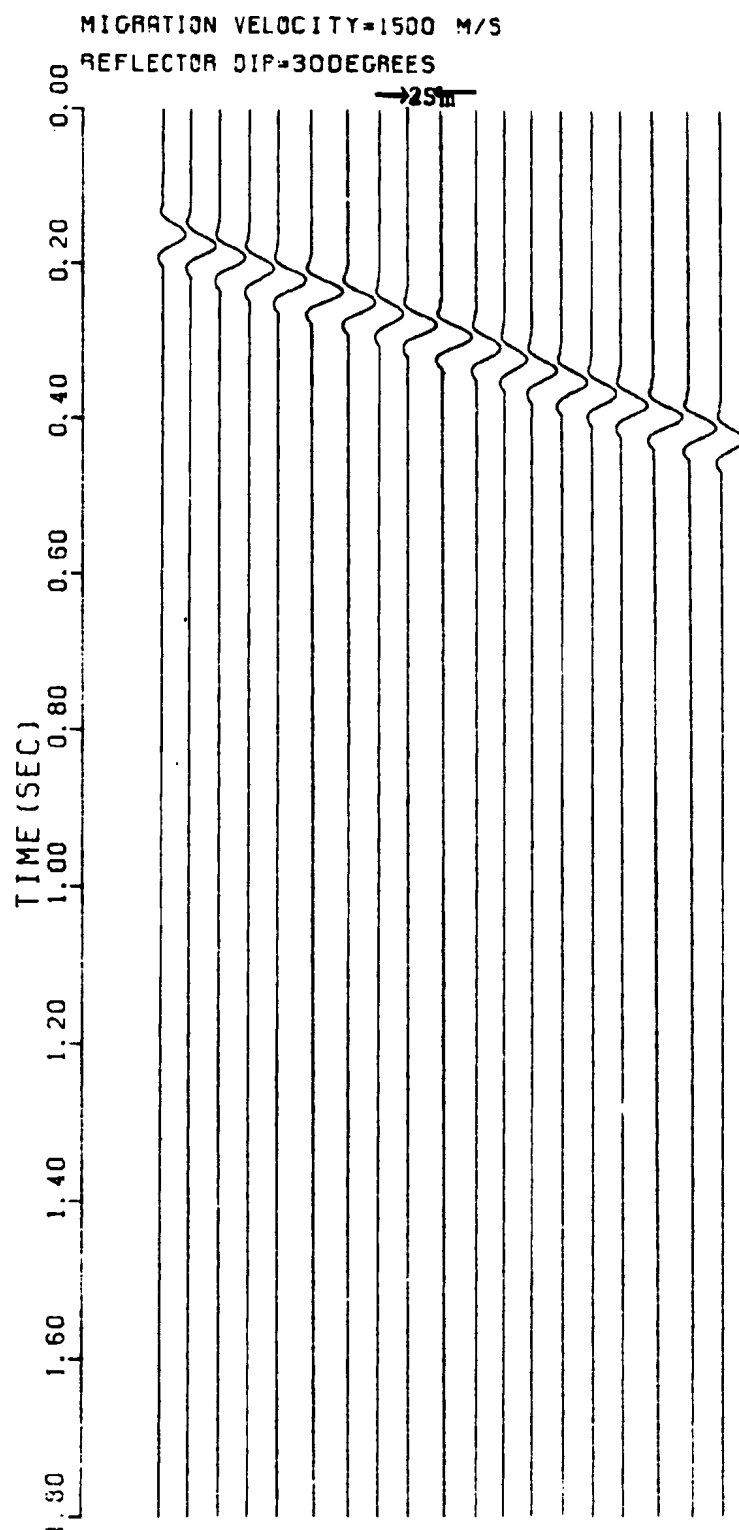


FIG. 33115 MIGRATED SECTION

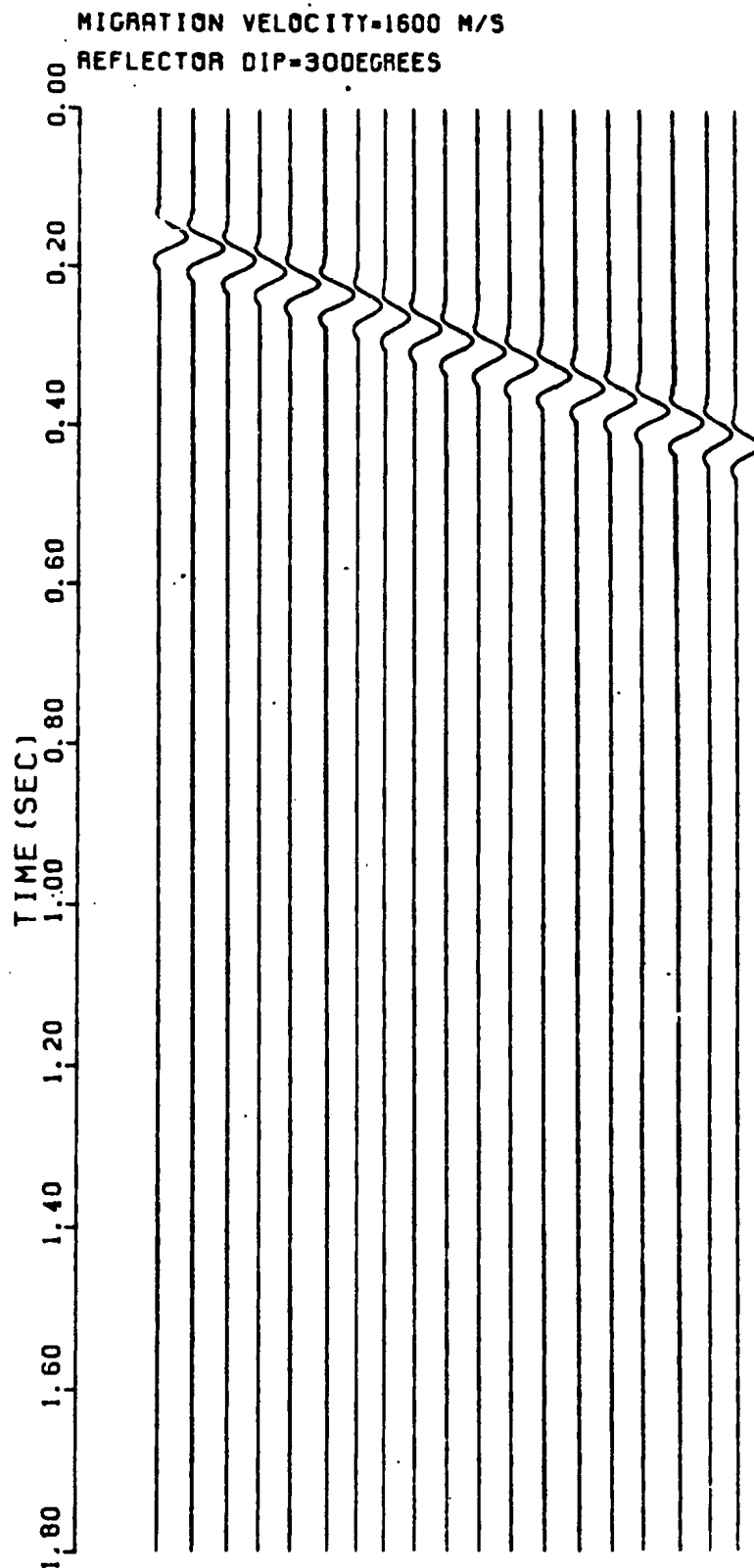


FIG. 2.3.1.14 MIGRATED SECTION

MIGRATION VELOCITY=1700 M/S
REFLECTOR DIP=30DEGREES

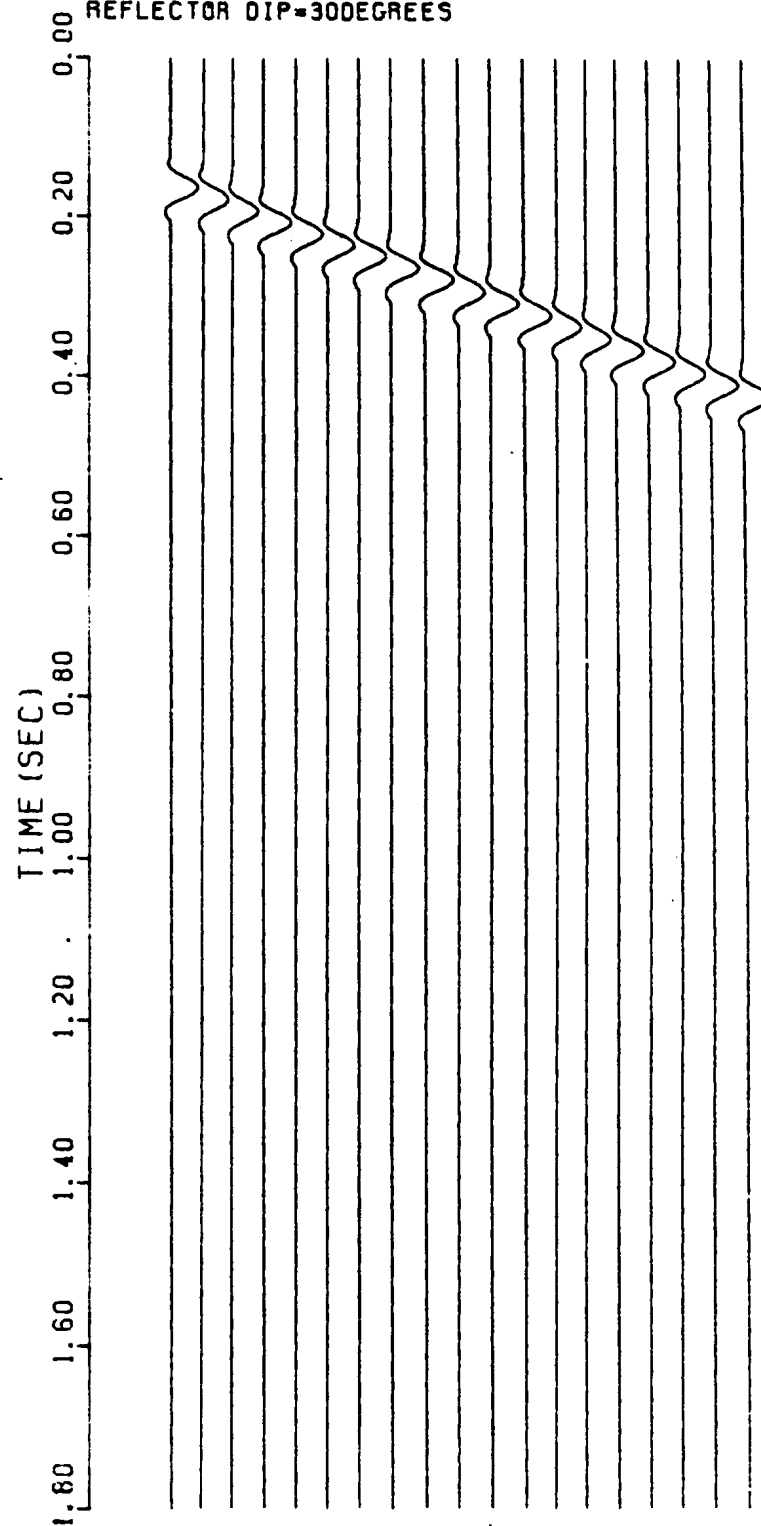


FIG. 3.1.17 MIGRATED SECTION

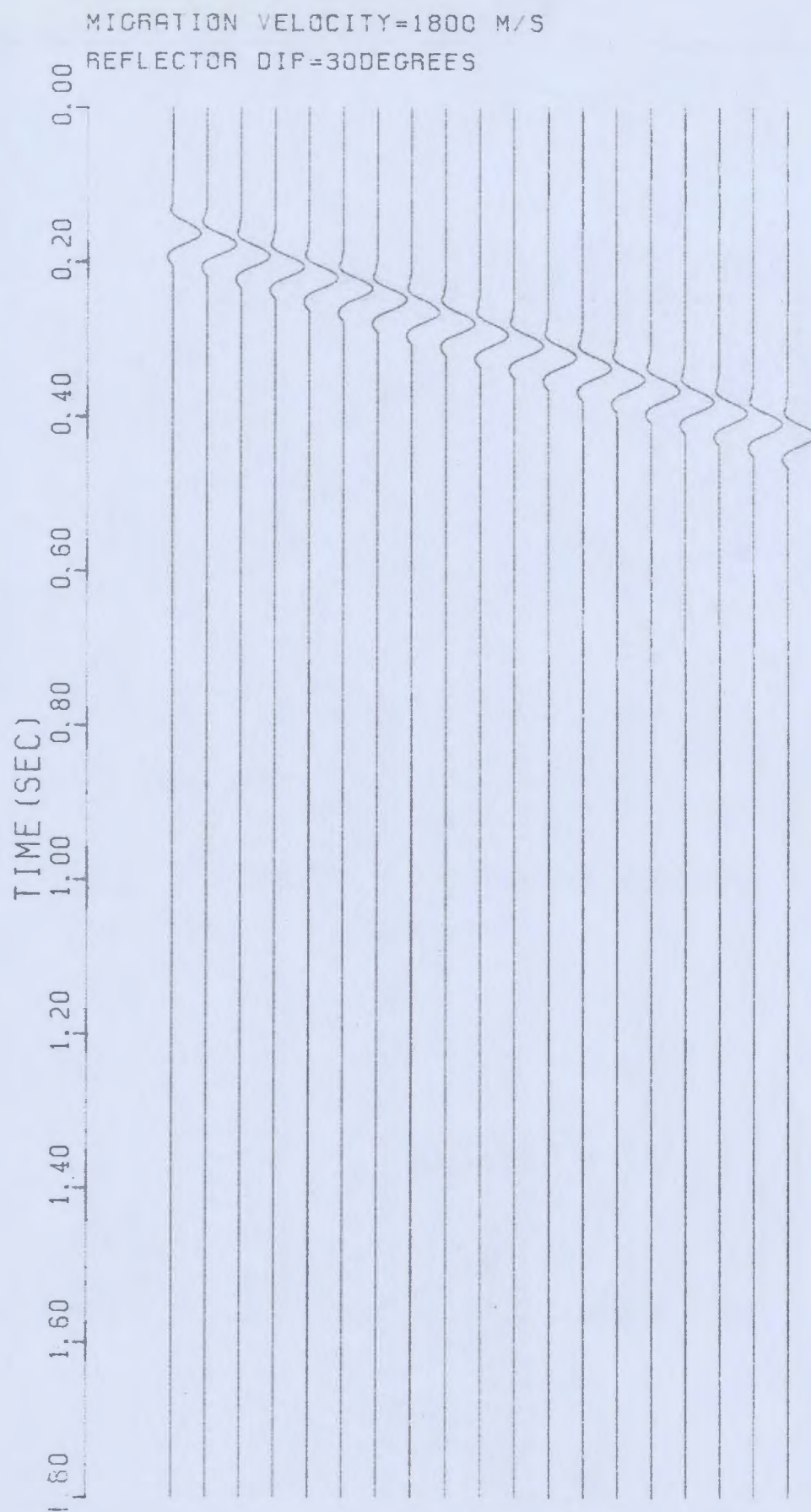


FIG.3.3.118 MIGRATED SECTION

MIGRATION VELOCITY=1900 M/S

REFLECTOR DIP=30DEGREES

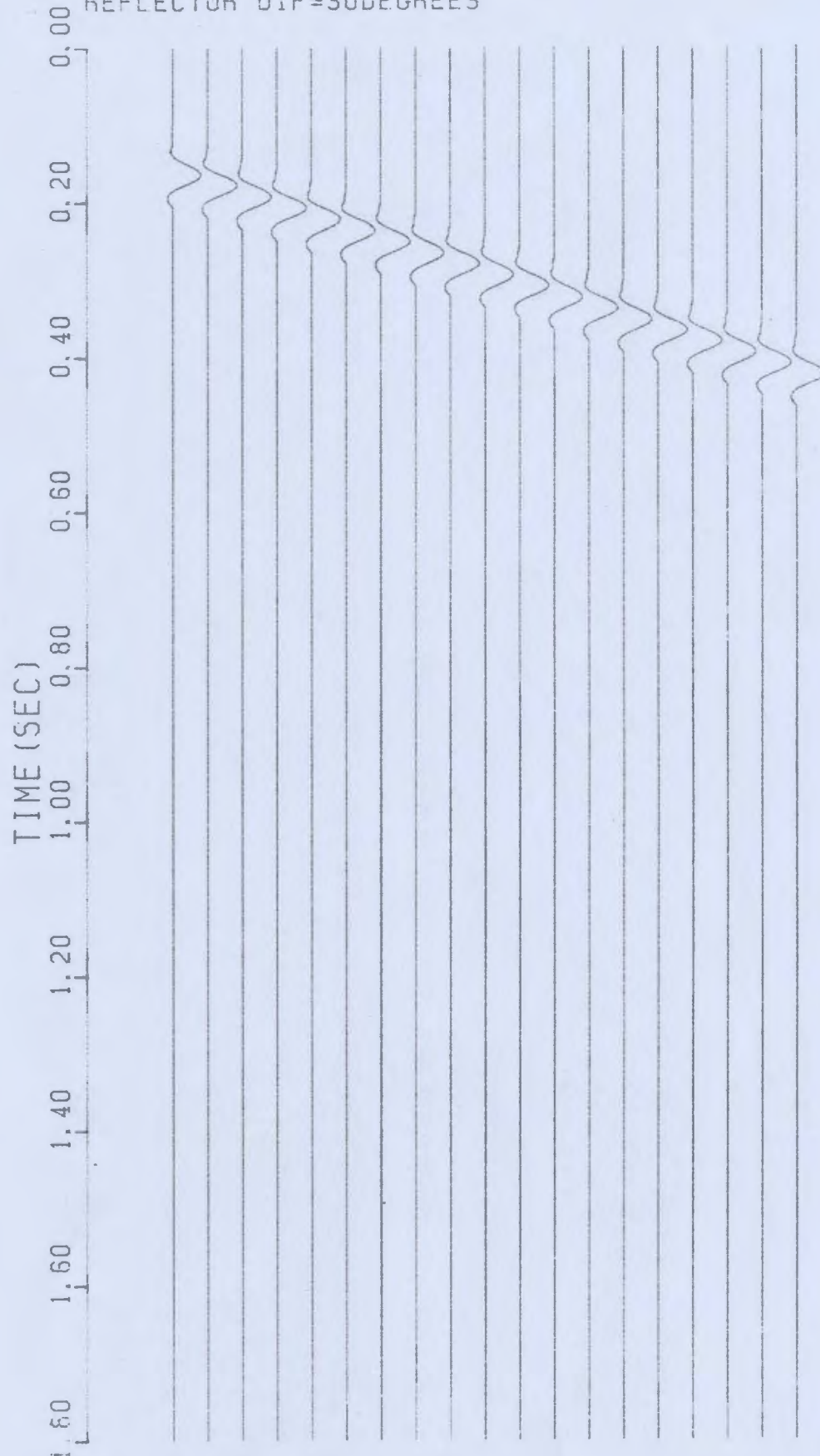


FIG.3.3.1.19 MIGRATED SECTION

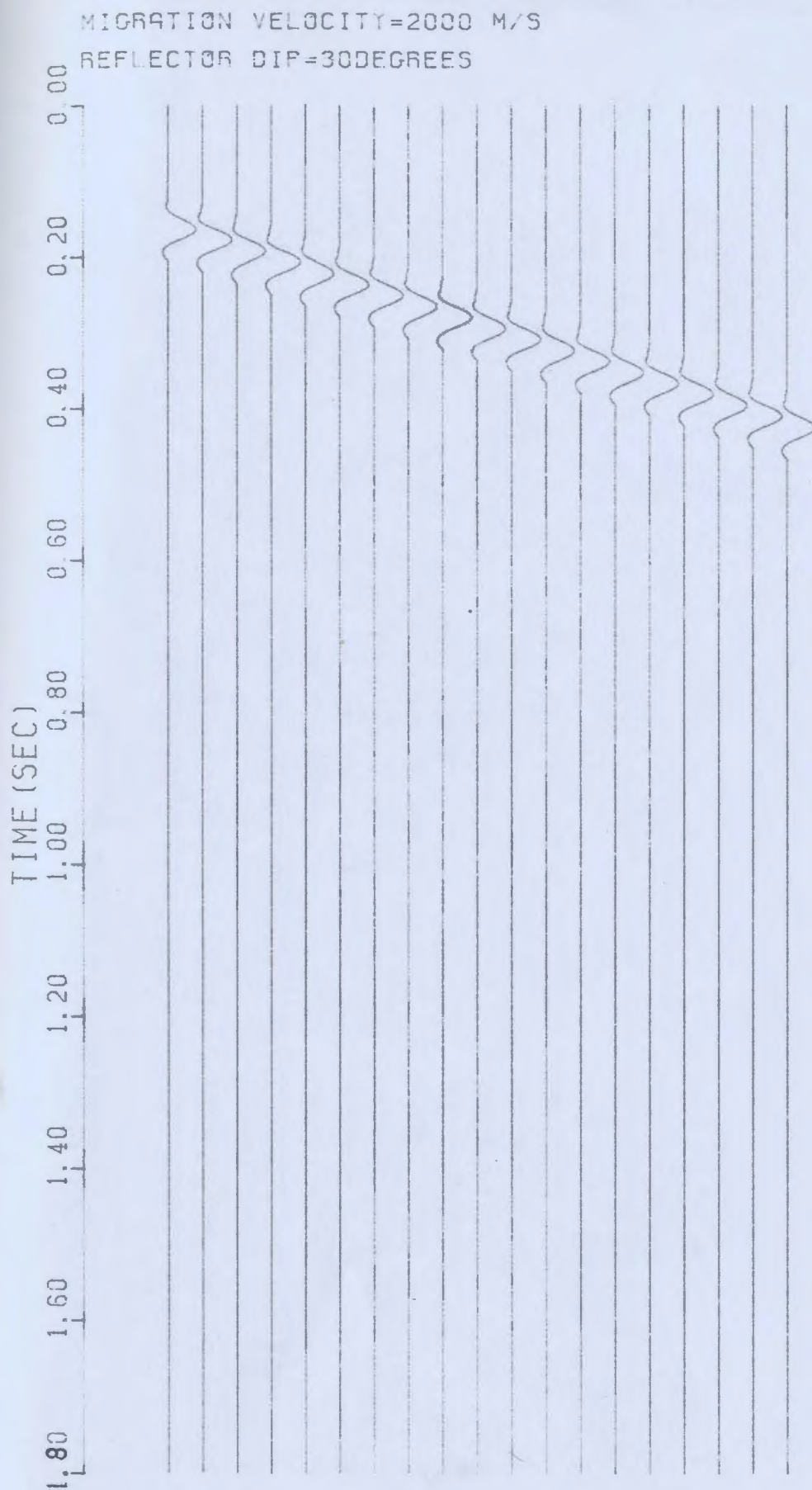


FIG.3.3.1.20 MIGRATED SECTION

MIGRATION VELOCITY=2100 M/S

REFLECTOR DIP=30DEGREES

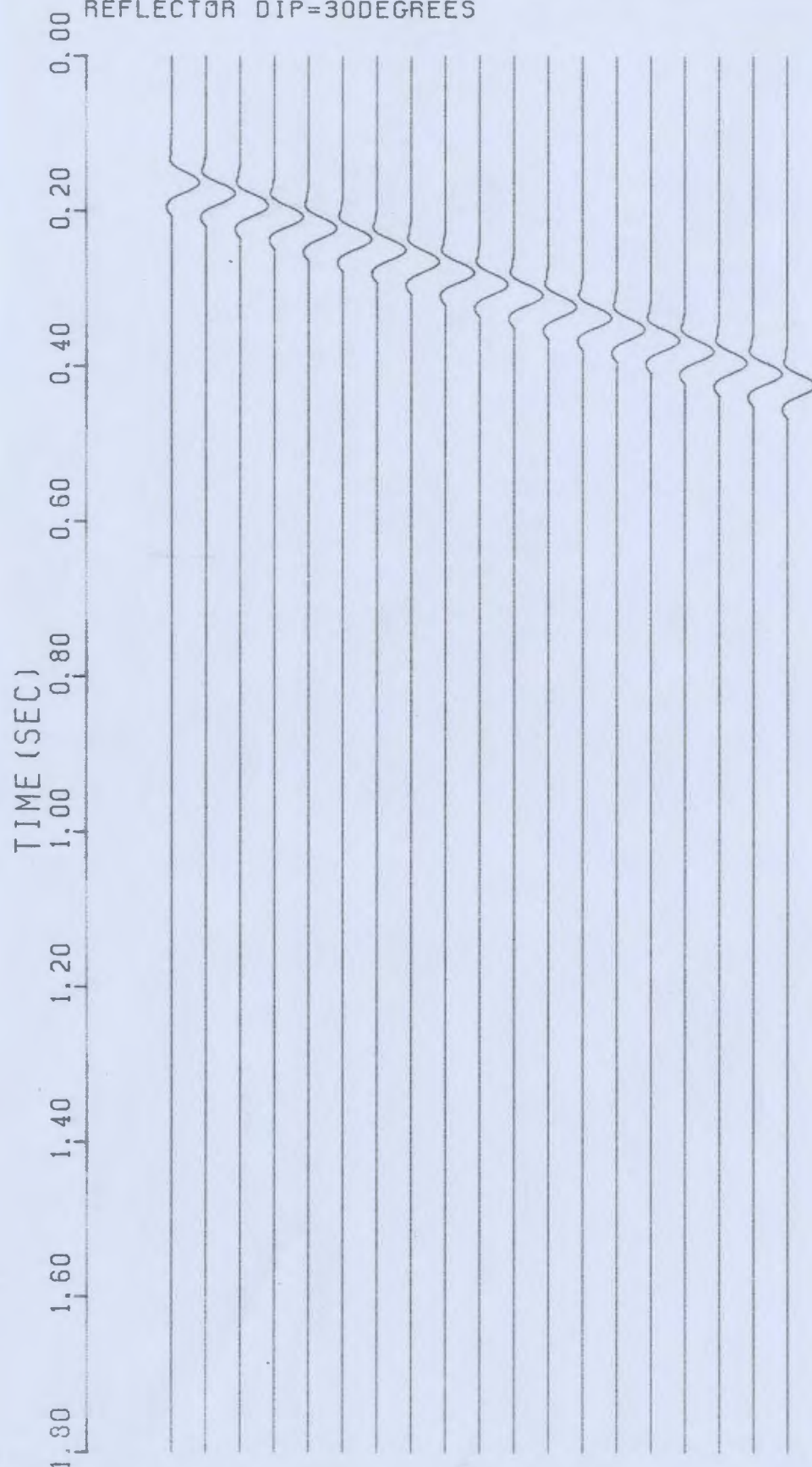


FIG.3.31.21 MIGRATED SECTION

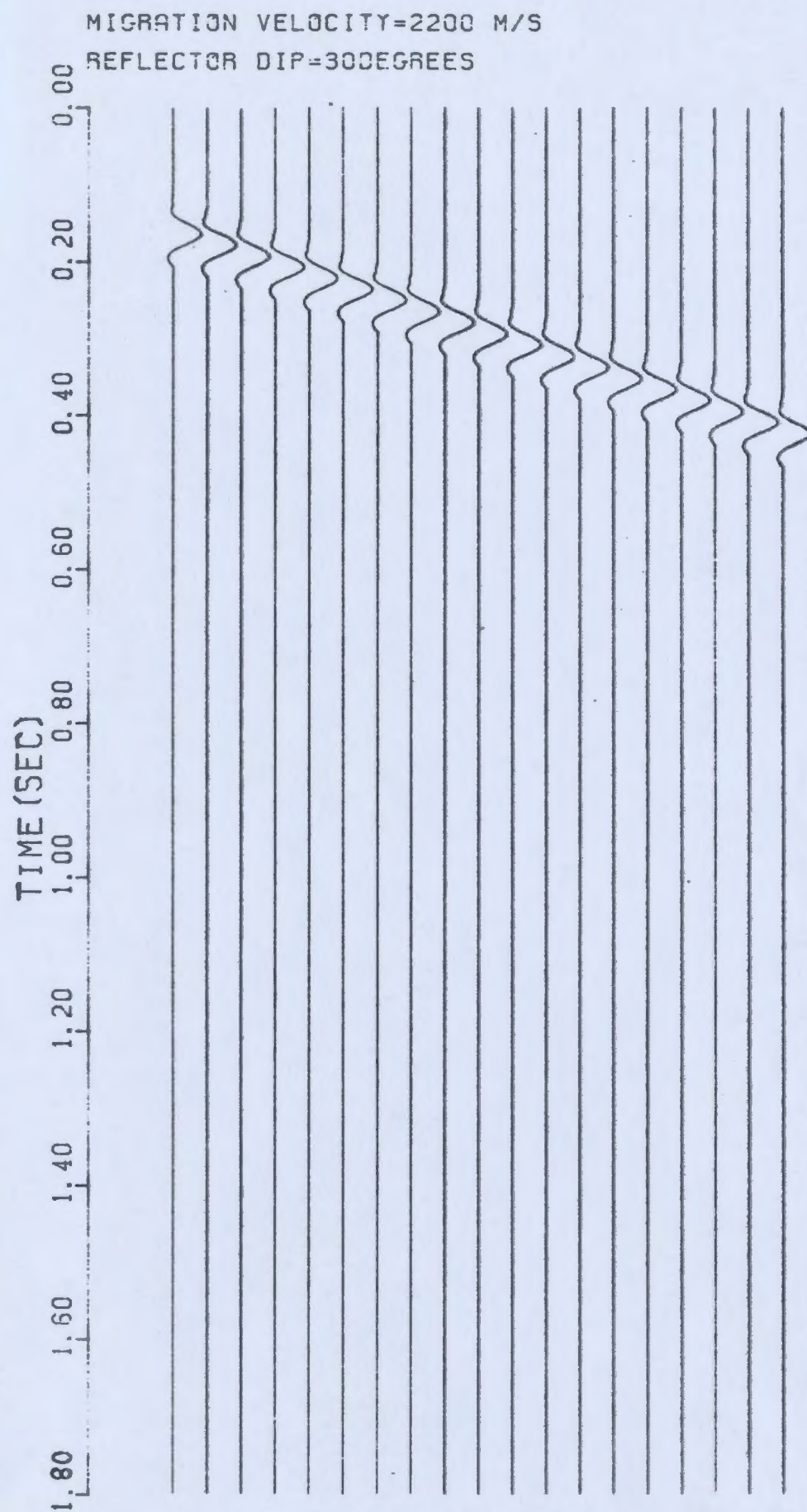


FIG.3.3.1.22 MIGRATED SECTION

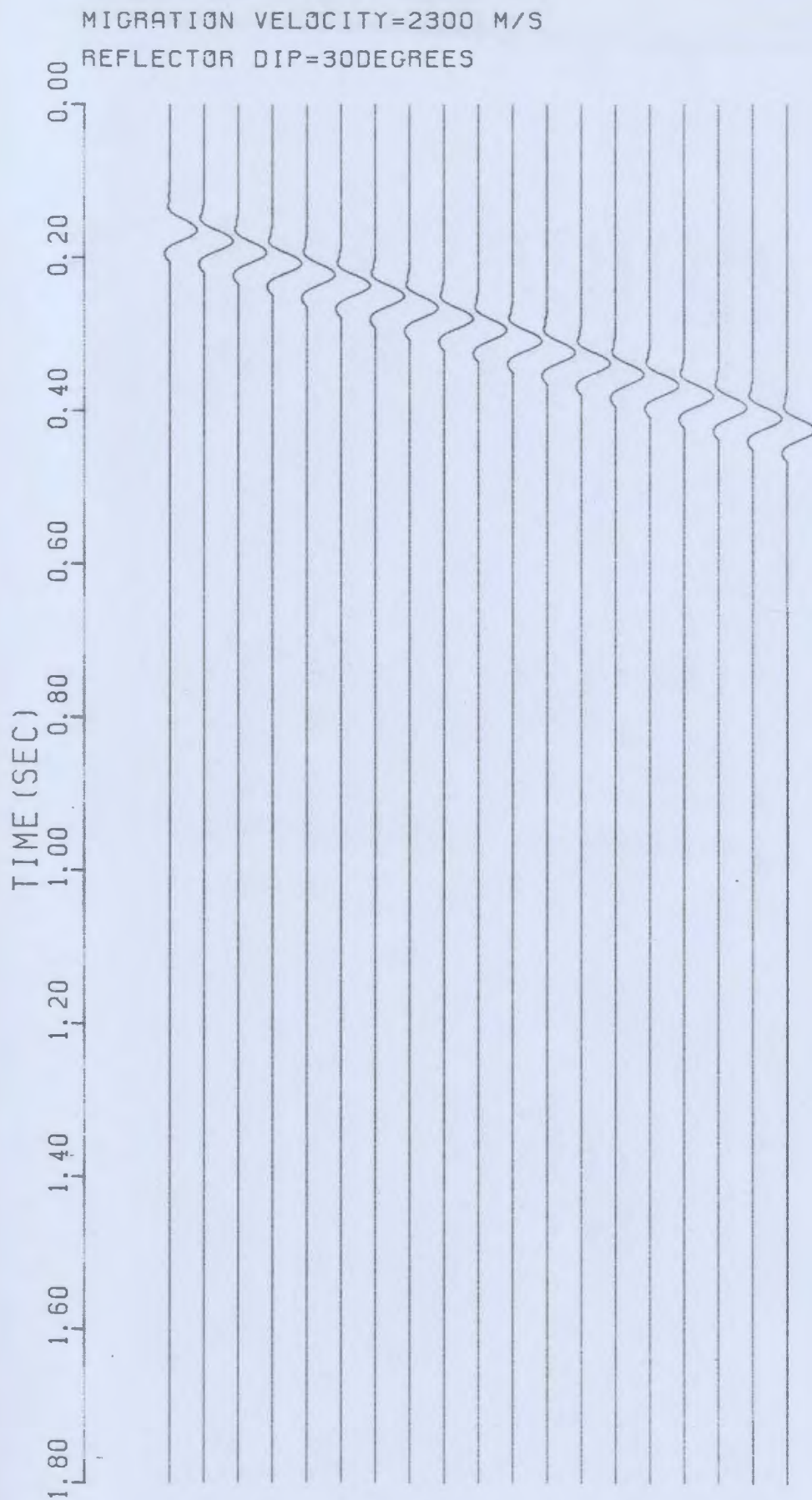


FIG.3.3.1.23 MIGRATED SECTION

MIGRATION VELOCITY=2400 M/S

REFLECTOR DIP=30DEGREES

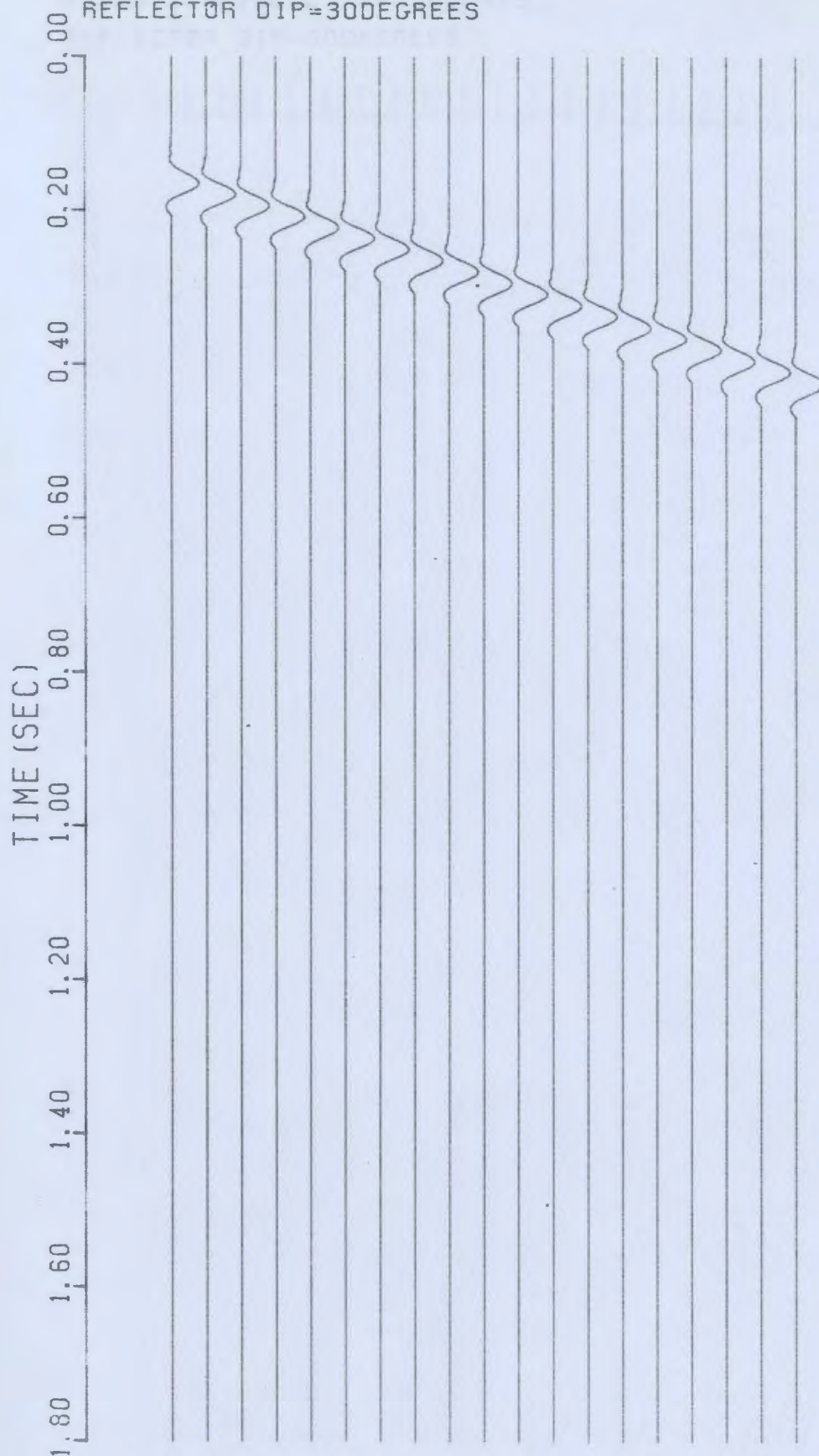


FIG.3.3.1.24 MIGRATED SECTION

MIGRATION VELOCITY=2500 M/S

REFLECTOR DIP=30DEGREES

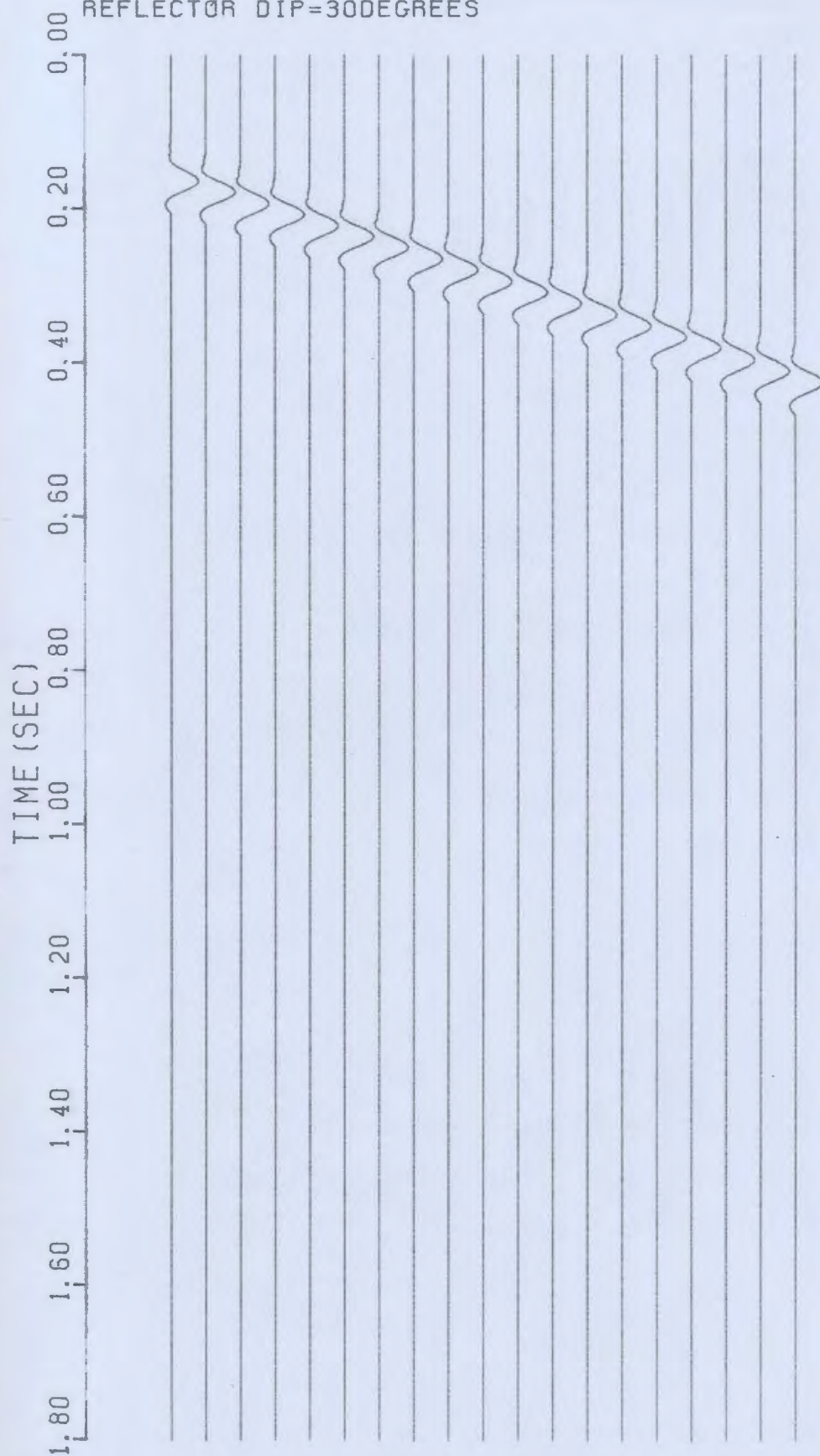


FIG.3.3.1.25 MIGRATED SECTION

sections, the anticline structure was better clarified than the unmigrated sections. The diffraction patterns generated at the sharp boundaries of the anticline were collapsed and breadth of anticline was reduced. The amplitude was reduced by a factor of 3.0 in all the migrated sections of the anticline portion compared to an amplitude reduction by a factor of 2.0 in the straight reflector portion of the anticline. The pulse shapes were broadened due to the loss of high frequency content in the reflected pulse. Noise was observed in the migrated sections (Figures 3.3.2.11 and 3.3.2.12) with their reflector dip angle 50° and 60° respectively. This indicates that noise was introduced during the migration process from steeply dipping events. The effect of velocity on diffraction stack migration was not studied for this particular model.

DIP OF ANTICLINE=10DEGREES

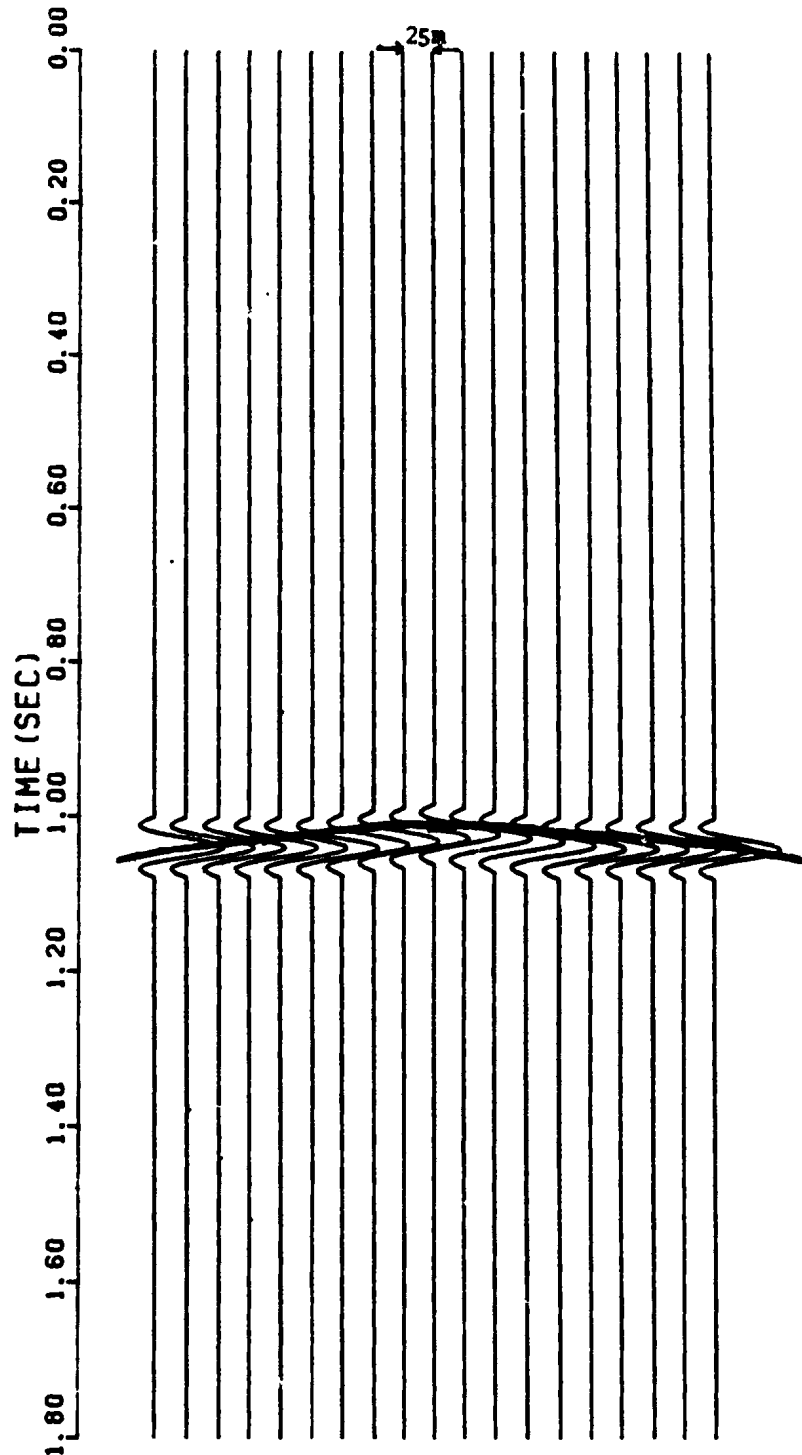


FIG.3321 UNMIGRATED SECTION

DIP OF ANTICLINE=20DEGREES

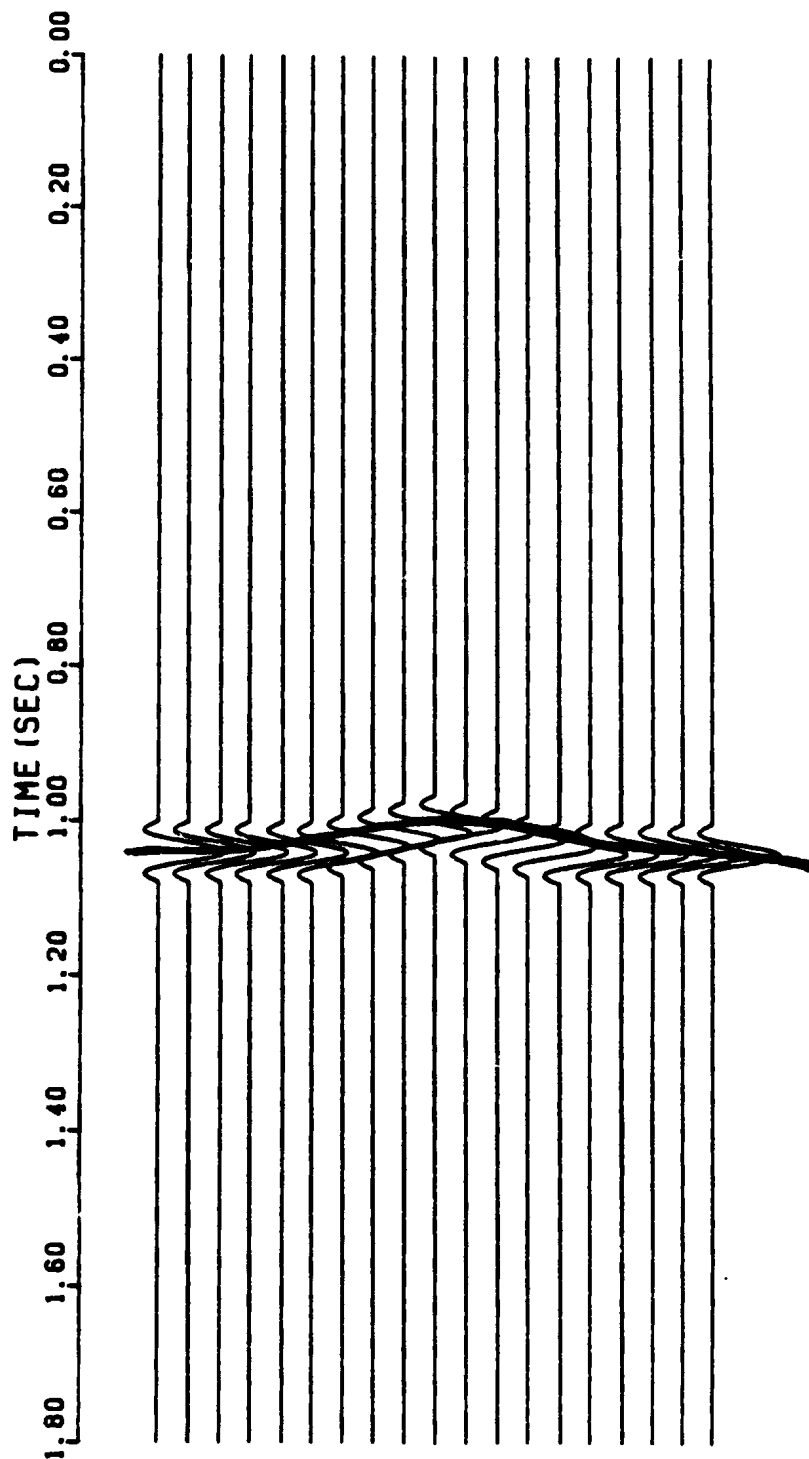


FIG.33.2.2.UNMIGRATED SECTION

DIP OF ANTICLINE=30DEGREES

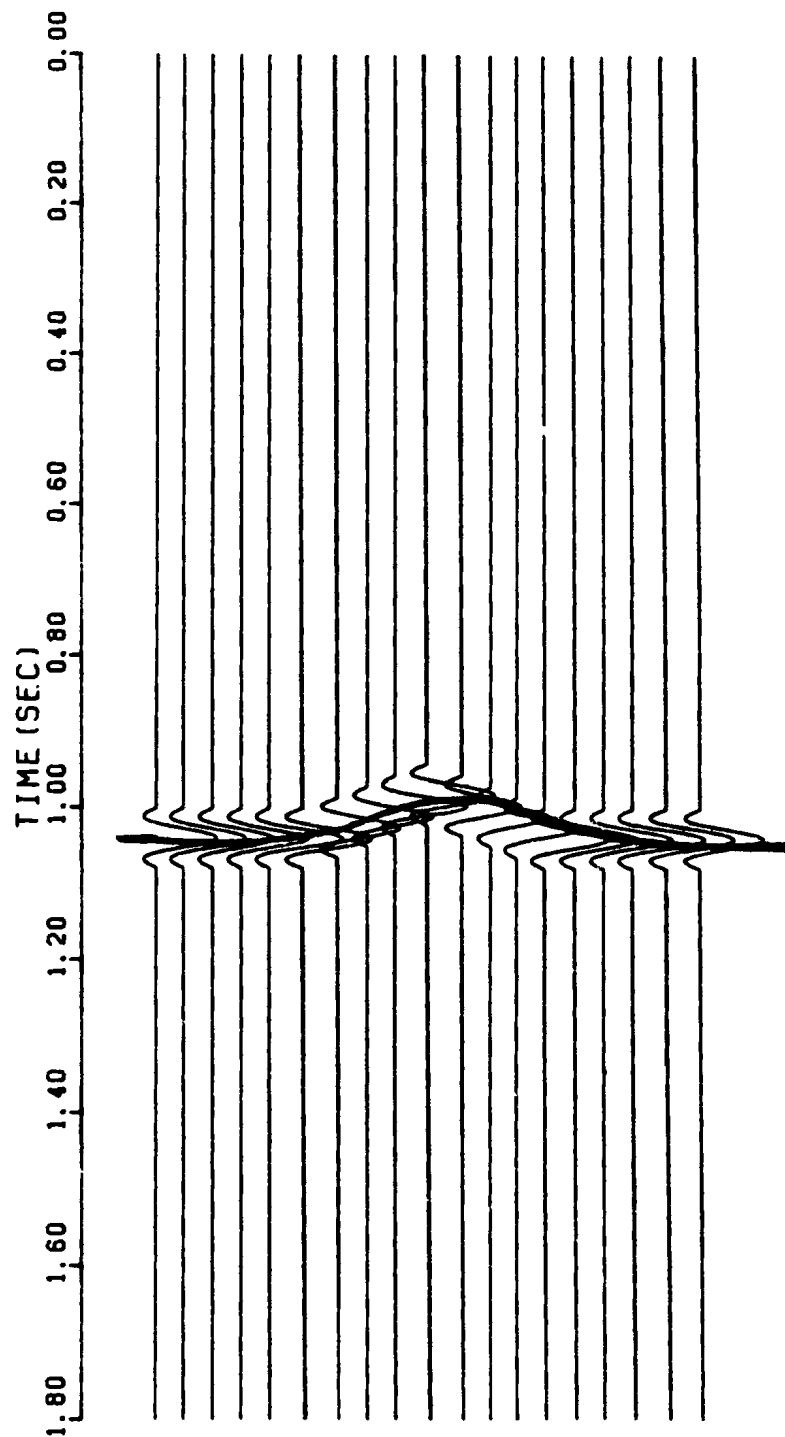


FIG.3323 UNMIGRATED SECTION

DIP OF ANTICLINE=400EGREES

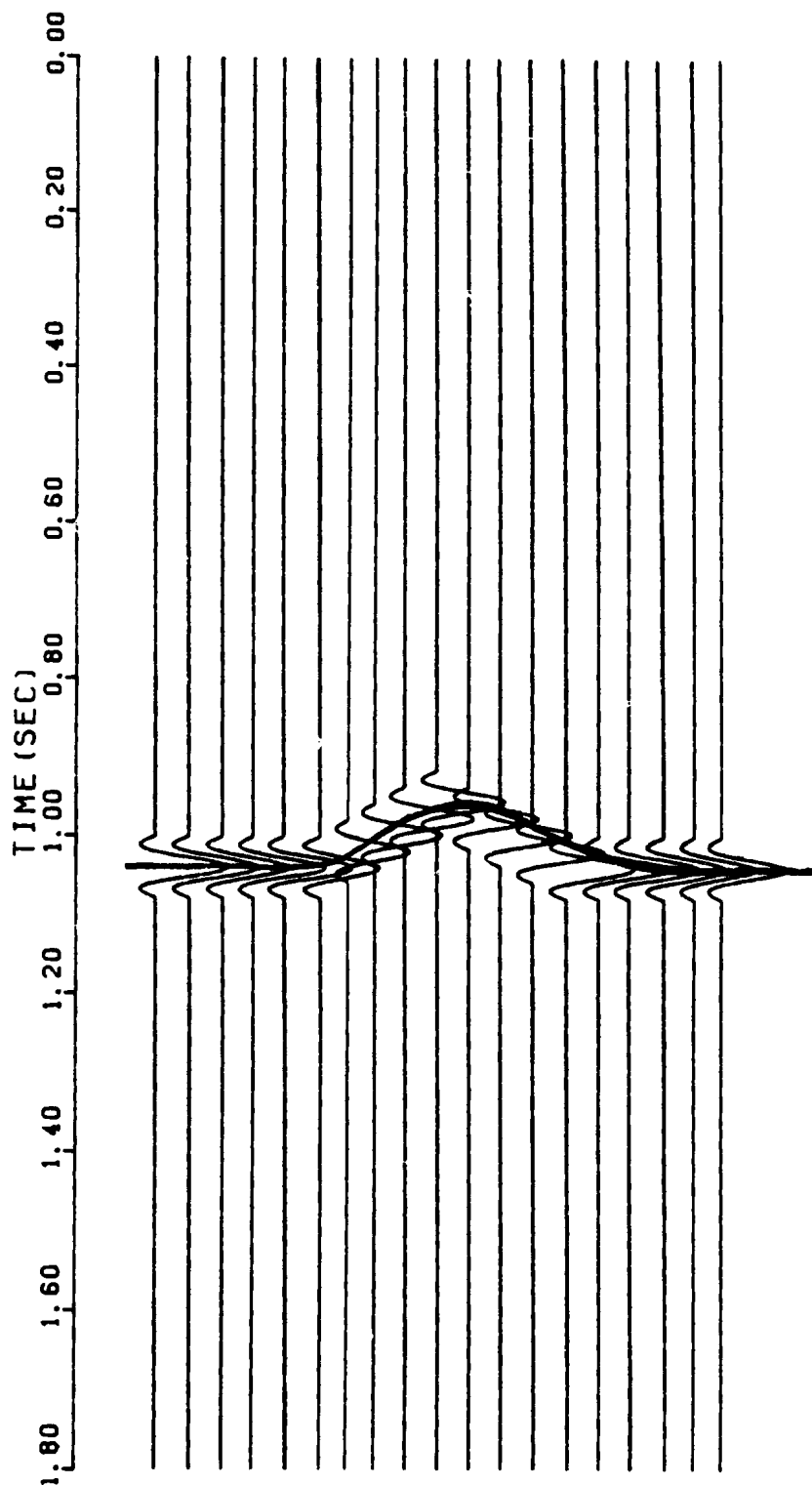


FIG.3324 UNMIGRATED SECTION

DIP OF ANTICLINE=50DEGREES

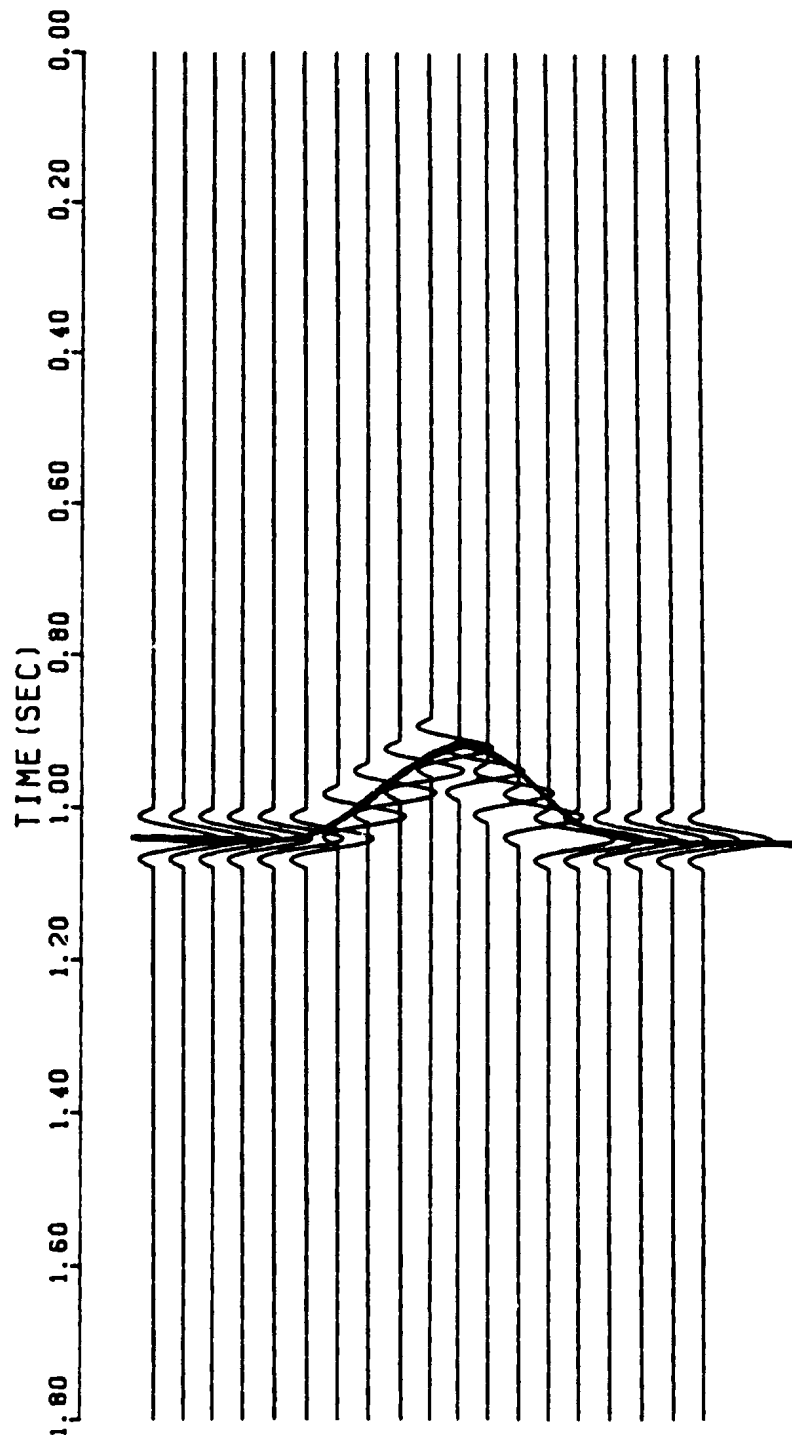


FIG.3.3.2.5 UNMIGRATED SECTION

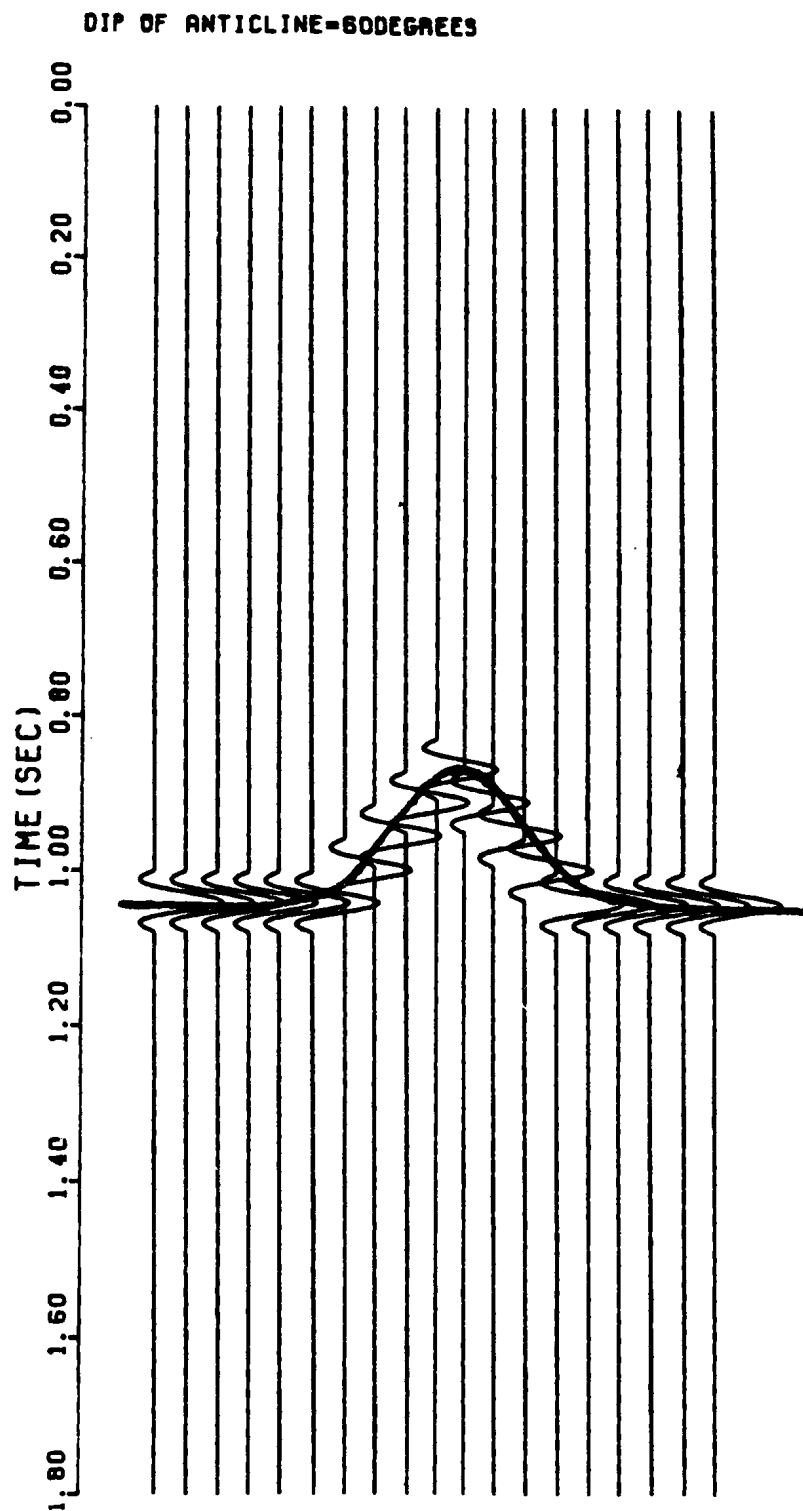


FIG3.32.6 OMMIGRATED SECTION

DIP OF ANTICLINE=100DEGREES

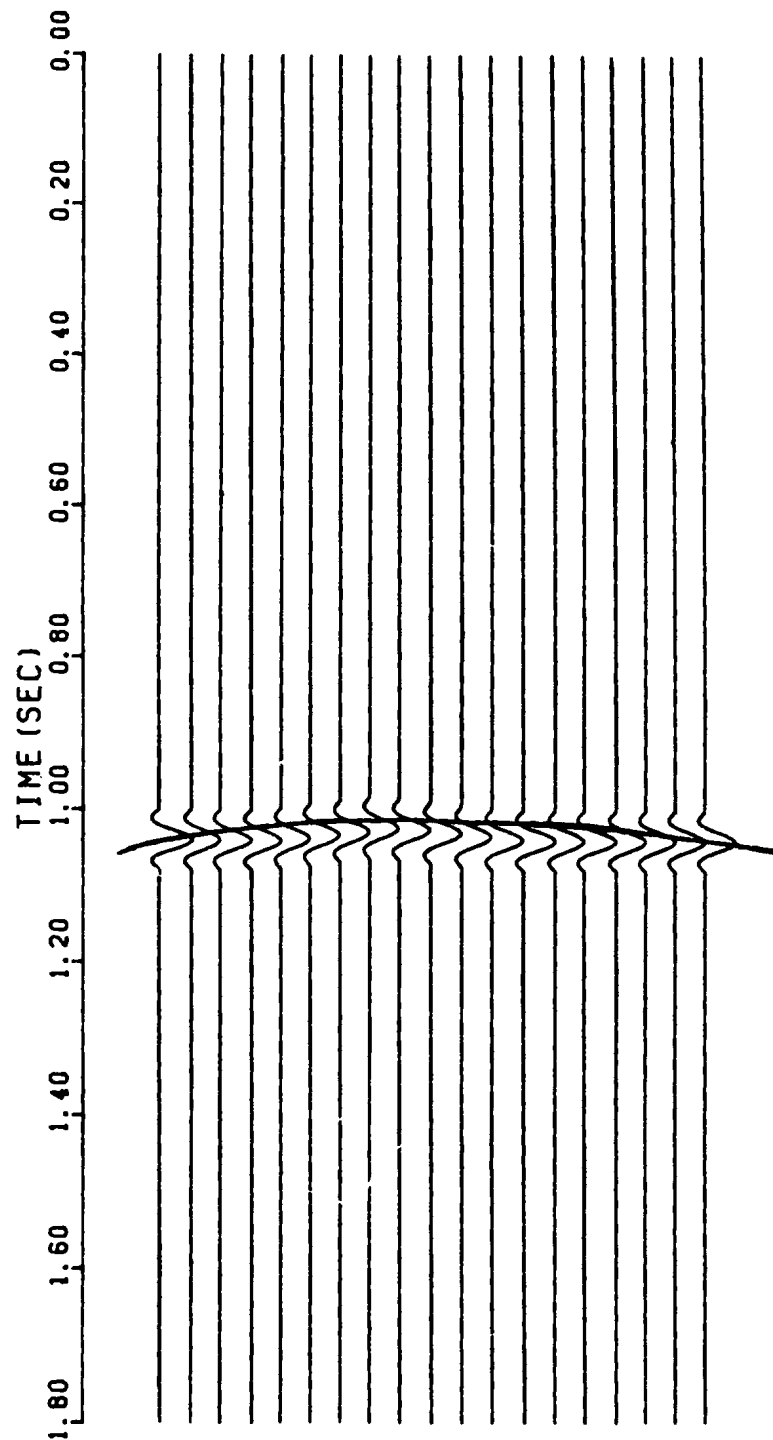


FIG.3.32.7 MIGRATED SECTION

DIP OF ANTICLINE=200DEGREES

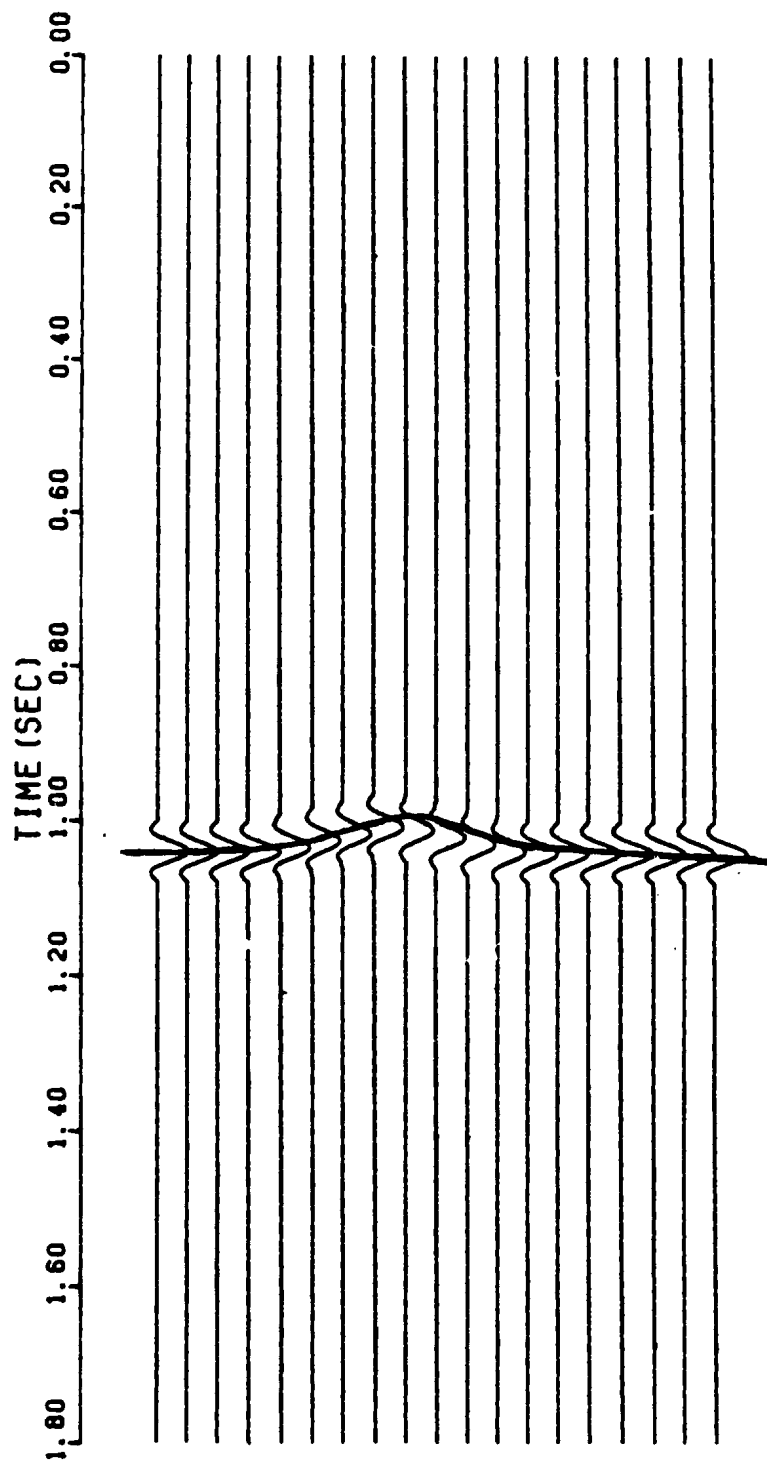


FIG.3.2.8 MIGRATED SECTION

DIP OF ANTICLINE=30DEGREES

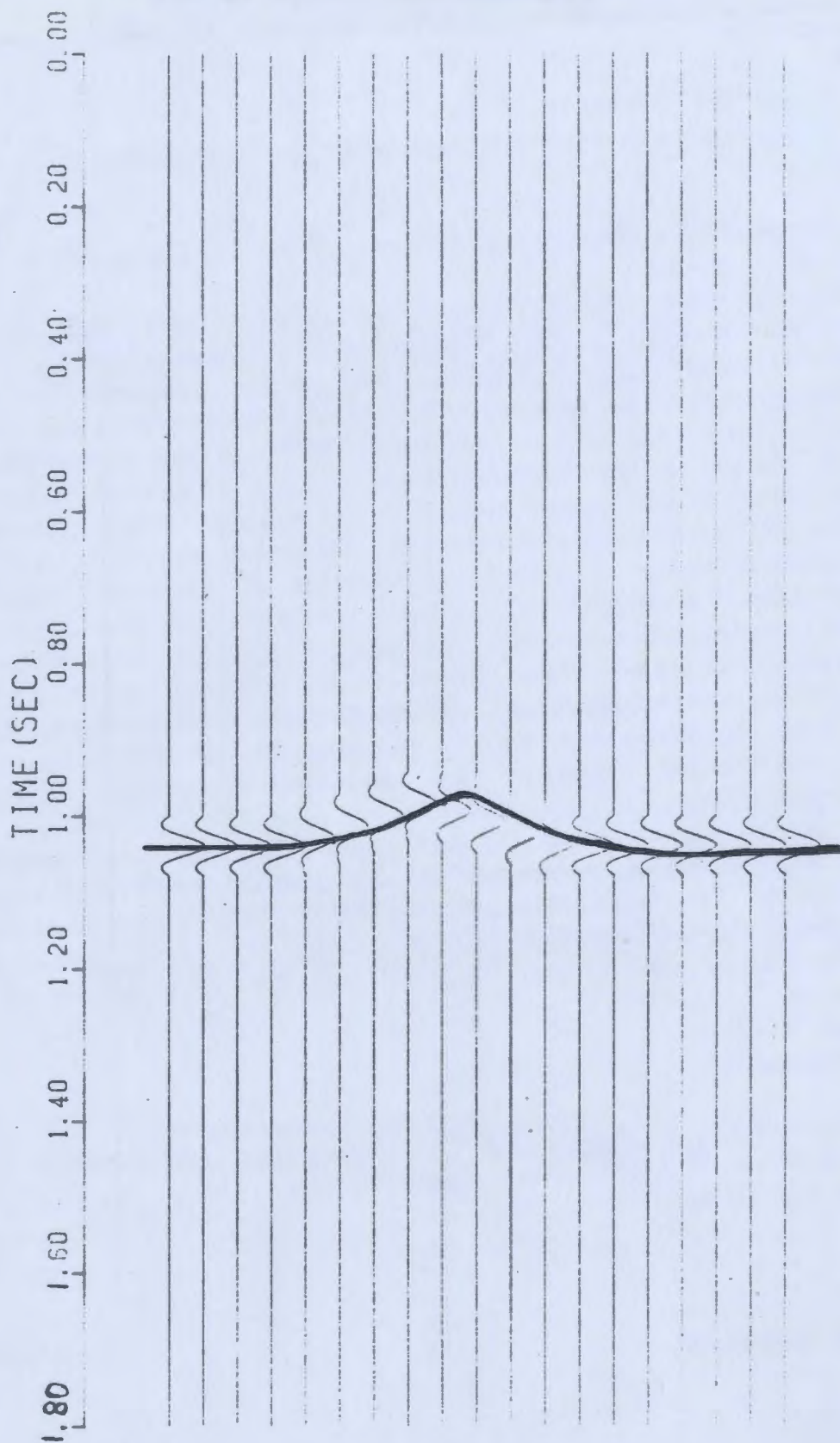


FIG.332.9 MIGRATED SECTION

DIP OF ANTICLINE=40DEGREES

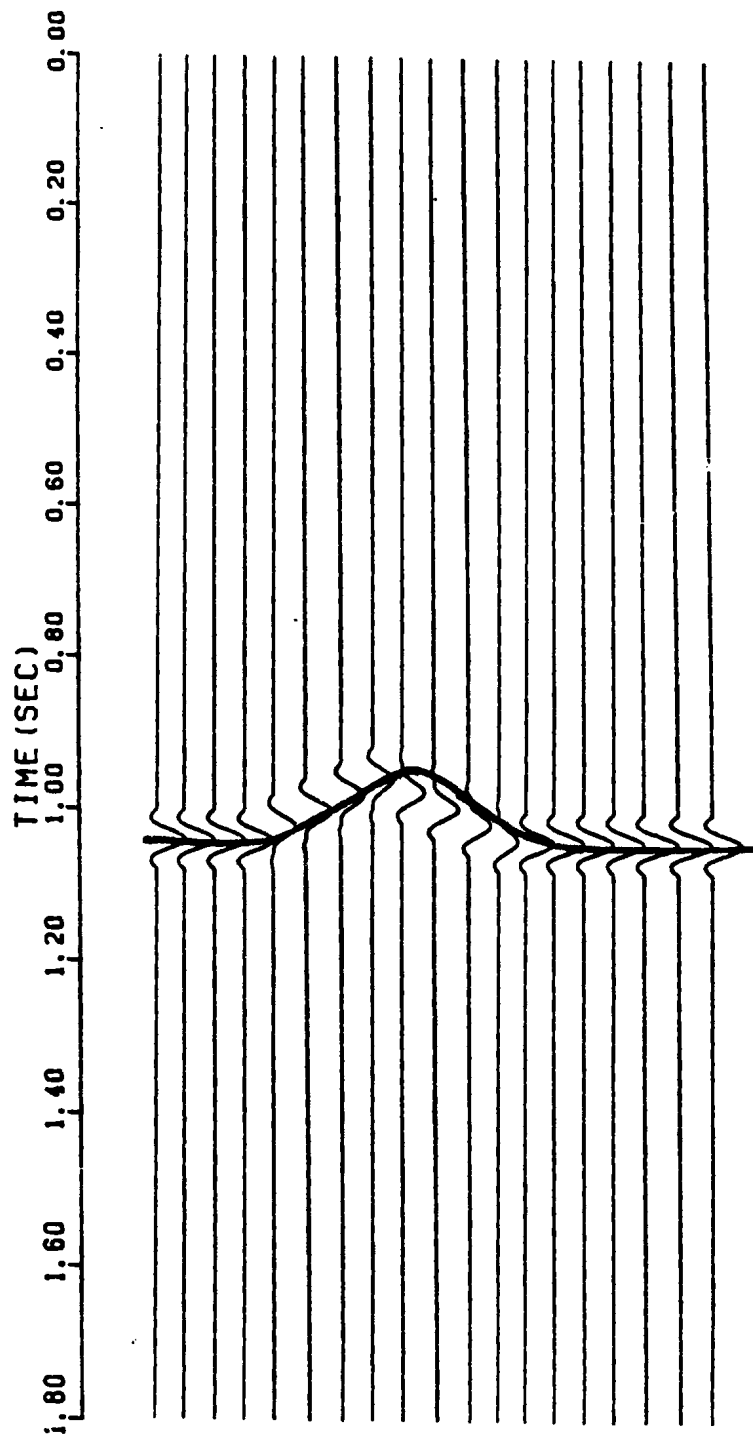


FIG.3.3210 MIGRATED SECTION

DIP OF ANTICLINE=500DEGREES

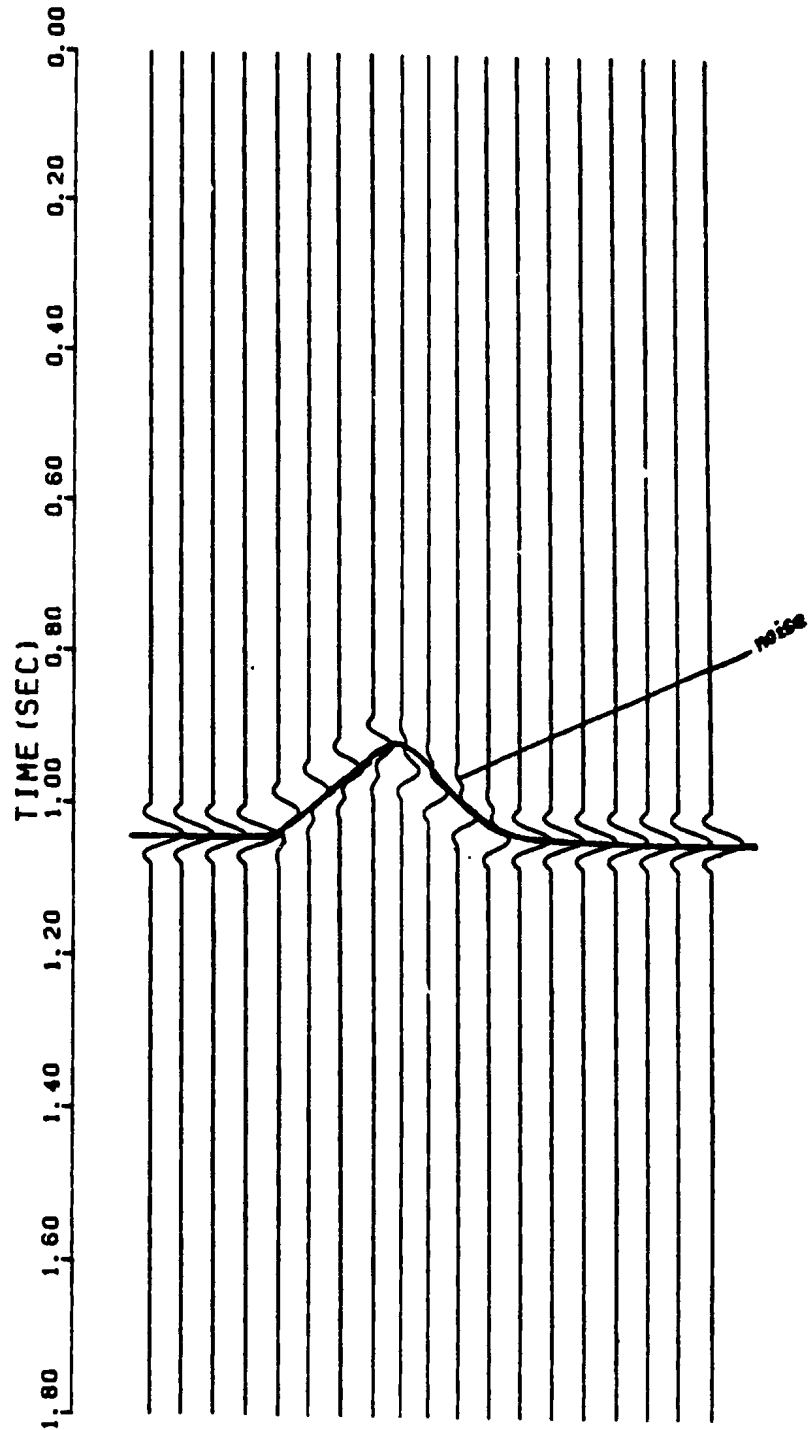


FIG.33.2.11 MIGRATED SECTION

DIP OF ANTICLINE=60DEGREES

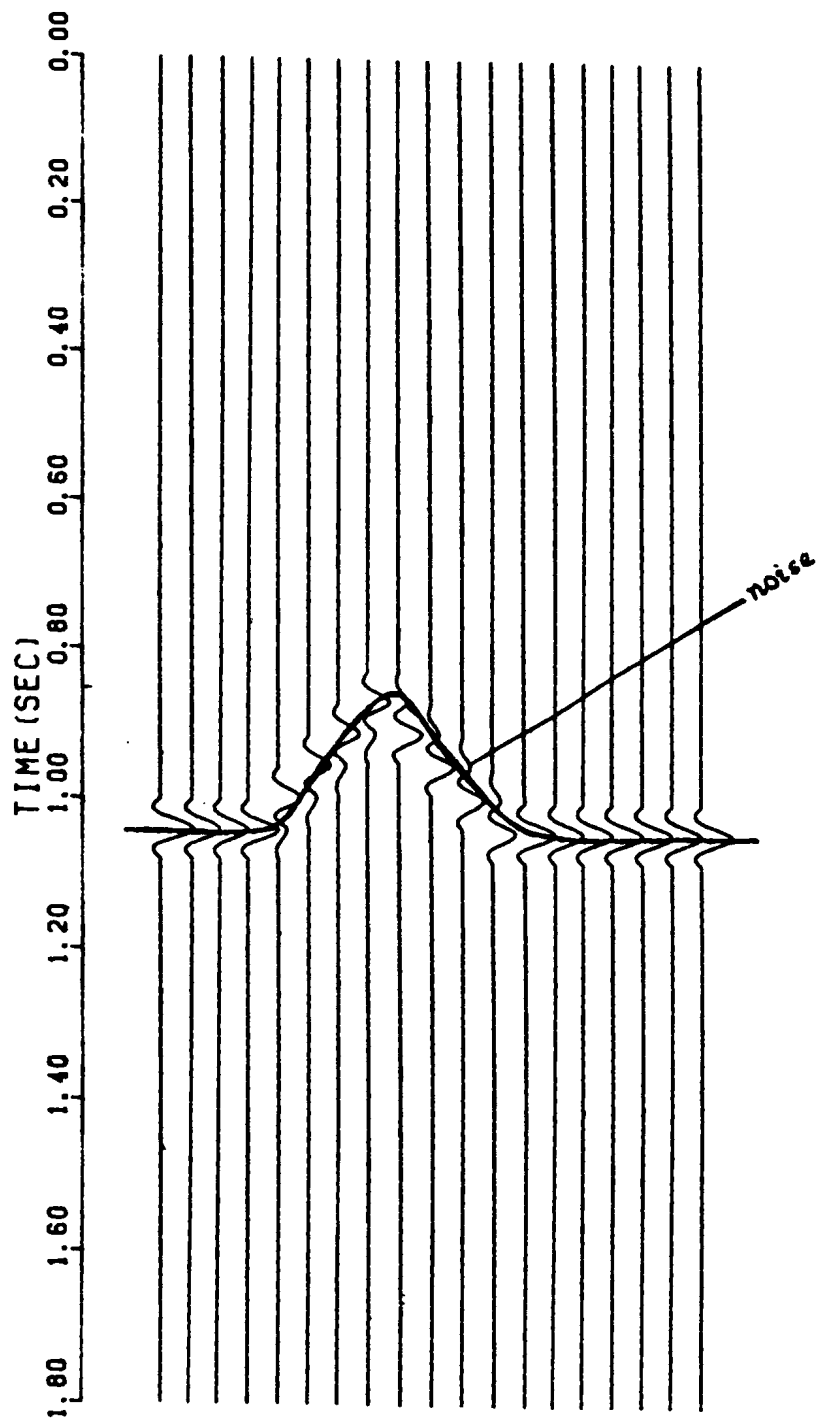


FIG.332.12 MIGRATED SECTION

CHAPTER 4

4.0 APPLICATION OF DIFFRACTION STACK METHOD TO FIELD DATA

In general, field reflection data are presented as record sections for final interpretation of the subsurface structures. These record sections display seismic traces side-by-side to show the continuity of reflection events. Such record sections can be compared with geological cross sections provided the following conditions are satisfied: (1) there should not be any lateral variation in velocity; (2) no geometrical bending of the ray paths away from the vertical. In steep dip areas the ray paths bend away from the vertical causing distortions in actual geometry of the subsurface structures. Migration is used in such cases to construct the correct configuration of the dipping subsurface structures for a more reliable interpretation than is possible from conventional record sections. The existing field seismic data (stacked sections) were used in implementing the diffraction stack migration scheme. The main purpose of implementing the above technique is to improve the lateral resolution over the dipping anticline structure after collapsing the diffraction patterns generated at the sharp boundaries. In addition, the actual boundary of the anticline structure can be delineated after applying the migration technique.

4.1 Local Geology of the Adolphus Structure

The salt generated domal structure known as "Adolphus" is located approximately 225 miles east of St. John's on the Grand Banks of Newfoundland (Fig. 4.1). Geophysical investigations from Mobil's survey indicated a number of favourable structures on the Grand Banks area which led to three well locations on a salt piercement structure. Three wells, Adolphus K-41, Adolphus 2K-41 and Adolphus D-50 were drilled in the Jeanne d'Arc Subbasin to evaluate combined stratigraphic and structural traps in the Tertiary and Cretaceous sandstones on a diapiric salt dome structure (Well history report, Petroleum Directorate, Govt. of Newfoundland and Labrador, 1975). Most of the lithological information of this structure was obtained from the drilling cores of one wildcat well and two exploratory wells.

First the K-41 wildcat well was drilled on the crest of a salt generated domal structure on the Grand Banks of Newfoundland. The well was spudded on November 16, 1972 and then abandoned at a total depth of 1239 m in the Tertiary Banquereau formation. The K-41 well penetrated approximately 335 m of undifferentiated Quaternary and Tertiary, and 904 m of Tertiary sediments. Between 0-352 m, no samples were collected from ditch cuttings. The major rocks encountered in the subsequent ditch cuttings were mudstones, siltstones and sandstones. Alternate layering of mudstone and sandstone beds was observed in the ditch cuttings. Sometimes very fine to coarse grained quartz and traces of pyrite were noticed along with mudstone formation.

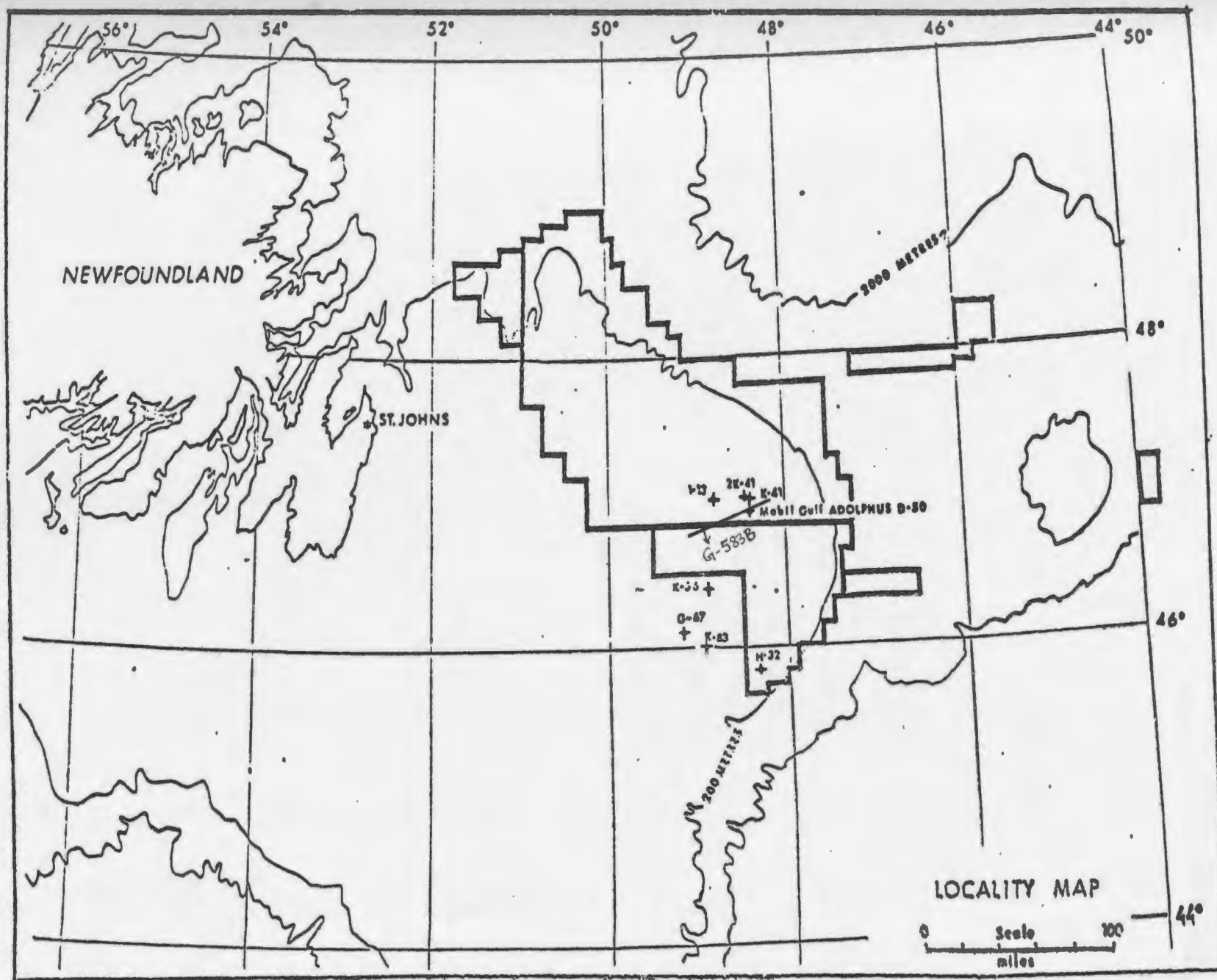


Figure 4.1 Map showing the Adolphus structure (From well history report, 1975).

Later two more exploratory wells were drilled on the Adolphus salt structure. The first of these "Adolphus 2K-41" was drilled on the crest of the salt dome structure followed by the second exploratory well "Adolphus D-50" drilled on the flank of the same salt structure. The major lithological units penetrated by these two exploratory wells are presented in Table 4.1 (Rashid, 1978). In the first exploratory well, 3660m of sedimentary strata were penetrated along with a salt thickness of 800m. It is believed that the salt age ranges from Triassic to Lower Jurassic. During the growth of diapiric structure, the salt pierced the lower section of sedimentary strata (Jurassic and Lower Cretaceous formations) and uplifted the upper sections of Dawson formations (Rashid, 1978). An average uplift of 370m was noticed between Adolphus 2K-41 and D-50 formations (Table-4.1). Several production tests were run in Adolphus 2K-41 in order to find commercial quantity of hydrocarbon reserves. However, only minor flows of oil and gas from the upper Cretaceous sandstones at depth 2610-2645m were observed. The flow rate was 268 barrels of oil per day. A gas flow of 5664 cubic meters per day was observed in the Adolphus 2K-41 well.

4.2 Data Translation from Consul Staked Reel

As a part of the analysis work, the diffraction stack migration technique was applied to field seismic data (stacked data) collected over the Adolphus structure on the Grand Banks of Newfoundland. These seismic data were supplied in the form of consul staked reels by Mobil Oil Canada

Formation	Depth range (m)	Thickness (m)	Major lithology
Adolphus 2-k-41			
Banquereau	Down to 2381	—	Shales and mudstone
Wyandot Equivalent	2381-2432	51 m	Chalk and limestone
Dawson Canyon	2432-2554	122 m	Limestone, sandstone, mud, and shale
Logan Canyon Equivalent	2554-2853	299 m	Mud, sandstone, limestone, chalk, and shale
Top of salt	2853-3653	800 m	Mostly halite with thin interbedded red-brown shales and minor dolomites
Adolphus D-50			
Banquereau	Down to 2659	—	Mudstone and shales
Wyandot Equivalent	2659-2916	257 m	Limestone
Dawson Canyon	2916-3103	187 m	Limestone and siltstone
Logan Canyon Equivalent	3103-3686	583 m	Limestone and siltstone

Table 4.1 Details of geological formations penetrated by Adolphus wells.
(After Rashid, 1978).

Limited, Calgary to undertake the present analysis. The stacked data were produced after applying the normal processing sequence (Fig. 1.4) and then stored in the magnetic tape as demultiplexed SEG Y Format. The stacked data over line G-583B were chosen for our present analysis because it cuts both sides of Adolphus anticline structure.

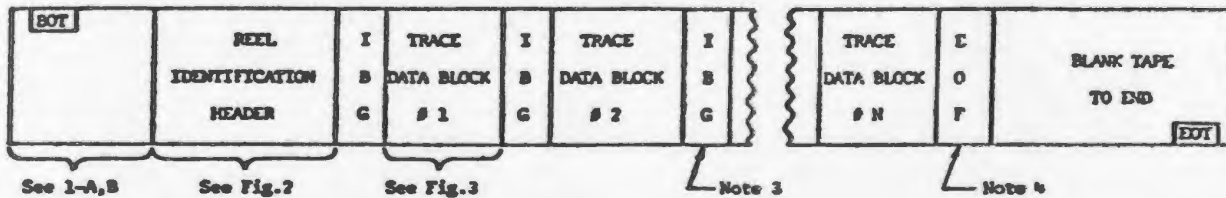
First the consul staked reel containing the data for line G-583B was transferred to the VAX/VMS 11/780 computing system using a computer programme developed (Appendix-1) in order to translate the data from demultiplexed SEG Y Format (Barry et al., 1975). The above computer programme was written to read the reel identification header as well as the trace data block (Fig 4.2) in SEG Y Format. A subroutine was incorporated in the above programme to translate the trace data samples correctly on VAX/VMS system because the original consul staked tape containing the data samples was written in IBM format.

4.3 Parameters for Migration of Field Data

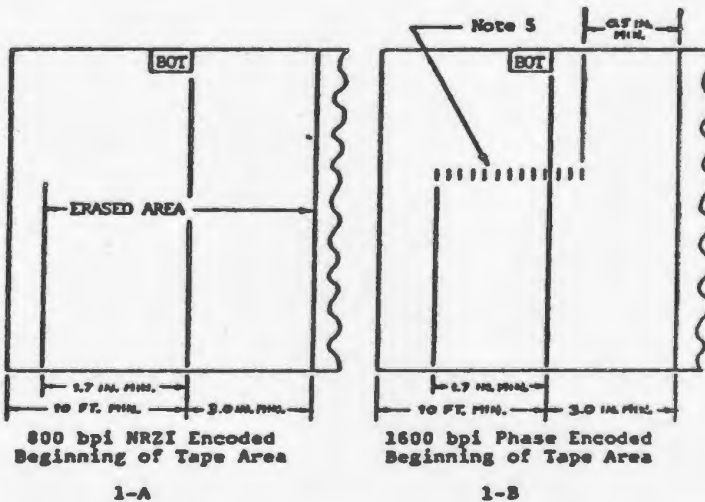
Before implementing the migration, it was necessary to fix the three basic parameters; sampling interval, aperture and migration velocity. As a rule of thumb, there should be at least two samples per cycle for the highest frequency (Nyquist frequency) present in the signal to be analysed. It was observed that most of the reflected energy in the unmigrated stack section (Fig. 4.4.1) was in the range of 10 to 50 HZ which was within Nyquist frequency range of the signal to be

Digital Tape Formats

Nine Track, 800 bpi NRZI or 1600 bpi Phase Encoded (PE) Demultiplex (Trace Sequential) Format



← Tape Motion (Tape viewed oxide down)



P	4	P	P	P	P
0	7	31	23	15	7
1	6	30	22	14	6
2	5	29	21	13	5
3	3	28	20	12	4
4	9	27	19	11	3
5	1	26	18	10	2
6	8	25	17	9	1
7	2	24	16	8	0

n (for 2ⁿ binary code)

Track number

Bit number

1-C

- NOTES:
1. Preamble-Precedes each of the 45 blocks within the reel identification header and each trace data block when 1600 bpi PE is used. Consists of 40 all-zero bytes followed by one all-ones byte.
 2. Postamble-Follows each of the 45 blocks within the reel identification header and each trace data block when 1600 bpi PE is used. Consists of one all-ones byte followed by 40 all-zero bytes.
 3. Interblock Gap (IBG)-Consists of 0.6" nominal, 0.5" minimum.
 4. End of file (EOF)-Consists of an IBG followed by:
 - (a) PE tape mark having 80 flux reversals at 3200 fci in bit numbers P, 0, 2, 5, 6, and 7. Bits 1, 3, and 4 are dc-erased.
 - or (b) NRZI tape mark having two bytes with one bits in bit numbers 3, 6, and 7 separated by seven all-zero bytes.
 5. PE Identification Burst-Consists of 1600 flux reversals per inch in bit number P; all other tracks are erased.

Figure 4.2 Recommended demultiplexed format (After Barry et al, 1975).

considered. An output sampling rate of 4 ms was used which gives a Nyquist frequency of 125 Hz. This latter value is well above the highest frequency observed in the seismic data and therefore there should be no aliasing problems. The 4 ms interval also allowed a reasonable computation time for the summation operation in the diffraction stack method.

In the implementation of the above technique, only data from a finite aperture are migrated. The seismic resolution can be improved by choosing the correct aperture. It is essential to use only data falling within the portion of the migration surface that contain the main contribution to the image. The aperture for the stacked data was estimated by applying the relation given in section 3.2.1. Three apertures were tried to migrate the stacked data over Adolphus structure. Table-4.3 gives the apertures used for three different migration velocities on stacked data.

Serial Number	Velocity of the medium 'm/s'	Frequency of the pulse 'HZ'	Maximum depth considered 'm'	Aperture value equivalent to no. of traces
1	2500	50	3750	12
2	3500	50	5250	17
3	4500	50	6750	22

Table 4.3 Different apertures values for different set of velocities for field stacked data.

The most important parameter in diffraction stack migration is the migration velocity. Velocity acts as a variable in defining the hyperbola

along which the summation is to be carried out. There are several choices available in selecting the correct velocity for migration. The common choices are interval velocity, average velocity and RMS velocity. Usually velocity analysis is performed on unstacked reflection data to assign the correct stacking velocity for migration. Stacking velocity can be determined in various methods such as applying NMO corrections, with a number of constant velocities, to the traces of a CDP gather; computing coherent energy for the NMO-corrected traces; and mapping the coherency obtained as a function of travel time and velocity (Sattlegger, 1975). But the existing field seismic data over the Adolphus structure was already stacked. So velocity analysis could not be attempted for our present analysis. On the basis of available geological information from three exploratory wells drilled on Adolphus structure, three different constant velocities were chosen to perform the diffraction stack migration method (Table-4.3).

4.4 Results of Migrated Sections

The diffraction stack algorithm (Appendix-1) was applied to the existing stacked seismic data on the Adolphus structure after testing the method on synthetic data. The implementation procedure has been discussed in section 3.2.2. The results of the migrated sections are discussed here. Figure 4.4.1 represents a 24-fold conventional stack seismic section (unmigrated) on Adolphus structure in the Grand Banks of Newfoundland. A sampling interval of 4 ms and trace spacing of 25m were used to plot the stacked seismic section. The horizontal scale was taken to be about

64 traces to a mile whereas the vertical scale was 50 samples per inch. A 3 sec record equivalent to 750 samples was used for diffraction stack migration. Three different constant velocities 2500 m/s, 3500 m/s and 4500 m/s were used to migrate the whole stacked section. These velocities were chosen on trial and error method on examining the coherency energy at the apex of diffraction hyperbola. A total of 504 traces were migrated covering about 12.6 km length along the profile. A trace interval of 25m was used for all three migrated sections.

Figures 4.4.1 to 4.4.4 represent the unmigrated and migrated time sections with migration velocities 2500 m/s, 3500 m/s and 4500 m/s respectively. These migrated sections were plotted with the amplitude scale multiplied by a factor of two relative to that for the unmigrated section. Figures 4.4.2 to 4.4.4. are the migrated-time sections across a medium-piercement salt dome (see Table-4.1). Three major reflectors D, E and F have been identified very clearly in the migrated sections. These three reflectors D, E and F are correlated with local geology (section 4.1) of the Adolphus structure as top of Cretaceous, limestone and unconformity beds respectively. These beds were penetrated by three exploratory wells drilled on the Adolphus structure confirming the above seismic markers. The top of Cretaceous marked as 'D' is clearly identified in all the three migrated sections. The second reflector 'E' is identified clearly on both sides of the salt structure except on the top of salt dome. The reflections are terminated at the salt top indicating the presence of a major unconformity. Pre-unconformity reflections above box A are better identified in the migrated sections than the unmigrated section. There is

clear gap between reflectors E and F showing the upliftment of sedimentary strata. This upliftment sedimentary strata were confirmed from the results of exploratory drilling on Adolphus 2K-41 and Adolphus D-50 wells (Table-4.1).

In all the migrated sections, the general structure was better clarified than in the original stacked section (Fig. 4.4.1). Weak diffractions are almost unnoticable in the migrated section due to the focussing effect. Majority of the strong diffractions (along the salt dome flank) are migrated to their true positions. In regions indicated by box A, B and C on both sections, we notice that considerable energy has been moved to their true spatial positions in reducing the breadth of the anticline.

The amplitude was not preserved properly. A reduction of amplitude by a factor 2 was observed in all three migrated time sections and pulse shapes were changed. During the migration process, high frequency content of the reflection pulse was lost and probably phase lag was introduced. The reflection character of flat event is nearly identical with that of unmigrated data indicating the medium to be nearly homogeneous. The highest frequency of the reflected pulse in the migrated sections were in the range of 20 to 30HZ. The scattered reflections within the salt are partly removed in the migrated sections. The salt dome flank was better delineated than the unmigrated section. The dimension of the salt structure was delineated properly.

Finally, migration noise was introduced from dipping events. Multiple-branched reflections at the flank of the anticline structure could not be removed totally. These reflections might have generated the noise during the diffraction stack process. On comparing the three migrated sections, it is observed that the section with migration velocity 3500m/s was migrated better than other two migrated sections. The above velocity was found suitable as it gave the maximum energy of coherence at the apex of the diffraction hyperbola curve. In other words, it gave the best migration stack by assigning the maximum energy at the apex of the diffraction curve.

CHAPTER 5

5.0 CONCLUSIONS

This thesis has presented the results of an investigation of the diffraction stack migration scheme applied to both stacked synthetic and field seismic data.

In order to implement the migration technique, computer programmes were developed. This migration scheme was applied to the zero offset synthetic data generated for two simple models. Zero offset (equivalent to stacked data) single fold synthetic seismograms were constructed for various reflector dips considering two models - an inclined reflector and an anticline. The effect of dip angle and migration velocity were examined for the first model in carrying out the diffraction stack migration process. Later the diffraction stack migration algorithm was applied to the anticline model. Only the effect of dip angle was considered in the above model while implementing the migration scheme.

After testing the diffraction stack migration technique on synthetic data, the same algorithm was applied to the field seismic data collected over Adolphus anticline structure located in the Grand Banks of Newfoundland. These field seismic data were provided to us from Mobil Oil Canada Limited, Calgary in form of a consul staked tape.

On the basis of synthetic and field data interpretation, the following conclusions were drawn:

- 1) The diffraction stack migration algorithm has clarified the general structure of the subsurface even though the velocity field was not known accurately.
- 2) The diffraction patterns were properly collapsed in the synthetic migrated sections as the velocity function was correctly assigned. The strong diffractions were not collapsed completely in the field seismic migrated section as the velocity function was not well known. Part of the record section was undermigrated as the velocity used is too low whereas part of the record section were overmigrated as a result of high velocity.
- 3) In general, amplitude reduction was observed in all migrated time sections both in synthetic and field data. The amplitude reduction was more prominent in the field migrated sections. The reflection character was maintained nearly identical for the flat event of the unmigrated field section indicating the medium to be nearly homogeneous.
- 4) Pulse shapes were broadened in all the migrated sections due to the loss of high frequency content in the reflected pulse.

- 5) Phase lag was observed in the synthetic migrated sections for an inclined reflector model. The results show that phase shift is independent of offset distance. As the dip increases the amount of phase change will increase. From the general character of the field migrated sections, phase lag was probably introduced during migration process.
- 6) Noise was observed in synthetic migrated sections for both geological models in the case of steep dip angles. This noise was introduced during the migration process due to the presence of dipping events. Appreciable noise was observed in the field migrated sections due to the presence of multiply-branched reflections at the flank of anticline structure. Noise is also introduced in the field migrated sections due to overmigration phenomena of the part of the record section. These noise were produced in form of a 'smiles' pattern as the limbs of hyperbolas migrate through the point reflector into smiles.
- 7) In general, the geological markers D, E and F are better clarified in the migrated sections than in the unmigrated section for the field seismic data. The salt flank was delineated better than in the original stacked section. The dimension of the salt structure was delineated better than the unmigrated section in reducing the breadth of the anticline. The above features are also observed in the synthetic anticline model.

- 8) From observations of migrated sections on two models, it is confirmed that the diffraction stack method works efficiently for steep dip reflectors up to dip angle 40 degrees.

5.1 Limitations and Suggestions for Further Work

These are the following limitations of the present investigation:

- 1) The diffraction stack migration method is an expensive method. The computational cost increases with sampling rate as it does summation along generated diffraction hyperbola for each sampling interval.
- 2) It does not preserve amplitude and frequency of the pulse properly during the migration process.
- 3) It cannot handle lateral velocity variations without a ray tracing programme.
- 4) It produces 'break-up' noise and smiles pattern during the migration process due to overmigration phenomena.

To overcome the above problems, it is suggested that the wave equation (finite-difference) migration technique should be applied to both synthetic and field data. The Frequency-wavenumber method based on the

FFT algorithm should be applied to this data to reduce the computational cost during the migration process. Corrections for amplitude and frequency can be incorporated during the diffraction stack process by applying Newman filter and Hubral correction.

Appendix 1: Computer Programmes

```
C          -----
C          TAPERREAD
C          -----
C          PROGRAM TO TRANSLATE MOBIL'S DATA FROM
C          THE DEMULTIPLEXED SEG Y FORMAT
C          THIS PROGRAM READS REEL IDENTIFICATION HEADER
C          AND TRACE DATA BLOCK
C          THIS DATA IS FROM GRAND BANKS SEISMIC LINE-G583B
C          PROGRAM TO READ TAPE EBC ASC CONVERSION
C          CHARACTER*3200CARD,EBCARD,LINE*80
C          INTEGER*2 HEAD2
C          INTEGER*4 HEAD1
C          INTEGER*4TH1,TH3,TH5
C          INTEGER*2TH2,TH4,TH6
C          INTEGER*2 ITRAC(1500)
C          DIMENSION TRACE(1500)
C
C          COMMON/ONE/ HEAD1(3),HEAD2(194)
C          COMMON TH1(7),TH2(4),TH3(8),TH4(2),TH5(4),TH6(76)
C          BYTE I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11
C
C          OPEN(UNIT=10,FILE='[GEOPH]MOBIL.DAT;1',STATUS='OLD')
C          READ(10,10) EBCARD
10          FORMAT(A)
C          CALL LIB$TRA EBC ASC(EBCARD,CARD)
C          DO 20 I=1,3200,80
C          LINE=CARD(I:I+79)
C          WRITE(6,10) LINE
20          CONTINUE
C          PROGRAM TO READ REEL IDENTIFICATION HEADER-PART2
C          READ(10,15) ((HEAD1(I),I=1,3),(HEAD2(K),K=1,194))
15          FORMAT(3A4,194A2)
C          CALL SW1
C          CALL SW2
C          CALL WRT
999          CONTINUE
C          THIS IS A PROGRAM TO READ TRACEHEAD AND DATA SAMPLE
C          DO 19K=1,50
C          DO 19J=1,24
C          READ (10,16) TH1,TH2,TH3,TH4,TH5,TH6,ITRAC
16          FORMAT(7A4,4A2,8A4,2A2,4A4,76A2,1500(A2,2X))
C          CALL SW3
C          CALL SW4
C          CALL SW5
C          CALL SW6
C          CALL SW7
C          CALL SW8
C          CALL WRT2
C          DO 18 I=1,1500
C          CALL IBMVAX(ITRAC(I),TRACE(I))
C          IF(TRACE(I).LE.-300.0) TRACE(I)=-300.0
18          IF(TRACE(I).GE.300.0) TRACE(I)=300.0
C          IF(K.GT.29) WRITE(4,80) (TRACE(I),I=1,750)
80          FORMAT(10F8.3)
19          CONTINUE
```

```
STOP
END
SUBROUTINE SW1
COMMON/ONE/ H1(12),H2(388)
BYTE H2,H1,I1,I2,I3,I4
DO 30 I=4,12,4
I1=H1(I)
I2=H1(I-1)
I3=H1(I-2)
I4=H1(I-3)
H1(I)=I4
H1(I-1)=I3
H1(I-2)=I2
H1(I-3)=I1
30 CONTINUE
RETURN
END
SUBROUTINE SW2
COMMON/ONE/ H(3),H1(388)
BYTE H2,H1
DO 30 I=2,388,2
H2=H1(I)
H1(I)=H1(I-1)
H1(I-1)=H2
30 CONTINUE
RETURN
END
SUBROUTINE WRT
COMMON/ONE/ HEAD1(3),HEAD2(194)
INTEGER HEAD1
INTEGER*2 HEAD2
WRITE(6,14) (HEAD1(I),I=1,3)
14 FORMAT(1X,3I10)
WRITE(6,15) HEAD2
15 FORMAT(1X,8I10)
RETURN
END
SUBROUTINE SW3
COMMON T1(28),T2(8),T3(32),T4(4),T5(16),T6(152)
BYTE T6,T5,T4,T3,T2,T1,I1,I2,I3,I4
DO 40 I=4,28,4
I1=T1(I)
I2=T1(I-1)
I3=T1(I-2)
I4=T1(I-3)
T1(I)=I4
T1(I-1)=I3
T1(I-2)=I2
T1(I-3)=I1
40 CONTINUE
RETURN
END
SUBROUTINE SW4
COMMON T(7),T1(8),T2(32),T3(4),T4(16),T5(152)
BYTE T5,T4,T3,T2,T1,I2,I1
DO 40 I=2,8,2
I2=T1(I)
T1(I)=T1(I-1)
```

```
40      T1(I-1)=I2
        CONTINUE
        RETURN
        END
        SUBROUTINE SW5
        COMMON A(7),B(2),T1(32),T2(4),T3(16),T4(152)
        BYTE T4,T3,T2,T1,I1,I2,I3,I4
        DO 40 I=4,32,4
        I1=T1(I)
        I2=T1(I-1)
        I3=T1(I-2)
        I4=T1(I-3)
        T1(I)=I4
        T1(I-1)=I3
        T1(I-2)=I2
        T1(I-3)=I1
40      CONTINUE
        RETURN
        END
        SUBROUTINE SW6
        COMMON C(7),D(2),E(8),T1(4),T2(16),T3(152)
        BYTE T3,T2,T1,H2,H1
        DO 40 I=2,4,2
        H2=T1(I)
        T1(I)=T1(I-1)
        T1(I-1)=H2
40      CONTINUE
        RETURN
        END
        SUBROUTINE SW7
        COMMON F(7),G(2),H(8),R(1),T1(16),T2(152)
        BYTE T2,T1,I1,I2,I3,I4
        DO 40 I=4,16,4
        I1=T1(I)
        I2=T1(I-1)
        I3=T1(I-2)
        I4=T1(I-3)
        T1(I)=I4
        T1(I-1)=I3
        T1(I-2)=I2
        T1(I-3)=I1
40      CONTINUE
        RETURN
        END
        SUBROUTINE SW8
        COMMON S(28),U(2),V(8),W(1),X(16),T1(152)
        BYTE G2,G1,T1,S,X
        DO 40 I=2,152,2
        G2=T1(I)
        T1(I)=T1(I-1)
        T1(I-1)=G2
40      CONTINUE
        RETURN
        END
        SUBROUTINE WRT2
        COMMON TH1(7),TH2(4),TH3(8),TH4(2),TH5(4),TH6(76)
        INTEGER*4 TH1,TH3,TH5
        INTEGER*2 TH2,TH4,TH6
```



```
14      WRITE(6,14) TH1,TH2,TH3,TH4,TH5,TH6
        FORMAT(1X,10I10)
        RETURN
        END
C      THIS SUBROUTINE WAS PROVIDED BY DR. J.A.WRIGHT
C      DEPT.OF EARTH SCIENCES,MUN,ST.JOHN'S
C      SUBROUTINE IBMVAX(IIVAL,VAL)
C      INPUT IIVAL AN INTEGER*2 VARIABLE IN IBM FORMAT
C      OUTPUT VAL A REAL*4 VARIABLE IN VAX FORMAT
C      INTEGER*2 IIVAL
C      TEST FOR 0.0
C      IF (IIVAL.NE.0) GO TO 1
C      VAL=0.
C      RETURN
C      PERFORM BYTE SWAP
1      IVAL=IIVAL
C      IF (IVAL.LT.0) IVAL=IVAL+65536
C      LSB=(IVAL/256)
C      MSB=(IVAL-(LSB*256))*256
C      IVAL=MSB+LSB
C      DETERMINE POLARITY POL=+/-1.
C      POL=+1.
C      IF (IVAL.GE.32768) POL=-1.
C      DETERMINE CHARACTERISTIC ICHAR
C      IF (IVAL.GE.32768) IVAL=IVAL-32768
C      ICHAR=(IVAL/256)-64
C      CALCULATE FRACTION
C      FRACT=(LSB/256.)
C      FORM NUMBER POL*FRACT*(16**ICAR)
C      CALL LIB$FLT UNDER(0)
C      VAL=POL*FRACT*(16.**ICAR)
C      RETURN
C      END
```

CCCCCCCC

SYNSEISGRAM

```

C      THIS IS A PROGRAM TO GENERATE SYNTHETIC SEISMOGRAM
C      FOR AN INCLINED REFLECTOR
C      DIP OF THE REFLECTOR=60 DEGREES
C      SYNTHETIC SEISMOGRAM FOR 19 TRACES
C      DELTA=SAMPLING INTERVAL
C      VARIABLE PP IS THE INPUT
C      REFLECTIVITY RR=.13
      DIMENSION RR(1721),X(40),Y(40),ZZ(80),T1(40),PP(19)
      PARAMETER DIM=1800
      DIMENSION A(DIM),B(DIM),C(DIM),PROD(DIM)
      DATA (PP(I),I=1,19)/100,143,187,230,273,317,360,403,446
3      ,490,533,576,620,663,706,750,793,836,879/
      DELTA=.001
      N=PP(1)
      DO 15 K=1,19
      DO 16 I=1,N
16      RR(I)=0
      RR(N+1)=.13
      OPEN(UNIT=4,FILE='A.DAT',STATUS='OLD')
      OPEN(UNIT=2,FILE='A.STO',STATUS='NEW')
      OPEN(UNIT=51,FILE='RIC25.DAT',STATUS='OLD')
      OPEN(UNIT=3,FILE='RIC25.STO',STATUS='NEW')
      OPEN(UNIT=9,FILE='SY257.OUT',STATUS='NEW')
      WRITE(2,71) (RR(I),I=1,1721)
15      IF(K.LT.19)N=PP(K+1)
      CLOSE(UNIT=2,STATUS='SAVE')
71      FORMAT(10F8.3)
C      PROGRAM TO GENERATE RICKER WAVELET(25HZ)
      W=2*3.1416*25
      DO 18 I=1,40
      T1(I)=I*DELTA
      X(I)=SIN(W*T1(I))
18      Y(I)=X(I)/(W*T1(I))
      DO 19 I=1,80
      IF (I.LE.40)THEN
      J=41-I
      ZZ(I)=Y(J)
      ELSE
      K=I-41+1
      ZZ(I)=Y(K)
      END IF
19      CONTINUE
      WRITE(3,71) ZZ
      CLOSE(UNIT=3,STATUS='SAVE')
C      THIS IS A PROGRAM TO DO CONVOLUTION
      N=1721
      M=80
      J=N+M-1
      READ(51,71) (B(L),L=1,M)
      KK=1
2      READ(4,71) (A(L),L=1,N)
      DO 6 JJ=(N+1),J
6      A(JJ)=0
      DO 8 JJ=(M+1),J
8      B(JJ)=0

```

```
DO 29 JJ=1,J
29 C(JJ)=0
DO 39 L=1,J
DO 39 K=1,M
IF((L-K+1).LE.0) GO TO 39
PROD(L)=B(K)*A(L-K+1)
C(L)=C(L)+PROD(L)
39 CONTINUE
WRITE(9,71) (C(L),L=1,J)
KK=KK+1
IF(KK.LT.20) GO TO 2
CLOSE(UNIT=9,STATUS='SAVE')
STOP
END
```

DPRST

```

C      PROGRAM TO DO DIFFRACTION STACK MIGRATION USING SYNTHETIC DATA
C      ZERO OFFSET SYNTHETIC DATA WAS GENERATED
C      FOR AN INCLINED REFLECTOR
C      DIP OF REFLECTOR=10 DEGREES
C      APERTURE SIZE=FIVE INPUT TRACES
C      INPUT AND OUTPUT SAMPLING INTERVAL=1MS
C      MIGRATION VELOCITY=2000 M/S
C      TRACE INTERVAL=25M
C      THIS PROGRAM WILL GENERATE MIGRATED OUTPUT FOR 19 TRACES
C      DIMENSION DSAM(1800,29),TSAM(1800),X(29),A1(1800)
C      DIMENSION TAM(1800),P(29)
C      THIS A PROGRAM TO GENERATE TIME INTERVAL
C      SI=.001
13      DO 13 I=1,1800
C      TAM(I)=SI*FLOAT(I)
C      OPEN(UNIT=8,FILE='TS.DAT',STATUS='NEW')
C      WRITE(8,7) TAM
C      CLOSE(UNIT=8,STATUS='SAVE')
C      FORMAT(10F8.3)
C
C      THIS IS A PROGRAM TO GENERATE OFFSET DISTANCES
C      DELTAX=25.0
C      DO 14 I=1,29
14      P(I)=DELTAX*(I-1)
C      OPEN(UNIT=9,FILE='OFFSET.DAT',STATUS='NEW')
C      WRITE(9,11) P
C      CLOSE(UNIT=9,STATUS='SAVE')
11      FORMAT(10F8.0)
C
C      THIS PROGRAM DOES DIFFRACTION STACK MIGRATION
C      SY252.DAT IS THE ZERO OFFSET SYNTHETIC DATA
C      OPEN(UNIT=3,FILE='SY252.DAT',STATUS='OLD')
C      OPEN(UNIT=4,FILE='TS.DAT',STATUS='OLD')
C      OPEN(UNIT=5,FILE='OFFSET.DAT',STATUS='OLD')
C      READ(3,51) ((DSAM(I,J),I=1,1800),J=1,29)
51      READ(4,52) (TSAM(I2),I2=1,1800)
52      FORMAT(10F8.3)
C      SIT=.001
C      V=2000.00
C      XZERO=125
C      READ(5,53) (X(I),I=1,29)
53      FORMAT(10F8.0)
C      J=1
55      DO 10 IX=1,1800
C      TST=SIT*FLOAT(IX)
C      DO 20 IY=J,J+10
C      TX=SQRT(((TST)**2)+((2*(X(IY)-XZERO)/V)**2))
C      DO 30 IZ=1,1800
C      TT=TX
C      TZ=ABS(TT-TSAM(IZ))
C      IF(TZ.LT..0005) GO TO 36
C      GO TO 30
36      A1(IY)=DSAM(IZ,IY)

```

```
30      CONTINUE
20      CONTINUE
        AB=0.0
        DO 40 I=J,J+10
        AB=AB+A1(I)
        AB=AB/11.0
40      CONTINUE
        DSAM(IX,J+5)=AB
45      FORMAT(10F8.3)
10      CONTINUE
        XZERO=XZERO+25
        J=J+1
        IF(J.LT.25) GO TO 55
        OPEN(UNIT=20,FILE='MIGRT.DAT',STATUS='NEW')
        WRITE(20,45) ((DSAM(I,J),I=1,1800),J=6,24)
        CLOSE(UNIT=20,STATUS='SAVE')
        STOP
        END
```

```

C                                     TRATIME
C                                     -----
C
C THIS IS A PROGRAM TO GENERATE TRAVEL TIME
C FOR AN INCLINED REFLECTOR
C IT CALCULATES TRAVEL TIME FOR REFLECTOR
C WITH DIP=0 TO 85 DEGREES
C TOTAL NO. OF OFFSET DISTANCES=21
C REAL T,DELTA X,THETA,D,VINT
C
C DIMENSION T(21,18),DELTA X(21),THETA(18),D(21,18),VINT(21,18)
C V STANDS FOR VELOCITY OF THE MEDIUM
C Z STANDS FOR DEPTH AT ZERO OFFSET DISTANCE
C V=2000.0
C Z=100.0
C DATA DELTA X/0.0,25.0,50.0,75.0,100.0,125.0,150.0,175.0
3 ,200.0,225.0,250.0,275.0,300.0,325.0,350.0,375.0,400.0
C 2 ,425.0,450.0,475.0,500.0/
C
C DATA THETA/0.0,5.0,10.0,15.0,20.0,25.0,30.0,35.0,40.0,45.0,50.0
4 ,55.0,60.0,65.0,70.0,75.0,80.0,85.0/
C DO 15 J=1,18
C DO 15 I=1,81
C T(I,J)=(2*(Z+DELTA X(I)*TAND(THETA(J))))/V
C D(I,J)=(T(I,J)*2000.00)/2.0
15 VINT(I,J)=2*D(I,J)/T(I,J)
C WRITE(6,213)
213 FORMAT(' INTERVAL VELO. OF DIFF. DEPTHS FOR A SINGLE INCLREFL')
C WRITE(6,210) VINT
C WRITE(6,212)
212 FORMAT(' DEPTH VALUES OF DIFFERENT TWO-WAY REFLECTIONTIME')
C WRITE(7,210) D
C WRITE(11,211)
211 FORMAT(' TWO-WAY REFLECTIONTIME IN SEC')
C WRITE(11,214) T
210 FORMAT(10F8.3)
214 FORMAT(10F8.3)
C STOP
C END

```

C
C
C
C
C
C
C

ANTRATIME

THIS IS A PROGRAM TO GENERATE TRAVEL TIME FOR AN ANTICLINE
DIP OF THE ANTICLINE=10 DEGREES
TOTAL NO. OF OFFSET DISTANCES=21

REAL T,DELX,THETA

C
C
C

DIMENSION DELX(21),THETA(21)

V STANDS FOR VELOCITY OF THE MEDIUM

Z STANDS FOR DEPTH AT ZERO OFFSET DISTANCE

V=2000.0

Z=1000.0

3 DATA THETA/0.,0.,0.,0.,0.,0.,10.,10.,10.,10.
-10.,-10.,-10.,-10.,0.,0.,0.,0.,0.,0./
2 DATA DELX/0.,25.,25.,25.,25.,25.,25.,25.,25.
25.,25.,25.,25.,25.,25.,25.,25.,25.
4 25.,25.,25.,25./

14

I=1
T=(2*(Z-DELX(I)*TAND(THETA(I))))/V
Z=Z-DELX(I)*TAND(THETA(I))
OPEN(UNIT=7,FILE'ANTRAT.DAT',STATUS='NEW')
WRITE(7,211) T
I=I+1
IF(I.LT.22) GO TO 14
CLOSE(UNIT=7,STATUS='SAVE')
211 FORMAT(10F8.3)
STOP
END

```
C          -----
C          FLDPLOT
C          -----
C          THIS IS A PROGRAM TO PLOT 504 MIGRATED SEISMIC TRACES
C          SEISMIC LINE-G583B IS LOCATED IN GRAND BANKS,NFLD.
          REAL DSAM(750,504),TRACE(752),TIME(752)
          OPEN(UNIT=10,FILE='FOR012.DAT',STATUS='OLD')
          READ(10,15) ((DSAM(I,J),I=1,750),J=1,504)
15          FORMAT(10F8.3)
C          THE AMPLITUDE IS ENHANCED BY A FACTOR OF 2.0
C          DF=DIVIDING FACTOR
C          DF=0.16666667
          TRACE(751)=-300.0
          TRACE(752)=3600.0
          TIME(751)=0.0
          TIME(752)=.2
          TIME(1)=3.0
          DO 20 I=2,750
          TIME(I)=TIME(I-1)-.004
20          TRACE(I)=DSAM(I,1)
          CALL PLOTS(53,0,-1)
C          CALL FACTOR(1.0)
          CALL SCALE(TIME,15.0,750,1)
          CALL PLOT(2.,2.,-3)
          CALL AXIS(0.0,0.0,9HTIME(SEC),9,15.,90.,3.0001,-0.2)
          CALL PLOT(0.25,0.,-3)
          CALL SYMBOL(1.0,16.,.2,30HGRAND BANKS SEISMIC LINE-G583B,0.,30)
          CALL SYMBOL(1.0,15.5,.1,27HMIGRATION VELOCITY=3500 M/S,0.,27)
          CALL SYMBOL(0.,-1.,.1,39HFIG.      SEISMIC SECTION AFTER MIGRATION
4          ,0.,39)
          DO 100 I1=1,504
          CALL LINE(TRACE,TIME,750,1,0,2)
          CALL PLOT(.04,0.,-3)
          IF(I1.EQ.504) GO TO 100
          DO 120 I2=1,750
120          TRACE(I2)=DSAM(I2,I1+1)
100          CONTINUE
          CALL PLOT(8.0,-.5,999)
          STOP
          END
```


Appendix 2: Calculation of Reflectivity for two Synthetic Models

Two synthetic models were considered - an inclined reflector and an anticline (Figures A2.1 and A2.2) respectively to calculate the reflectivity at the reflecting interface. Both models consist of a single reflecting surface overlain by a material of constant velocity 2000 m/s with density value 2.2 gm/c.c. The layer below the first reflecting surface has velocity and density values of 3000 m/s and 2.3 gm/c.c respectively. The reflectivity or reflection co-efficient of the single reflecting surface (Waters, 1981, p. 26) can be obtained from the simple relationship.

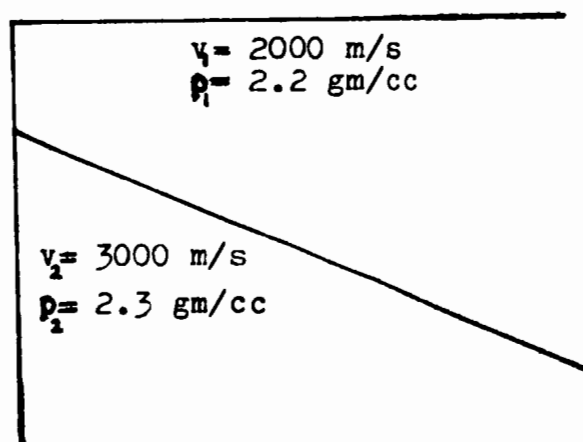


Fig. A2.1 An Inclined Reflector Model

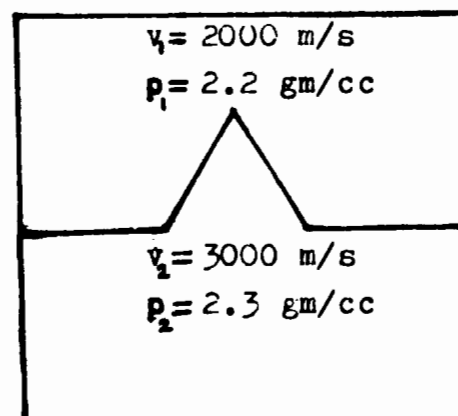


Fig. A2.2 An Anticline Model

$$R_1 = (P_{1+1}V_{11} - P_1V_1)/(P_{1+1} + P_1V_1) \quad \text{A2.1}$$

$$1 = 1$$

where P_1 and V_1 denote the density and velocity. Using the values of P 's and V 's in the equation A2.1, the reflectivity $R_1 = 0.13$ is obtained.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my supervisor, Dr. H.G. Miller, for his constant guidance and valuable suggestions through all stages of this thesis.

I am grateful to Dr. J.A. Wright, Department of Earth Sciences for providing me the computer subroutine to transfer the field data to the VAX computer system. I would like to thank Dr. C.R. Barnes, Head of the Department of Earth Sciences for providing the departmental equipment and facilities. I am also thankful to Mr. Greg Bennett of University Computer Services, Mr. Shivaram Prasad and Mr. Ramakant Reddy, graduate students of the engineering faculty for their help in computer programming.

I acknowledge with thanks Mobil Oil Canada Limited, Calgary for providing the field seismic data over Adolphus structure on the Grand Banks of Newfoundland to carry out this thesis work. Also I would like to give thanks to Mr. Robert Stokes, Petroleum Directorate, Government of Newfoundland and Labrador, St. John's for supplying useful information on Adolphus structure.

The financial support received from the Memorial University of Newfoundland in the form of Graduate Fellowship and Teaching Assistantship, and bursary from Dr. H.G. Miller's NSERC grant are gratefully acknowledged. Finally, I am thankful to Mrs. Gerri Starkes, Department of Earth Sciences for typing this thesis.

REFERENCES

- Al-Sadi, N.H., 1980, Seismic Exploration Technique and Processing, Birkhauser Verlag, Basel.
- Amoco and Imperial Oil, 1973, Regional Geology of the Grand Banks, Bull. Can. Pet. Geol. v. 21, p. 479-503.
- Anstey, N.A., 1977, Seismic Interpretation: The Physical Aspects, IHRDC Publications, Boston.
- Barry, K.M., Cavers, D.A., and Kneale, C.W., 1975, Recommended standards for digital tape formats, Geophysics, v. 40, p. 344-352.
- Bentley, C.R. and Worzel, J.L., 1956, Geophysical investigations in the emerged and submerged Atlantic Coastal Plain, Part X: Continental Slope and Continental Rise south of the Grand Banks, Geol. Soc. America Bull., v. 67, p. 1-18.
- Bower, M.E., 1962, Sea magnetometer surveys of the Grand Banks of Newfoundland, Burgeo Bank, and St. Pierre Bank, Geol. Surv. Canada, Paper 61-30, 11p.
- Claerbout, J.F., 1970, Coarse grid calculations of waves in inhomogeneous media with application to delineation of complicated seismic structure, Geophysics, v. 35, p. 407-418.

Dobrin, M.B., 1976, Introduction to Geophysical Prospecting, 3rd Edition, McGraw-Hill Publishing Co., New York.

Dohr, G., 1981, Applied Geophysics, 2nd Edition, Ferdinand Enke Verlag, Stuttgart.

Ewing, J., and Ewing, M., 1959, Seismic refraction measurements in the Atlantic Ocean Basins, in the Mediterranean Sea, on the Mid-Atlantic Ridge and in the Norwegian Sea, Geol. Soc. America Bull., v. 70, p. 291-318.

French, W.S., 1975, Computer migration of oblique seismic reflection profiles, Geophysics, v. 40, p. 961-980

Hagedoorn, J.G., 1954, A process of seismic reflection interpretation, Geophys. Prosp., v. 2, p. 85-127.

Hood, P., and Godby, E.A., 1965, Magnetic profile across the Grand Banks and Flemish Cap off Newfoundland, Can. J. Earth Sciences, v. 1, p. 85-92.

James, M.L., Smith, G.M., and Welford, J.C., 1977, Applied Numerical Methods for Digital Computation With Fortran and CSMP, 2nd Edition, Harper and Row, Publishers, New York.

Lilly, H.D., 1965, Submarine examination of the Virgin Rocks area, Grand Banks, Newfoundland, Preliminary note, Geol. Soc. America Bull., v. 76, p. 131.

McMillan, N.J., 1982, Canada's east coast: the new super petroleum province, Journal of Canadian Petroleum Technology, v. 21, no. 2, p. 1-15.

Owusu, K., Gardner, G.H.F., and Massell, W.F., 1981, Velocity estimates derived from three-dimensional seismic data, presented at 51st Ann. International Mtg. of SEG, Los Angeles.

Pelletier, B.R., 1971, A granodioritic drill core from Flemish Cap, eastern Canadian continental margin, Can. J. Earth Sciences, v. 8, p. 1499-1503.

Peterson, R.A., Fillippone, W.R., and Coker, F.B., 1955, The synthesis of seismograms from Well Log Data, Geophysics, v. 20, p. 516-538.

Petroleum Directorate Information Kit, 1984, Government of Newfoundland and Labrador, St. John's, Canada.

Press, F., and Beckmann, W., 1954, Geophysical investigations in the emerged and submerged Atlantic Coastal Plain, Part VIII, Grand Banks and adjacent shelves, Geol. Soc. America Bull., v. 65, p. 299-314

Proctor, R.M., Taylor, G.C., and Wade, J.A., 1983, Oil and Natural Gas Resources of Canada, Geological Survey of Canada - Open file 966, Ottawa, Canada.

Rashid, M.A., 1978, The influence of salt dome on the diagenesis of organic matter in the Jeanne d'Arc Subbasin of the northeast Grand Banks of Newfoundland Organic Geochemistry, v. 1, p. 67-77.

Robinson, E.A., and Silvia, M.T., 1977, Digital Foundations of Time Series Analysis: Wave-Equation Space-Time Processing, Holden-Day, Inc., San Francisco.

Robinson, E.A., 1983, Migration of geophysical data, IHRDC Publications, Boston.

Rockwell, D.V., 1971, Migration stack aids interpretation, Oil and Gas J., April 19, p. 202-218.

Sattlegger, J.W., 1975, Migration velocity determination, Part I. Philosophy, Geophysics, v. 40, p. 1-5.

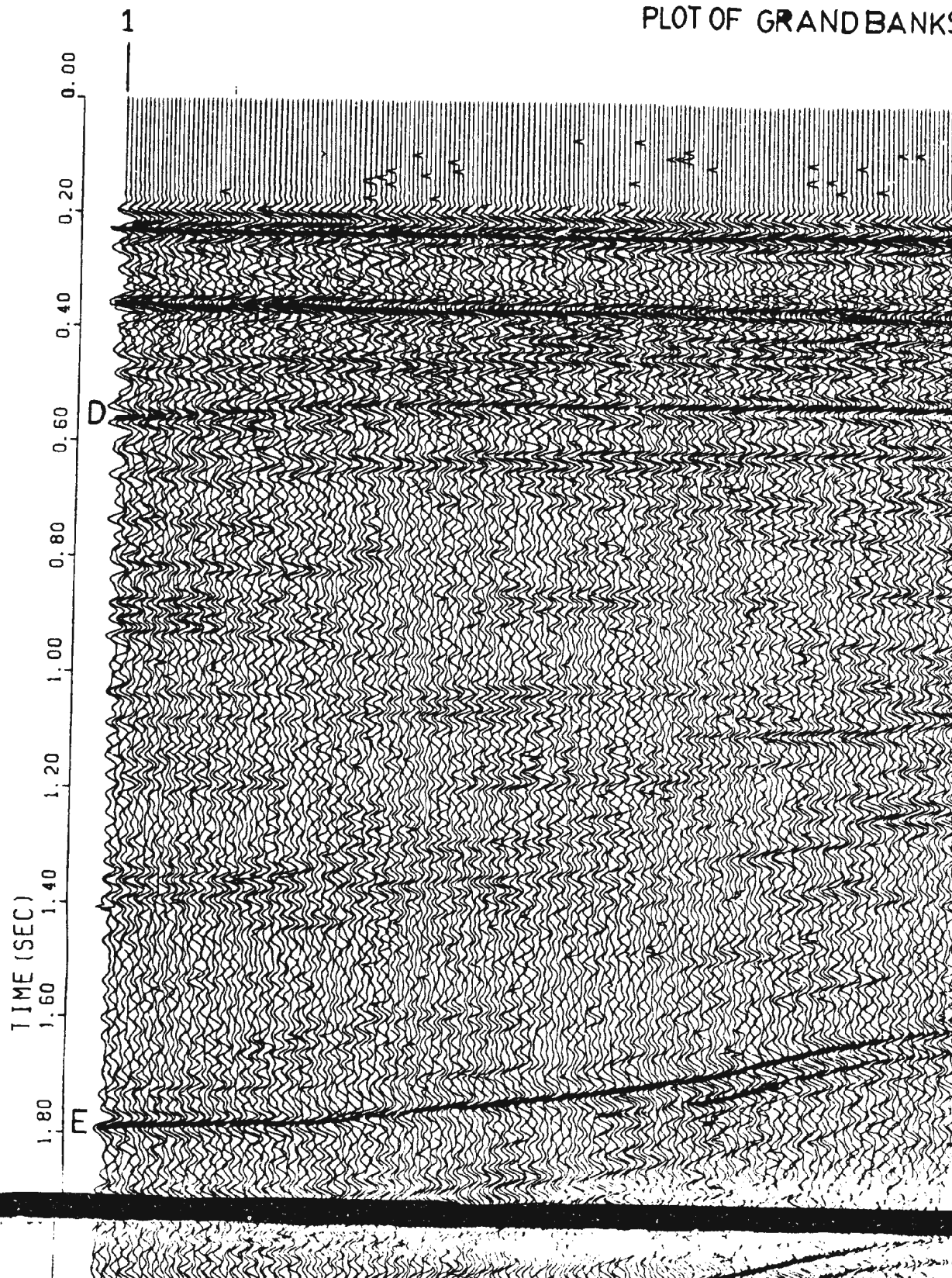
Stolt, R.H., 1978, Migration by Fourier transform, Geophysics, v. 43, p. 23-48.

Waters, K.H., 1981, Reflection Seismology, John-Wiley and Sons, Inc.,
New York.

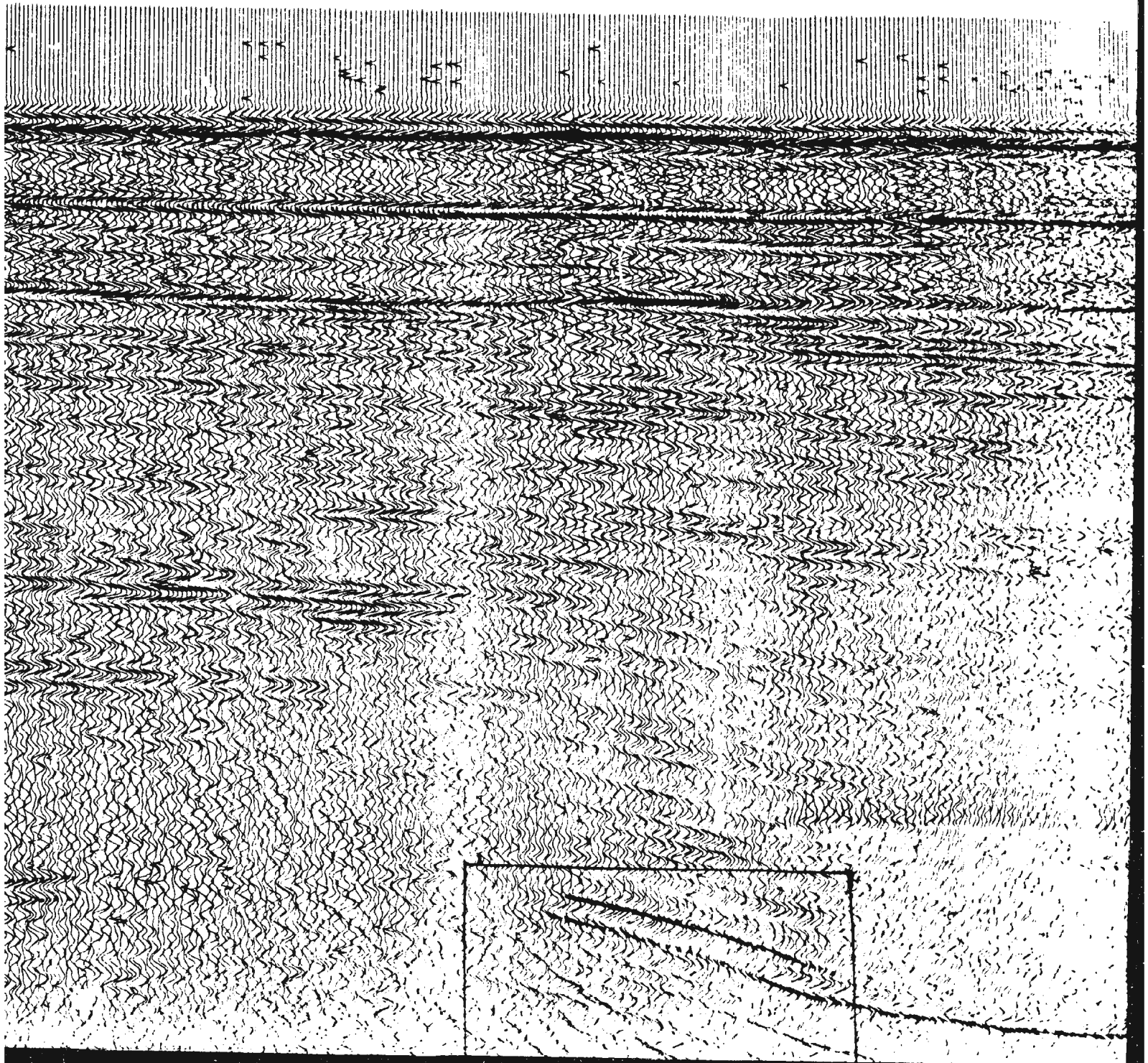
Well History Report, 1975, Mobil Gulf Adolphus D-50, Petroleum
Directorate, Government of Newfoundland and Labrador, St. John's,
Canada.

Well location map, 1984, Petroleum Directorate, Government of Newfoundland
and Labrador, St. John's, Canada.

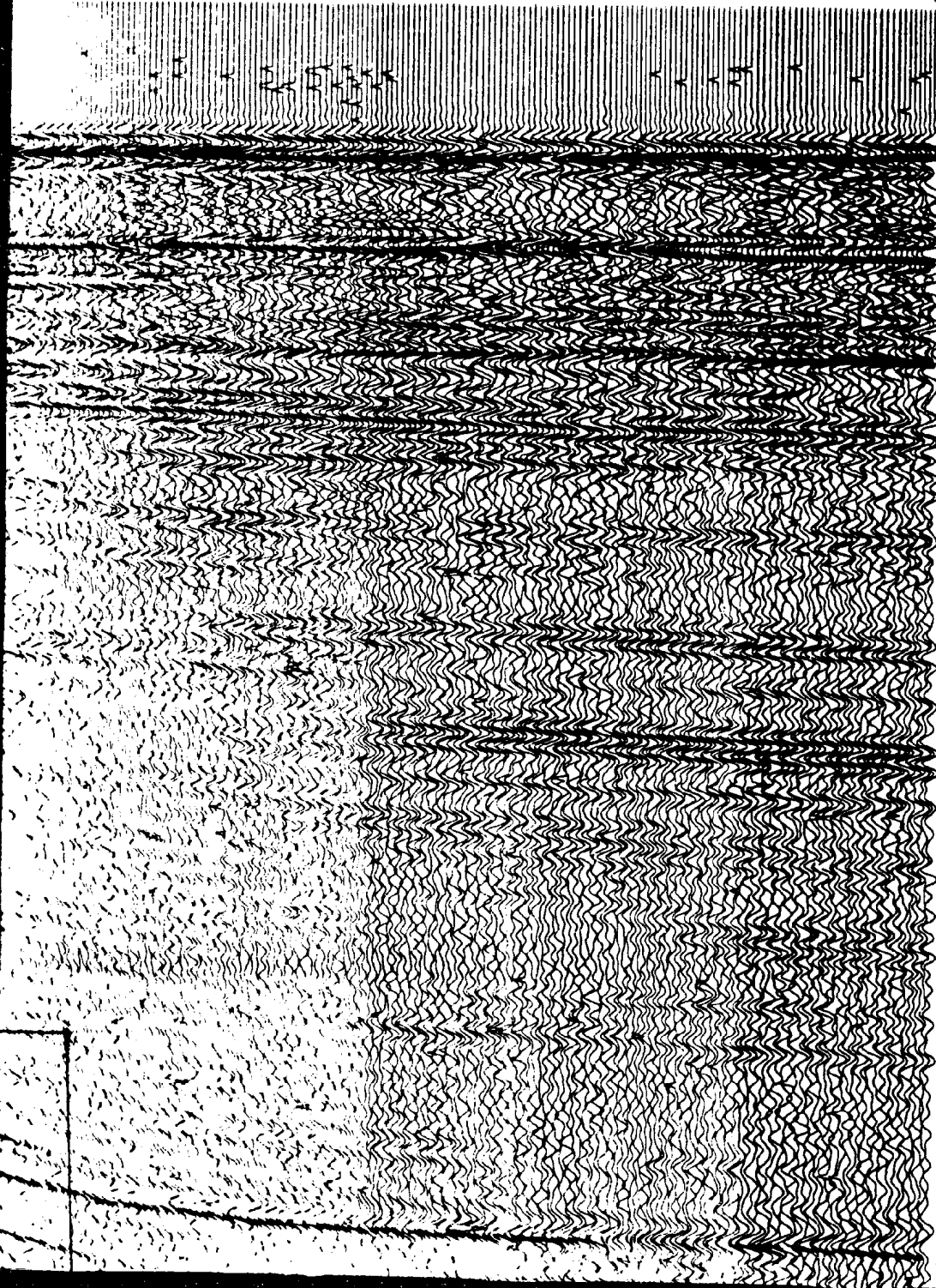
PLOT OF GRAND BANKS



NKS SEISMIC LINE- G583B



504

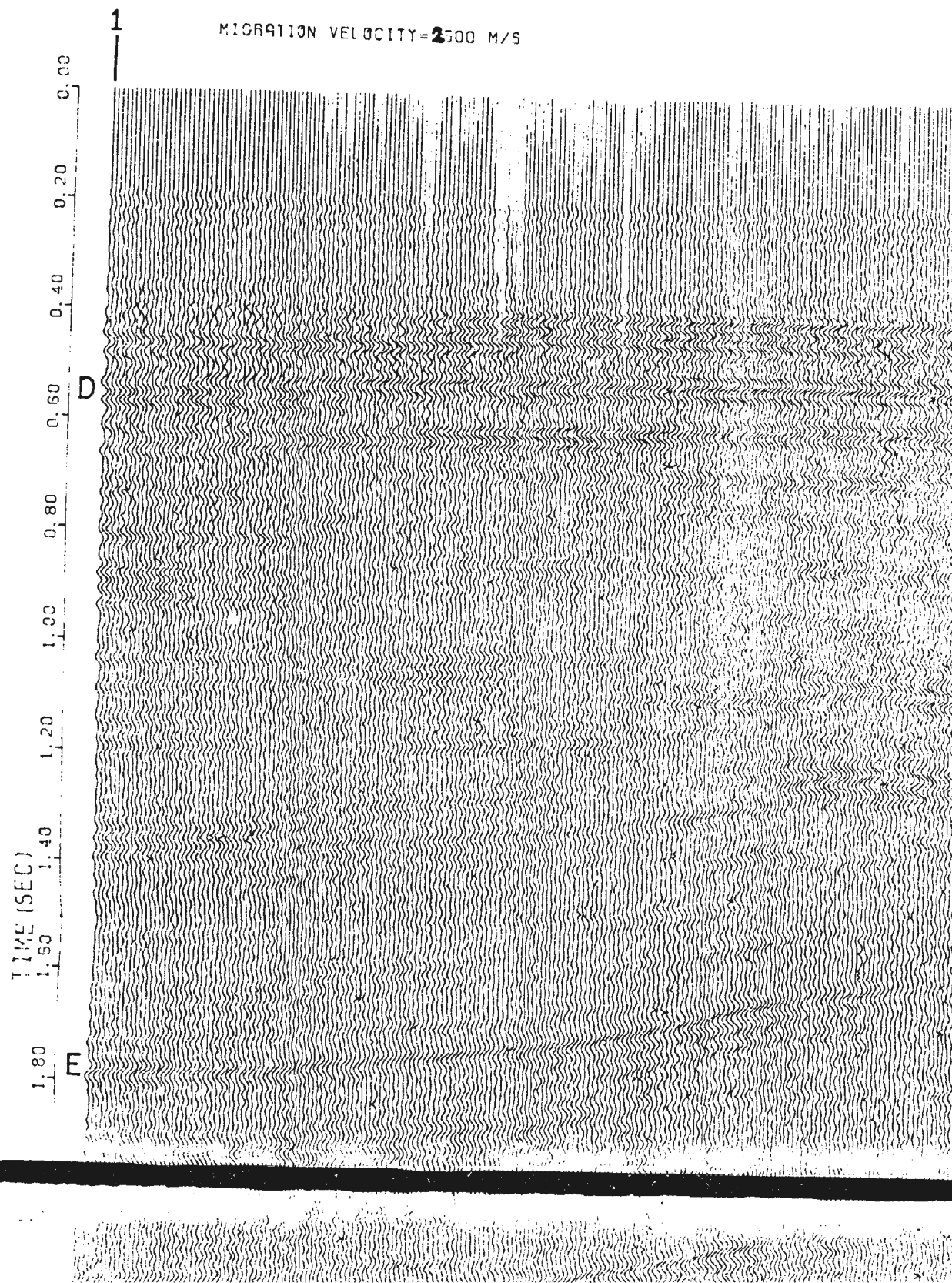


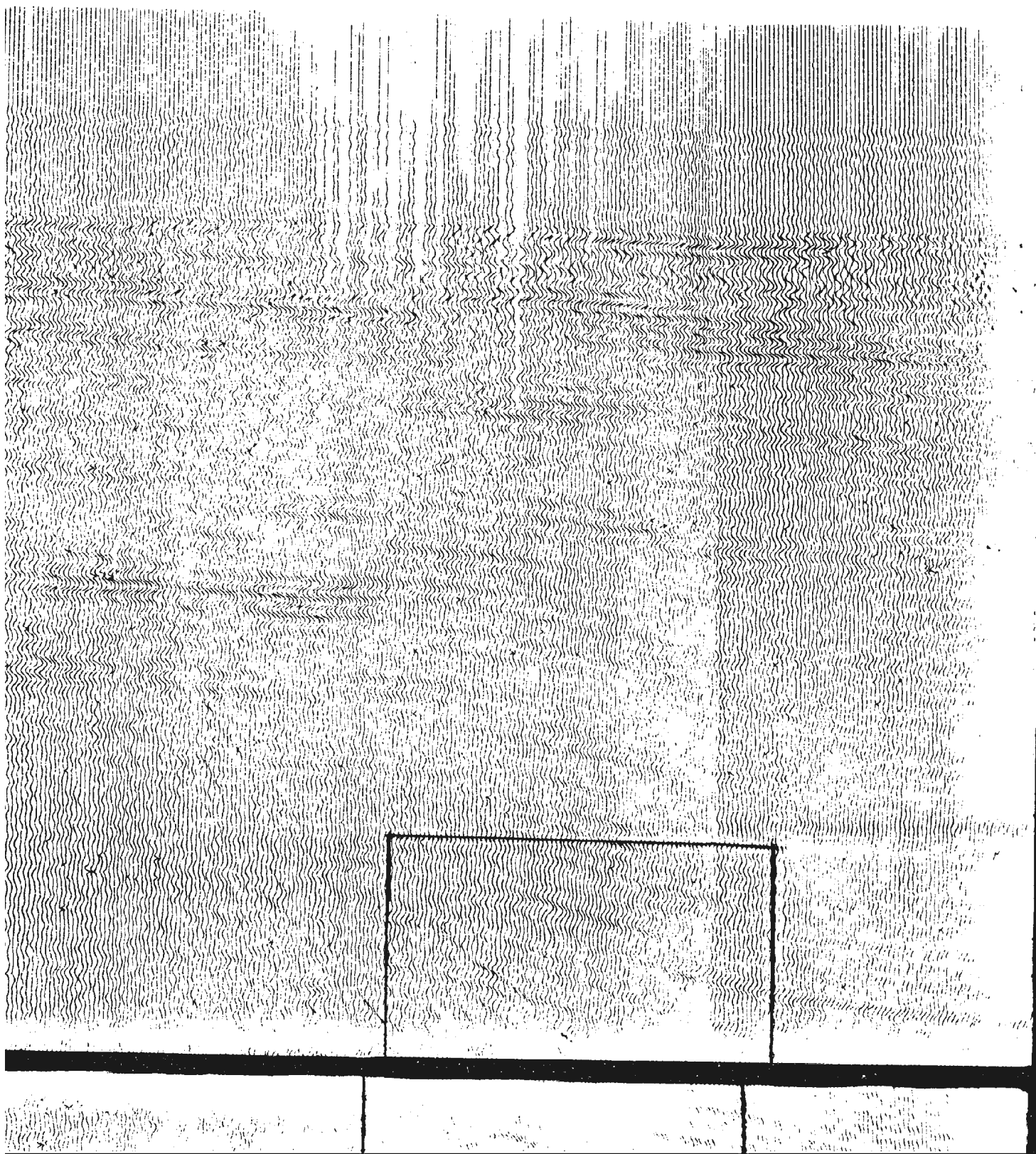
D

E

GRAND BANKS SEISMIC LINE-G583B

MIGRATION VELOCITY=2500 M/S





504

|

D

E

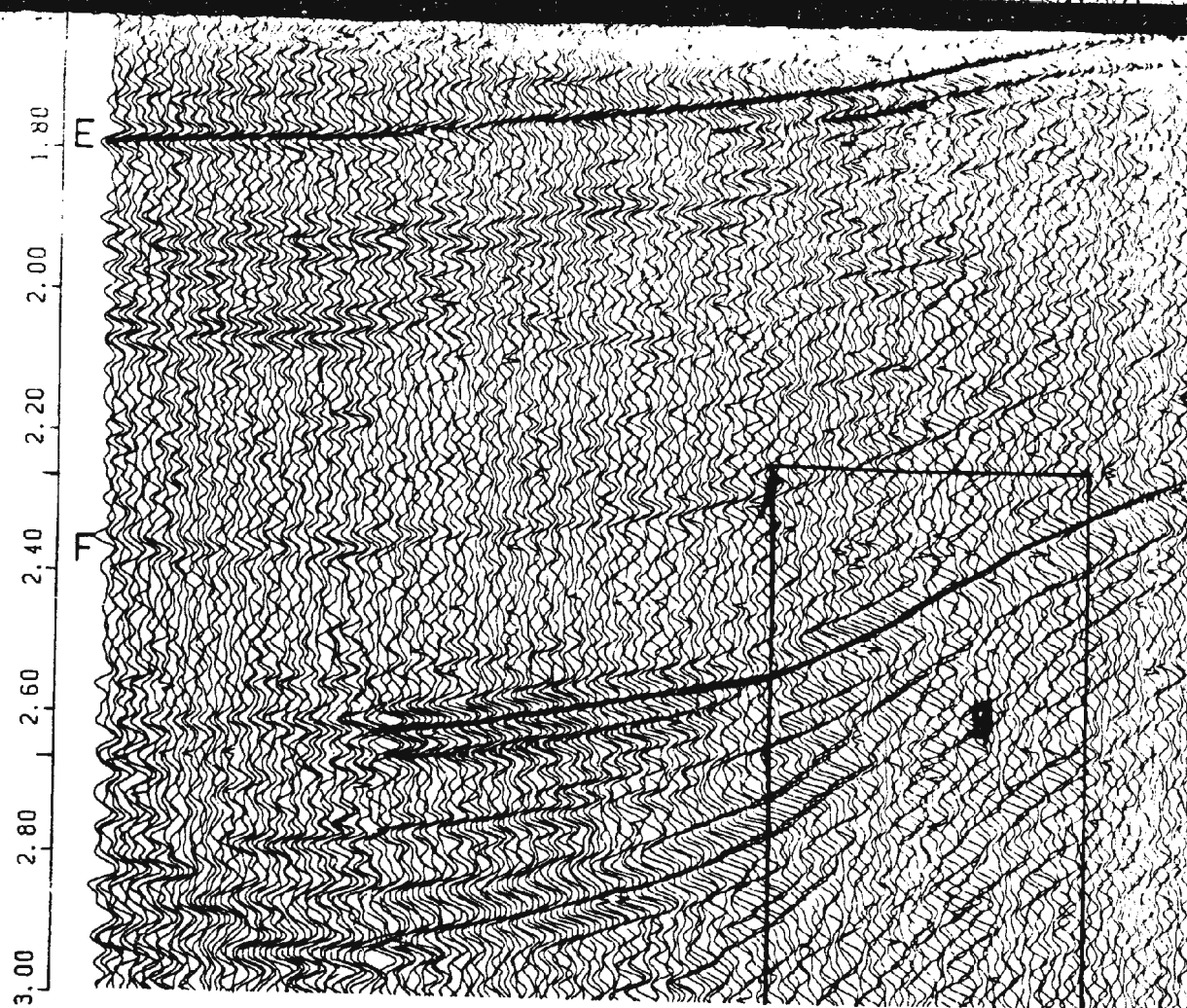
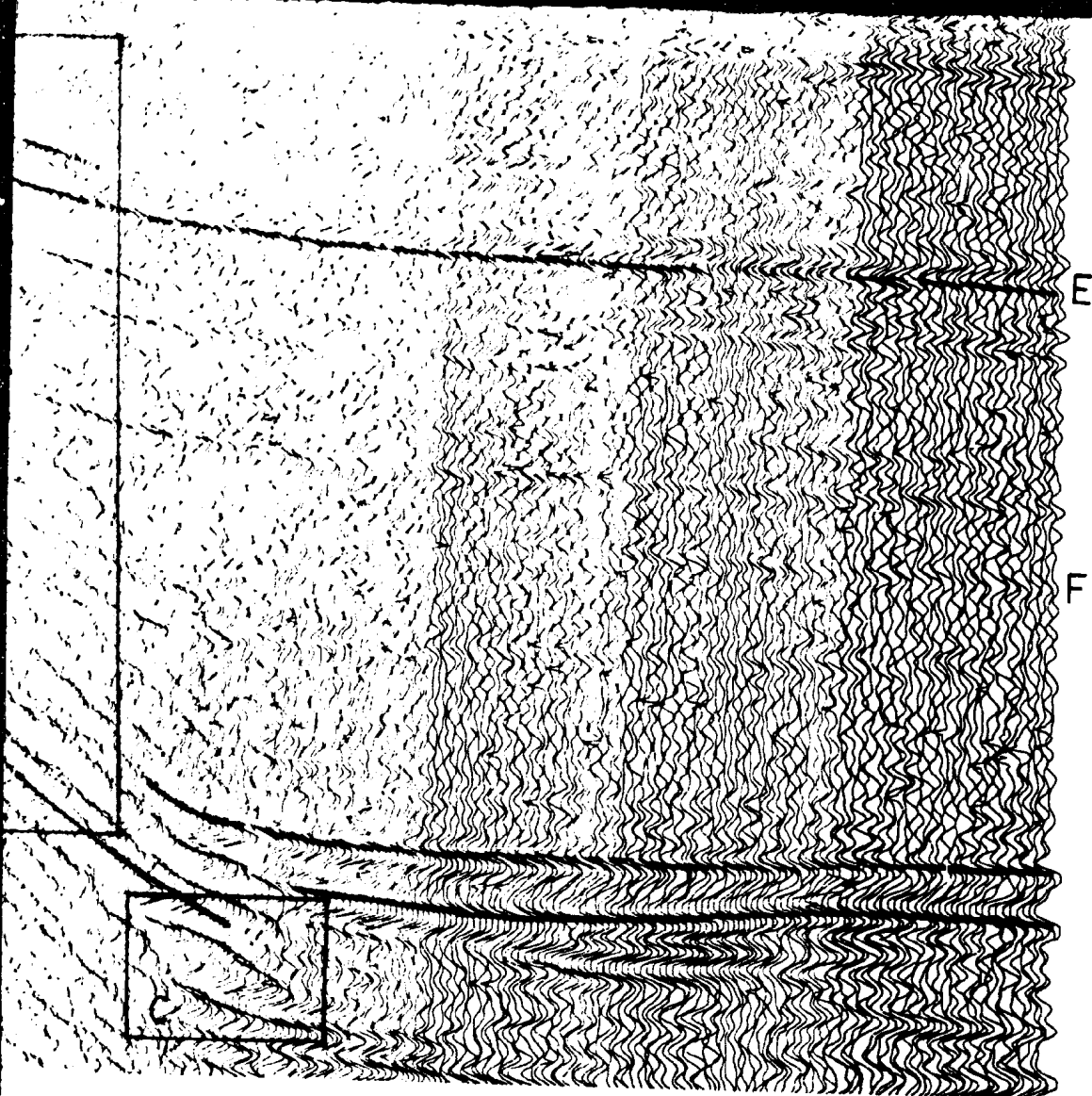


FIG. 4.1 SEISMIC SECTION BEFORE MIGRATION





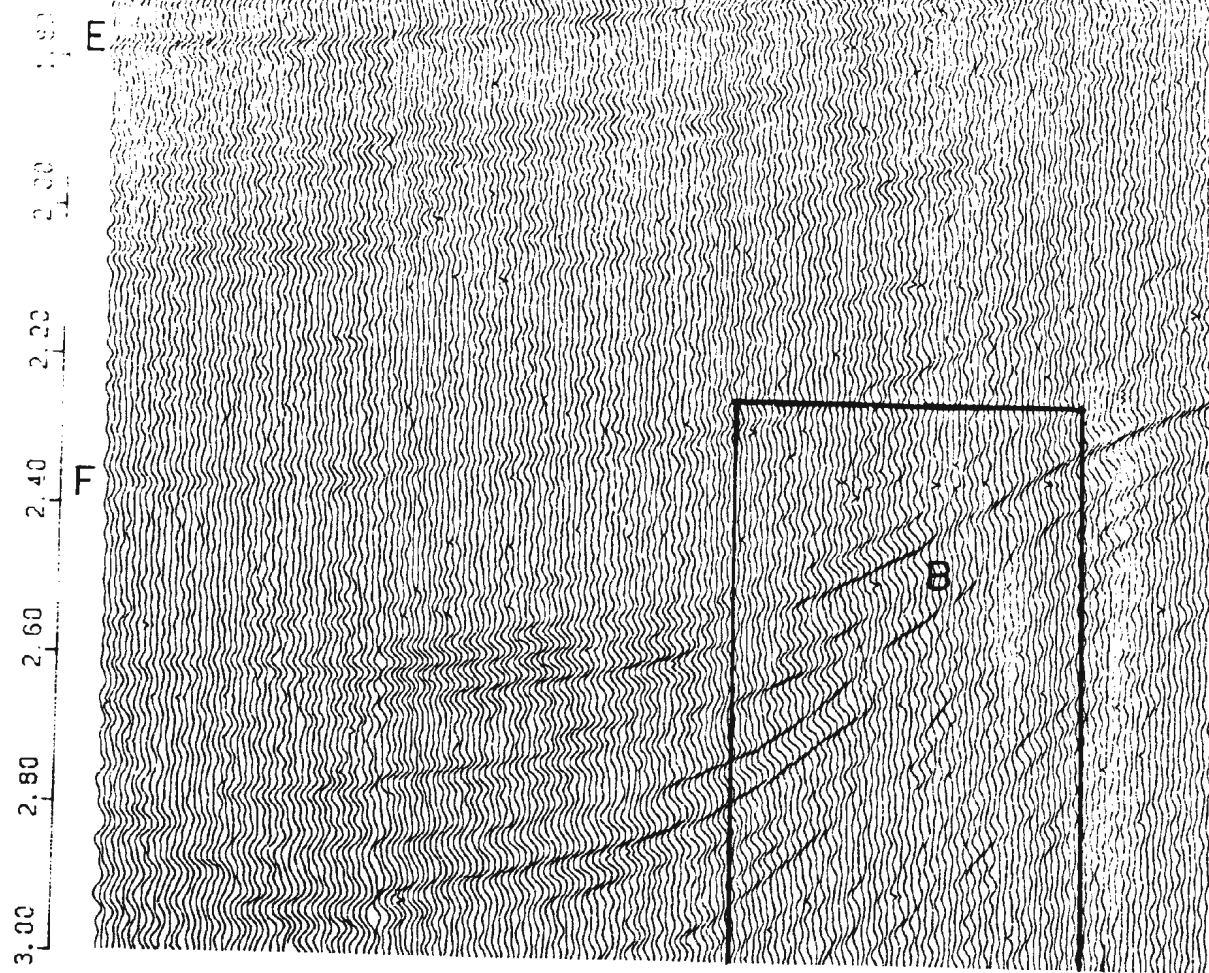
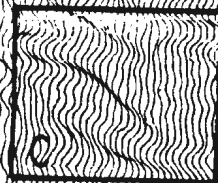
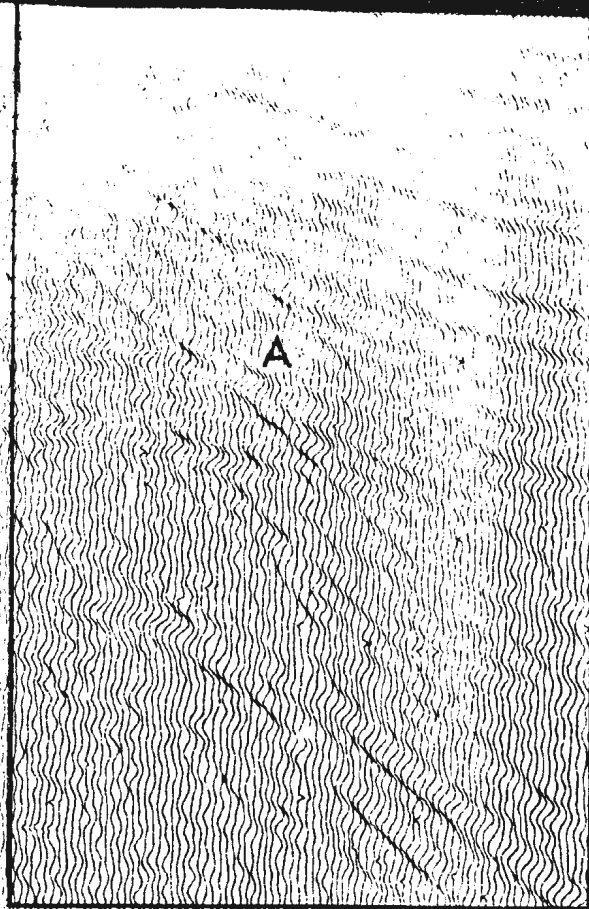
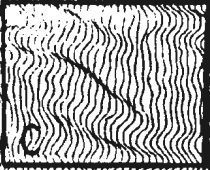


FIG. 4.4.2 SEISMIC SECTION AFTER MIGRATION



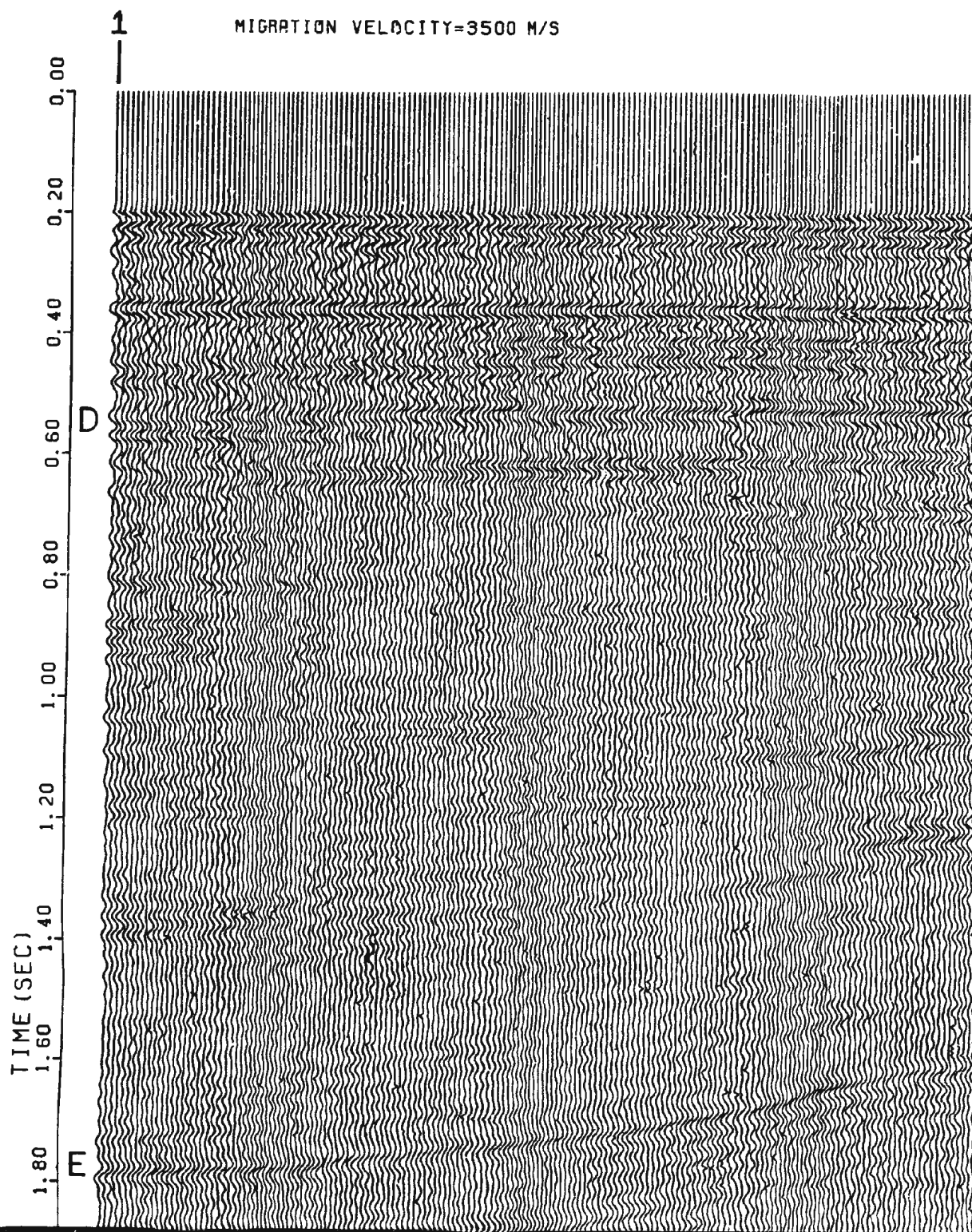
E

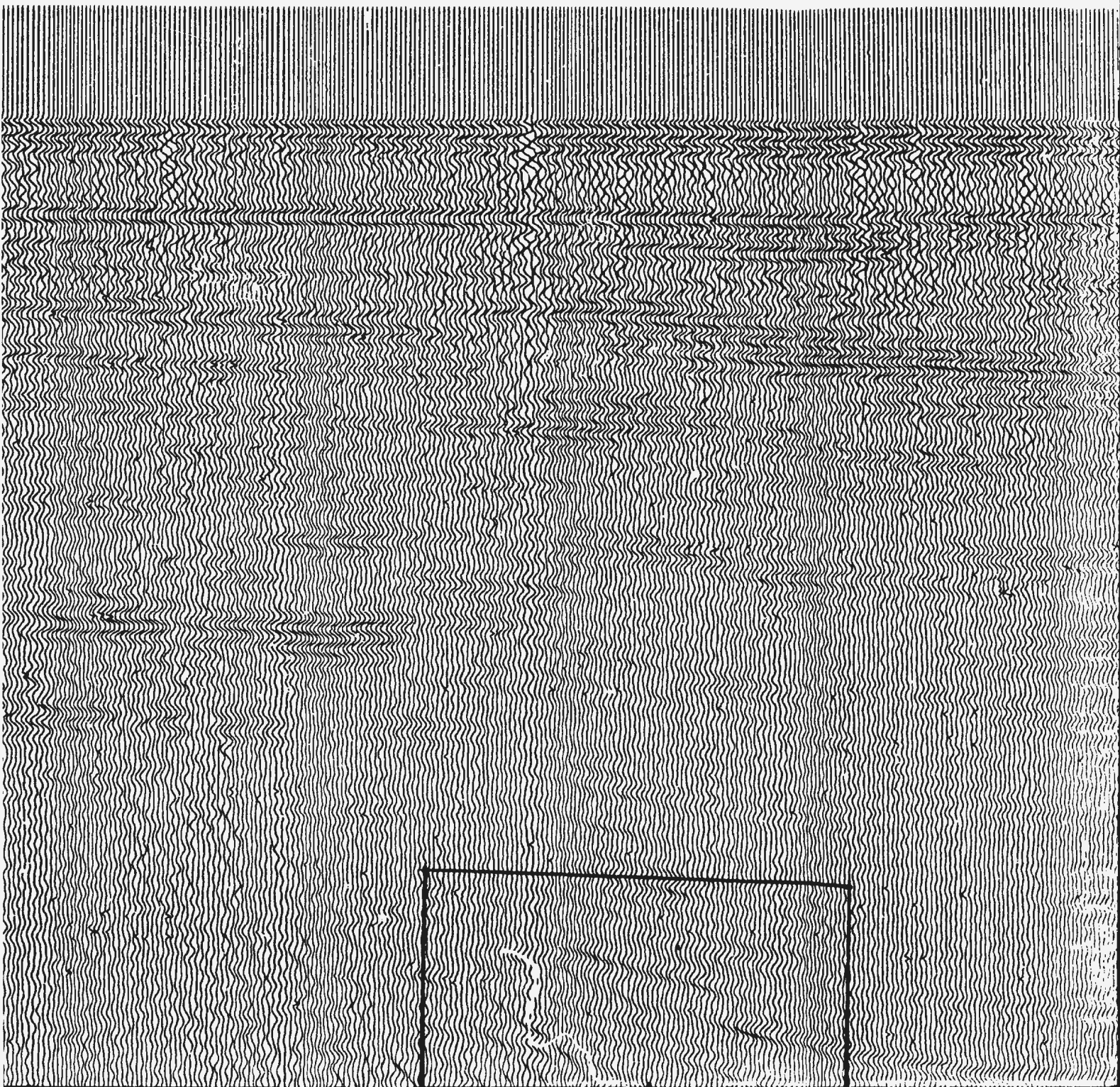
F



GRAND BANKS SEISMIC LINE-G583B

MIGRATION VELOCITY=3500 M/S





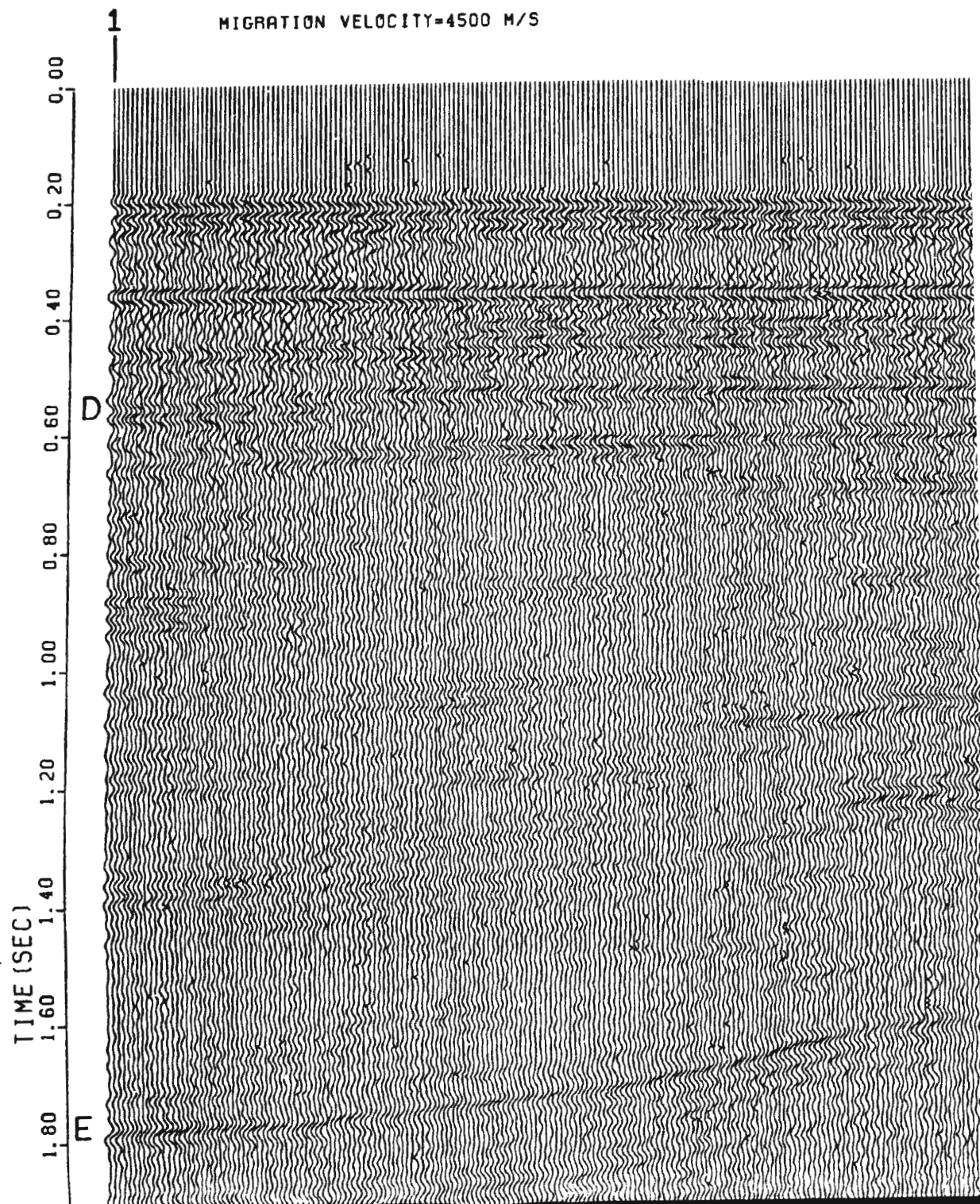
504

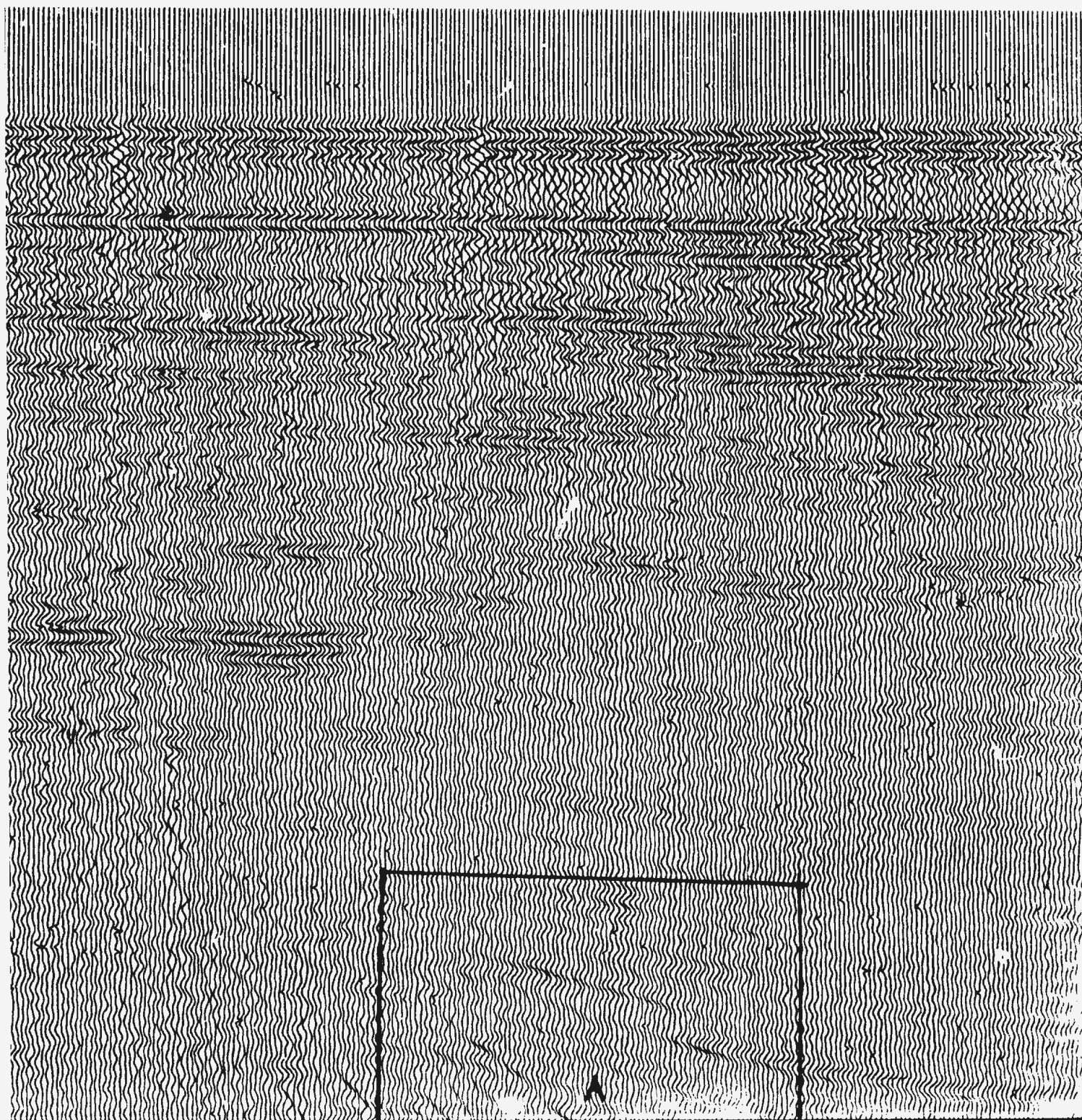
D

E

GRAND BANKS SEISMIC LINE-G583B

MIGRATION VELOCITY=4500 M/S





504

D

E

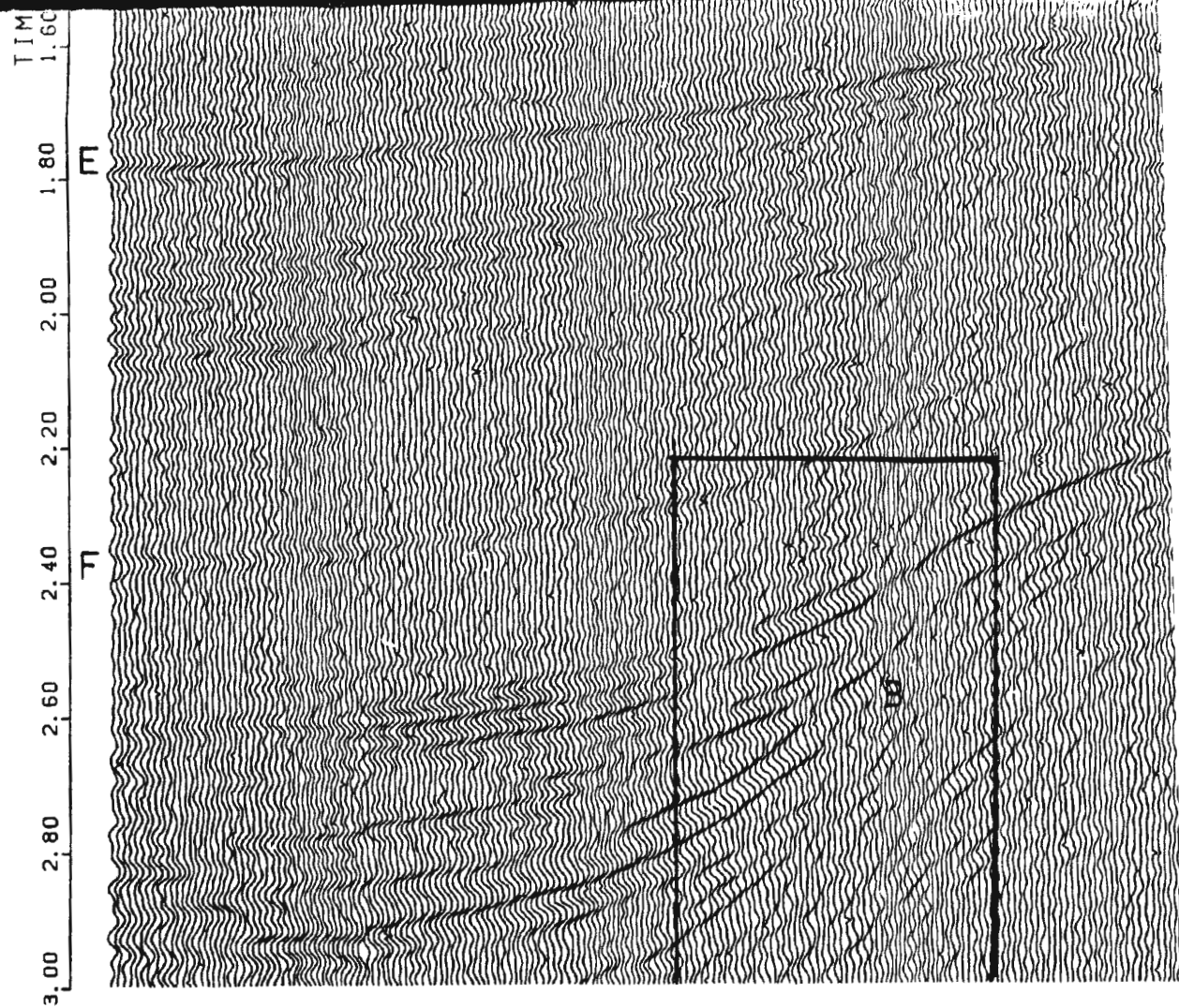
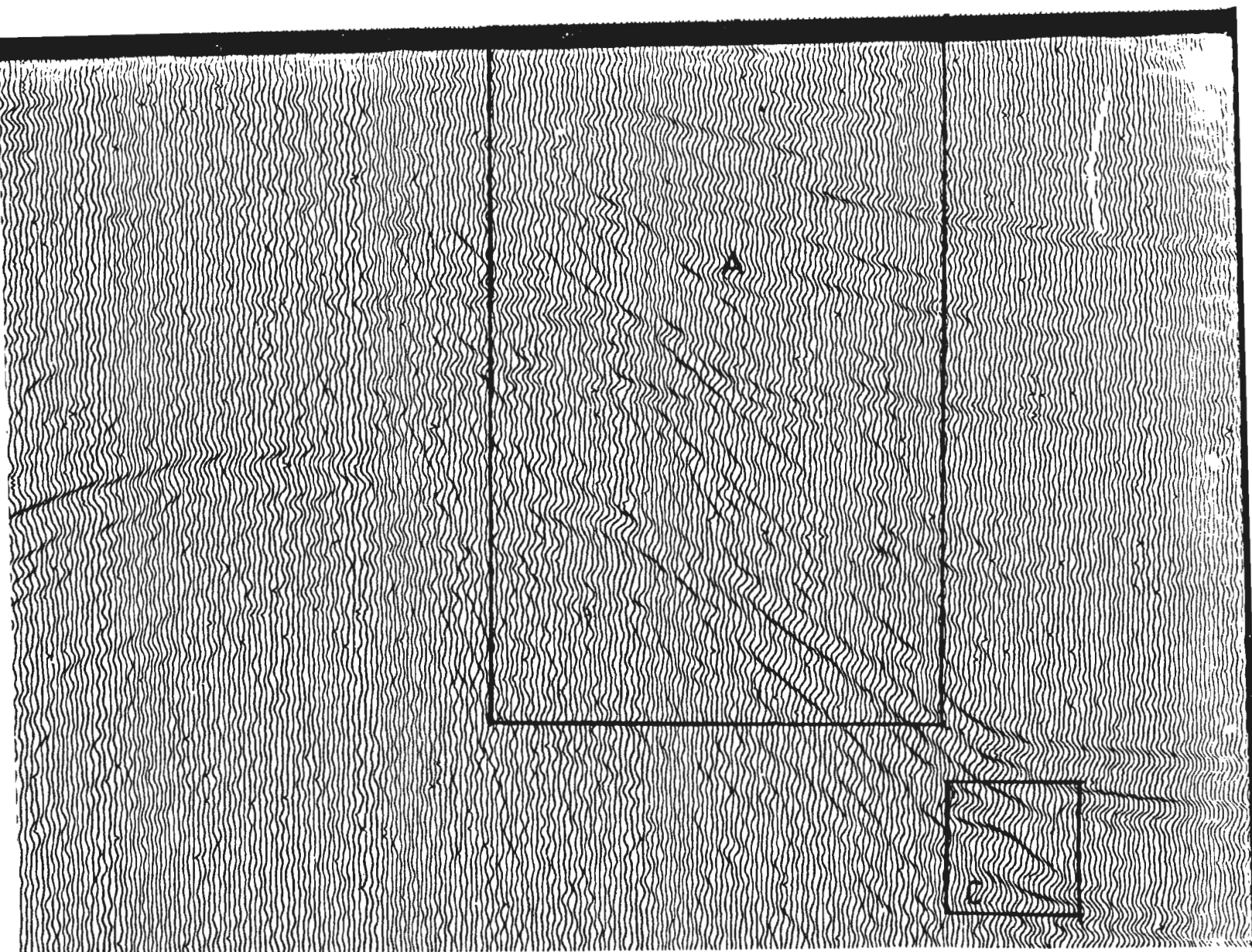
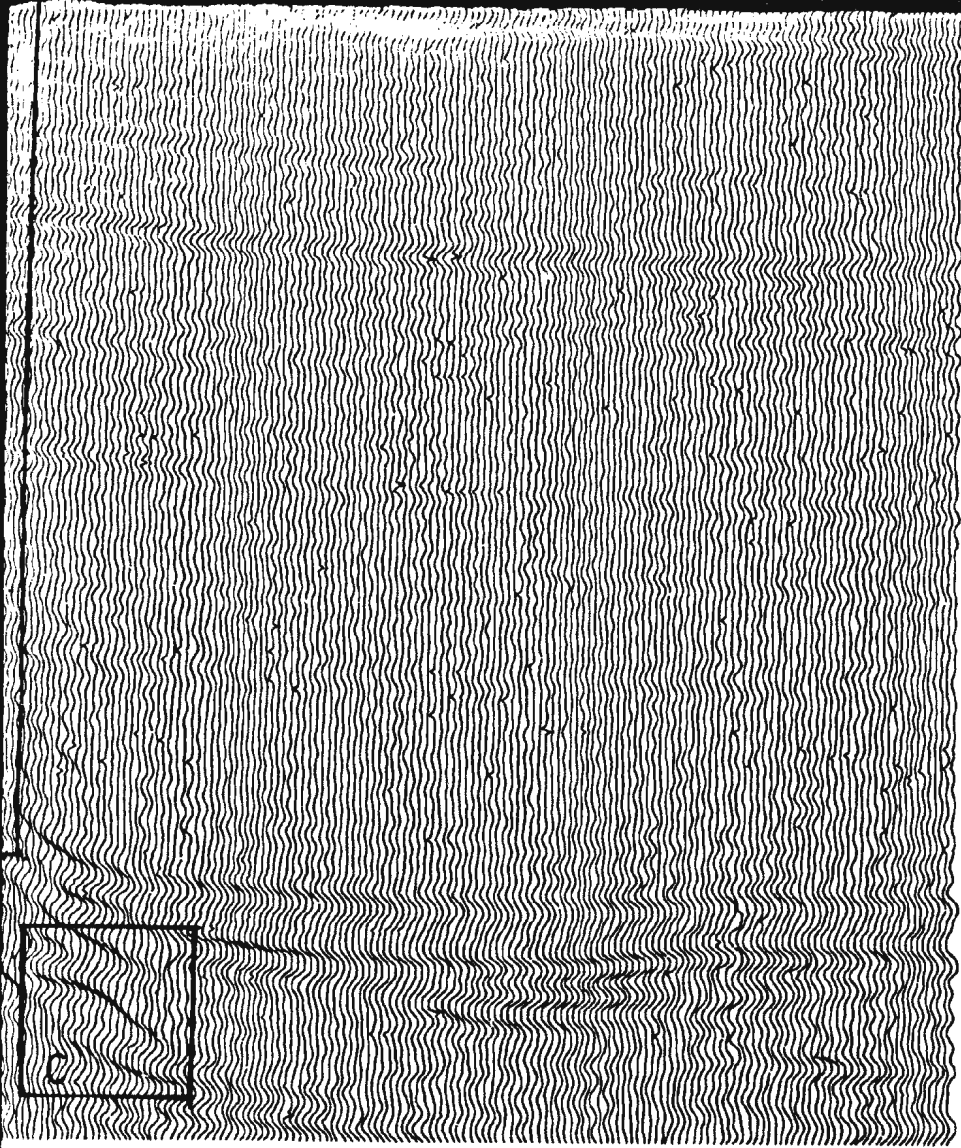


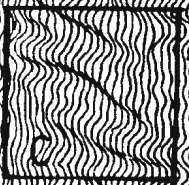
FIG. 4.43 SEISMIC SECTION AFTER MIGRATION





E

F



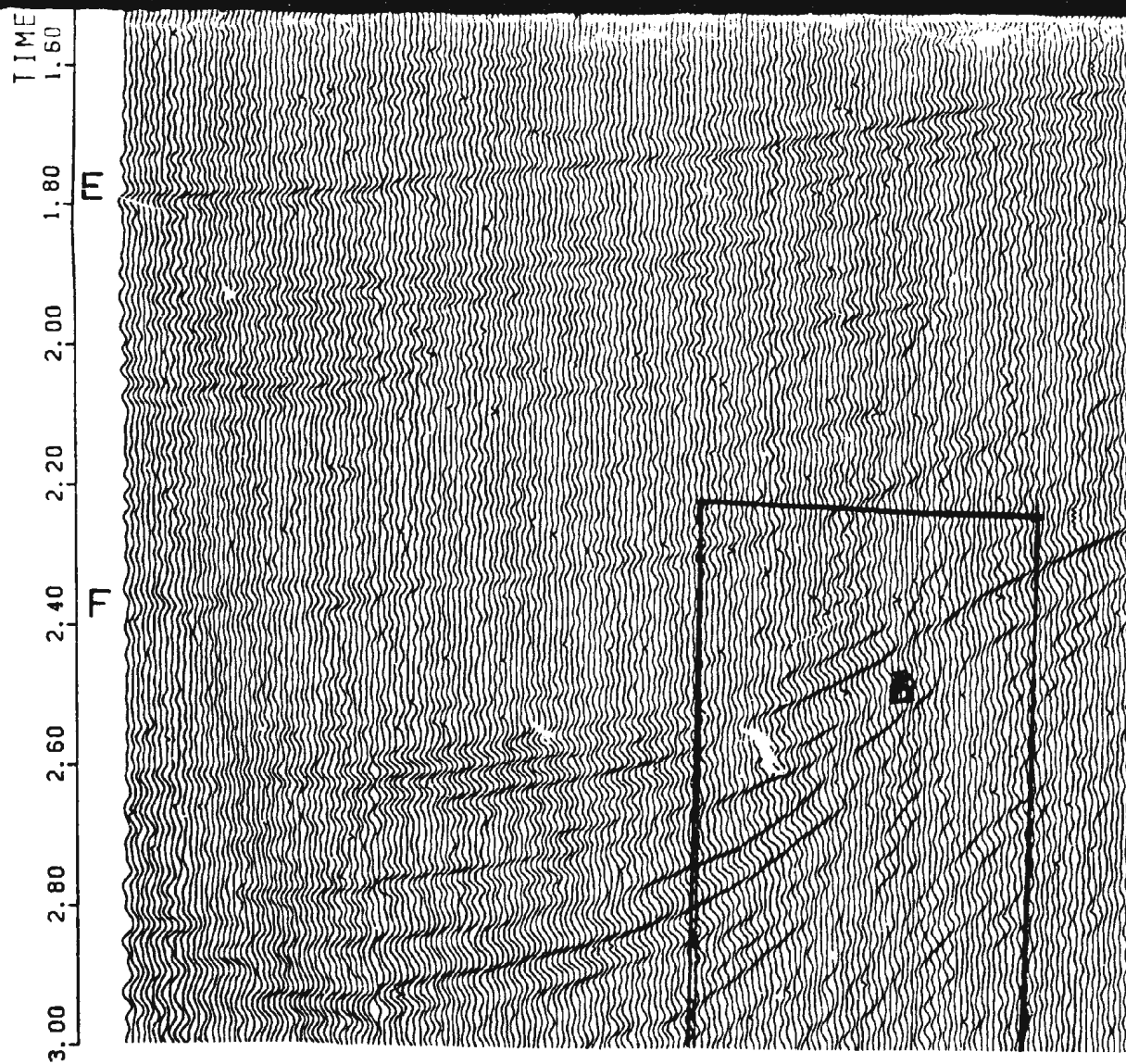
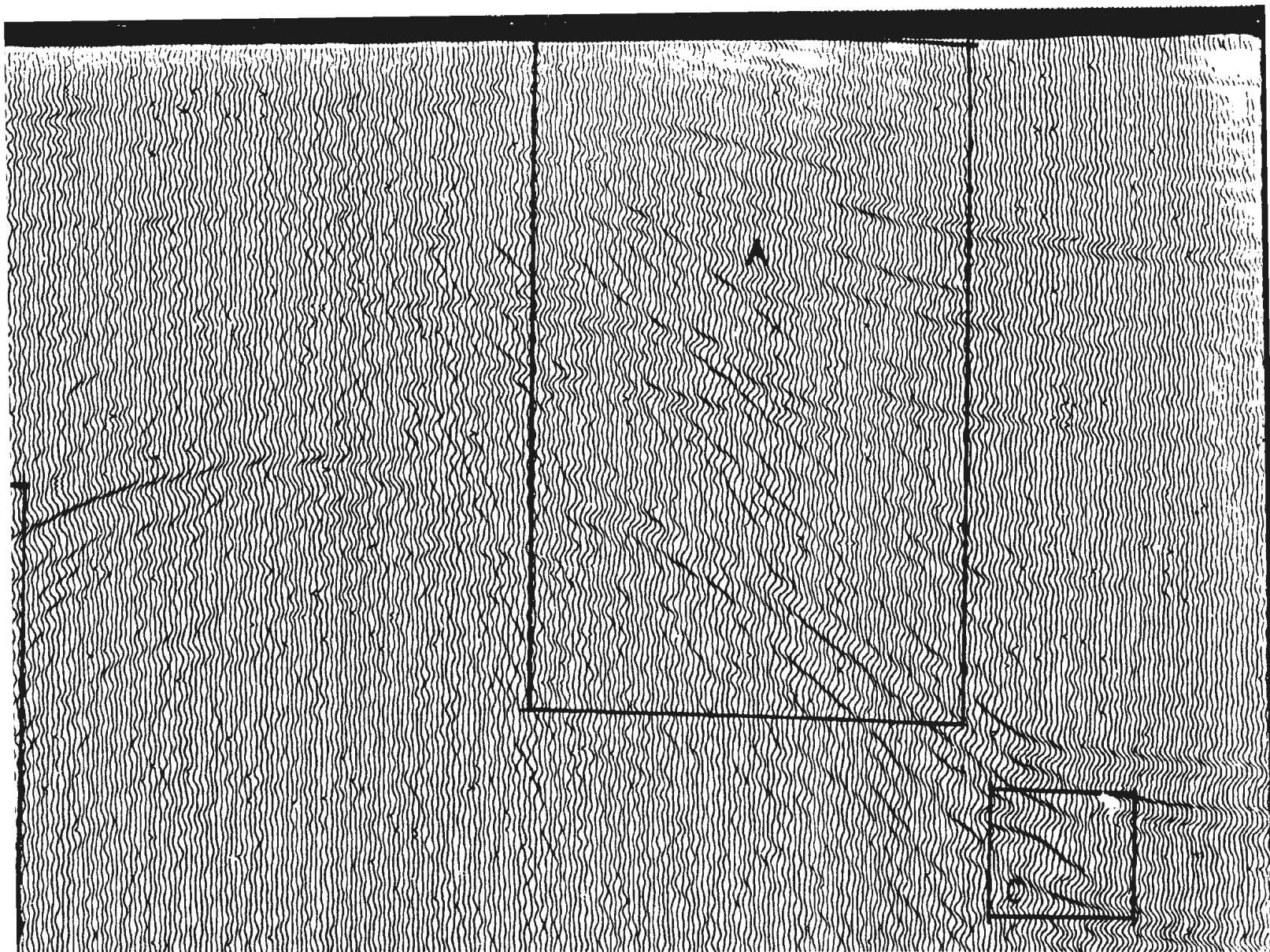
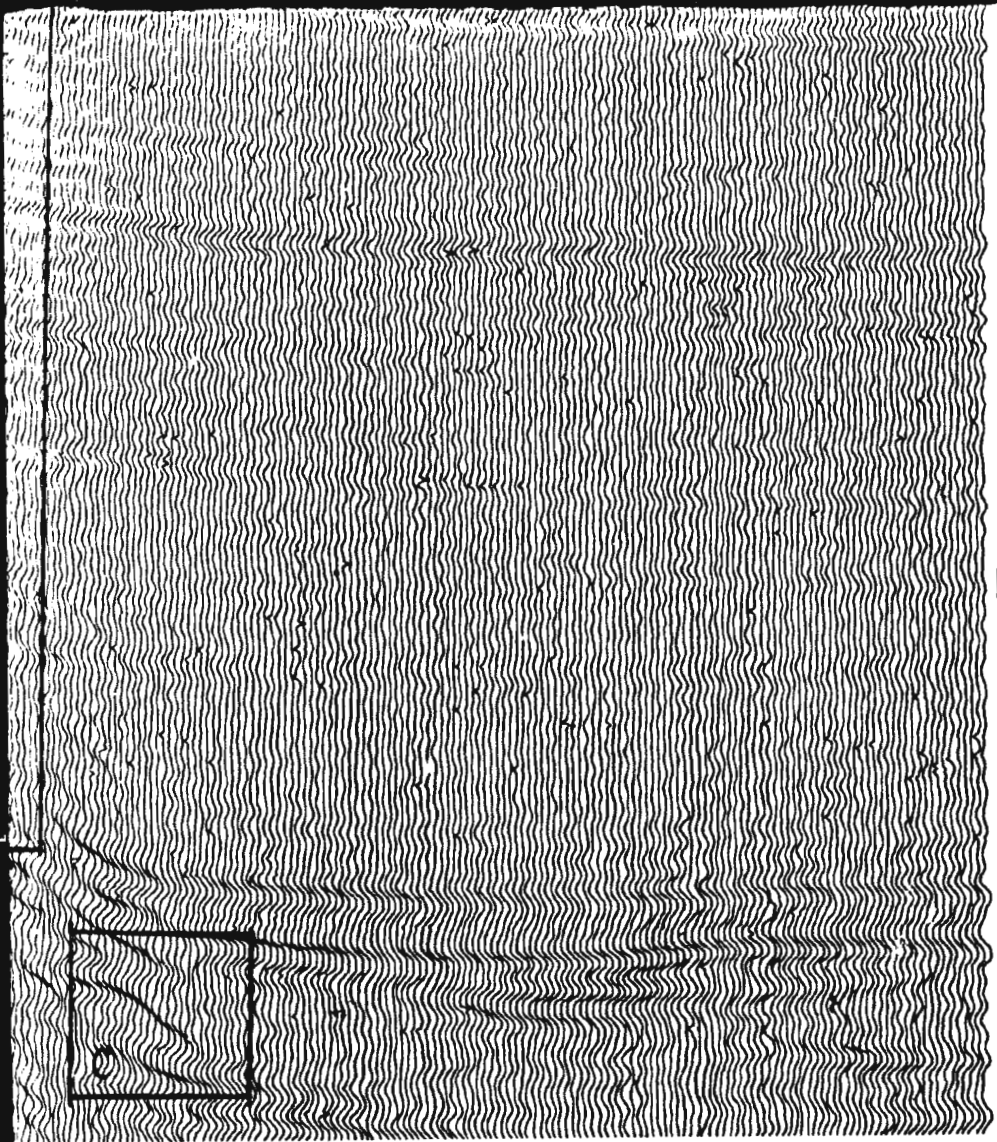


FIG. 4-4 SEISMIC SECTION AFTER MIGRATION





E

F

