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**STRUCTURAL NATURE OF THE HUMBOLDT FAULT ZONE IN  
NORTHEASTERN NEMAHA COUNTY, KANSAS**

by

Thomas W. Stander

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Kansas Geological Survey  
1930 Constant Avenue  
University of Kansas  
Lawrence, KS 66047-3726

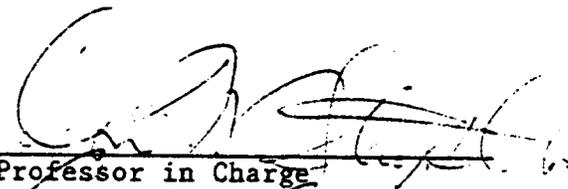
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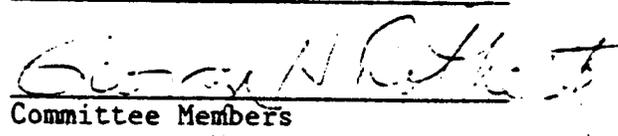
Thomas W. Stander

B.A., University of Northern Colorado, 1974

Submitted to the Department of Geology and the Faculty of  
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\_\_\_\_\_  
Professor in Charge

  
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\_\_\_\_\_  
Committee Members

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For the Department

### Abstract

A six-fold CDP seismic reflection survey was conducted across 5.3 km. (3.3 miles) of partially glaciated land in northeastern Nemaha County, near Bern, Kansas. An 11 degree easterly dipping slope with a 12 meter fault offset was interpreted in the Late Pennsylvanian and Early Permian beds where the seismic line crosses the Humboldt Fault. West of this fault, over the Nemaha Ridge, Late Pennsylvanian rocks of the Cherokee Group overlie Precambrian granite basement rocks at a depth of 353 meters (1165 ft.) and an elevation of eight meters (26 ft.). To the east of the fault, over the Forest City Basin, the deepest reflector interpreted was the top of the Cherokee Group at a depth of 563 meters (1845 ft.) and elevation of -166 meters (-545 ft.) at a well four km. (2.5 mi) east of the fault. All of the Late Pennsylvanian and Early Permian rocks in the Forest City Basin above the top of the Cherokee Group have very little structure or dip between the fault zone and the well.

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STRUCTURAL NATURE OF THE HUMBOLDT FAULT ZONE  
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Introduction

The Kansas Geological Survey is conducting a major re-evaluation of the geology and seismicity of Kansas in connection with design criteria for dams, nuclear power plants and other earthquake-sensitive structures. Northeast Kansas was chosen as a study area because of the concentration of seismic activity and the stratigraphic evidence for the maximum amount of vertical displacement on the Humboldt fault (Steeple and others 1979). McCauley and others (1978) searched for surface lineaments using LANDSAT-MSS, side-looking airborne radar, satellite, and conventional photography. DuBois (1978) investigated the origin of surface lineaments in Nemaha County and interpreted a post-Permian throw of 53-74 meters (174-242 ft.) on the Humboldt fault in the northern area of the county.

The purpose of this study was to determine the nature of the deformation on the Humboldt fault and to better resolve its lateral position and total vertical throw in the near-surface.

### Geologic Background

A major geologic feature in Nebraska, Kansas and Oklahoma (figure 1) is the north-south trending asymmetrical Nemaha Anticline extending nearly 500 km from near Lincoln, Nebraska, to Oklahoma City, Oklahoma. In northeastern Kansas, this approximately 50 km (30 mi) wide anticline borders the west side of the Forest City Basin and the east side of the Salina Basin.

The core of the Nemaha Anticline (the Nemaha Ridge) is composed of Precambrian granitic rocks. In northeast Nemaha County, this ridge is overlain by younger, post-Pennsylvanian and pre-Permian [Gaudalupian], sedimentary rocks that have been folded and faulted into a long, narrow, north-south trending, asymmetrical anticline. On the steeper eastern flank, the Precambrian granite basement has a maximum of 1.2 km (4,000 ft) of vertical displacement in northeastern Nemaha County (Ward, 1974). The Precambrian Surface Map of Kansas (Cole, 1978, figure 2) shows this displacement as a single fault. Other studies (DuBois, 1978; Berendsen and others, 1978) indicate this displacement is distributed over a fault zone.

The Keweenawan mafic belt (Midcontinent Geophysical Anomaly or MGA) is a late Precambrian rift zone filled with basalts and gabbros (King and Zeitz, 1970; Coons and others, 1967). This belt is bounded by faults where it is exposed at the surface in the Lake Superior region, and geophysical data suggest that similar faults exist to the south where the feature is deeply buried beneath Paleozoic and younger strata (King and Zeitz, 1970). Surface structures (figure 1) associated with the MGA

in northern Kansas include the Abilene anticline and Irving syncline (Jewett, 1941) which both parallel the southeast flank of the MGA; and the Riley County kimberlite intrusions (Brookins, 1970) which follow the structural trend of the MGA. These intrusions have been associated with right lateral strike-slip movement along a buried fault on the east flank of the Abilene anticline (Chelikowsky, 1972).

Although Kansas has long been identified with the Central Stable Region of the North American continent (Merriam, 1963; Synder, 1968), 25 historic earthquake epicenters have been recorded in the state since the mid-1800's (DuBois and Wilson, 1978) and 56 microearthquakes have been recorded by the Kansas Geological Survey's seismograph network between August, 1977, and February, 1980 (Steeple, personal communication). Merriam (1963), Lee (1954), and other early investigators attributed many historic earthquakes to movement along the Nemaha anticline. Much of the recent seismicity is also related to the Nemaha Anticline (Steeple and others, 1979). The mechanisms of these events are still undetermined. Docekal (1970) studied the isoseismal patterns of Modified Mercalli intensity VII-VIII historic earthquakes in the midcontinent and showed a relationship to basement structure and lithology. He concluded the stronger seismic events were genetically related to the Arbuckle, Nemaha, or Keweenawan mafic structures.

#### Description of Study Area

Bedrock exposures are scarce throughout northeastern Kansas because of the cover of Pleistocene glacial debris. Outcrops in Nemaha County are found only along stream-valley walls, except in the northeastern

corner of the county where erosion has removed some of the glacial deposits from the uplands (Ward, 1974). Both the Nebraskan and Kansan glaciers deposited glacial materials that vary in thickness from zero to 115 meters (Ward, 1974; Frye and Walters, 1950; Mudge and others, 1959). Alluvial deposits beneath the terraces and along the present stream valleys are of Illinoisan to Recent age (Ward, 1974). Scattered loess deposits are found throughout the area.

Many of the present streams display prominent angular and rectangular drainage patterns. Alignment of streams, such as Manley Creek, Negro Creek, and North Fork of the Vermillion River, along with apparent parallelism of many tributaries, suggests the influence of underlying structure on the drainage network. Aeromagnetic and gravity surveys conducted by Yarger and others (1978) indicate that many of the geophysical anomalies in northeast Kansas are outlined by circular drainage features and lineaments found on the remote sensing imagery (McCauley and others, 1978). In Nemaha County several circular drainage patterns have developed, such as Rock Creek, Fourmile Creek, Harris Creek, Turkey Creek, Wolf Creek and Deer Creek (DuBois, 1978).

The seismic reflection profile of this study was located in northeastern Nemaha County (figure 3), in a Pleistocene glaciated region underlain by bedrock of Late Pennsylvanian and Early Permian age (figures 4 and 5). As a result of Late Permian and possibly post-Permian movements (Ward, 1974) along the Nemaha anticline, the general northwestward dip of the sedimentary strata in northeast Kansas is interrupted in Nemaha, Pottawatomie, and Jackson counties. Localized deformation of Permian beds occurs near Bern in Nemaha County where an eastward dip of

up to 20 degrees is recorded on the eastern flank of the anticline (DuBois, 1978).

The Precambrian Surface Map of Kansas (Cole, 1978) (figure 2) shows the Humboldt Fault at the eastern flank of the Nemaha Ridge extending through Nemaha County into Pottawatomie County in the south. The fault enters the northern edge of Nemaha County from Richardson County, Nebraska, 4.8 km (3 mi) northeast of Bern, Kansas.

Movement along the Nemaha Ridge has greatly affected the total thickness of the sedimentary section. To the east in the Forest City Basin, within a few kilometers of the ridge axis, the sedimentary rocks attain a total thickness of 1200 meters (4000 ft). Sedimentary rocks over the Nemaha Ridge, where the pre-Mississippian section has been eroded away, range in thickness from 175 meters (600 ft.) near Seneca to 300 meters (1000 ft.) at the western border of Nemaha County (DuBois, 1978).

#### Previous Work

Cole (1976) has suggested that a single Humboldt Fault enters Nemaha County from Nebraska (figures 2 and 6). Additional data suggest a more complex system of faults and fractures in this area (Burchett and Maroney, 1979; Steeples and others, 1979).

Numerous other publications and reports concerning the local and regional geology of northeastern Kansas are available (Merriam, 1963; Davis, 1951; Frye and Walters, 1950; Chelikowsky, 1972). In addition specific reports of stratigraphy, structure, and groundwater conditions have been published for Nemaha (Mudge and others, 1959; Ward, 1974),

Marshall (Walters, 1954), Jackson (Walters, 1953), Brown (Bayne and Schoewe, 1967) and Pottawatomie (Scott and others, 1959; Seyrafian, 1977) counties. Materials inventory reports by the Kansas Highway Commission exist for Nemaha (Hargadine, 1970), Marshall (Hargadine, 1965) and Brown (Stallard and Fenity, 1966) counties. Soil surveys have been completed by the Soil Conservation Service for Jackson (Campbell, 1979), Brown (Eikleberry, 1960) and Marshall (Kutnink, 1980) counties.

Others sources of information include water, oil and gas well records and measured sections kept on file at the Kansas Geological Survey (Cole and Ebanks, 1974). Yarger and others (open file, 1978) have compiled aeromagnetic and gravity maps of northeastern Kansas; Bickford and others (1978) have produced a map of basement lithologies for the same region. Steeples and others (1979, personal communication) have conducted numerous seismic reflection surveys in Nemaha county.

#### Field Methods

A 12 channel digital INPUT/OUTPUT 1632MS recording system was used to collect shallow, high-resolution seismic reflection data. The sample rate was set at one sample per two milliseconds, allowing two seconds of recording. The high cut recording filter was set open while the low cut filter was set at 60 Hz with a 12 dB per octave attenuation slope. Sixty Hz interference noise was eliminated by a notch filter. The recording amplifier gain levels were set at highest possible settings, usually at 106 dB, to ensure maximum signal strength. Each seismic record was plotted on paper for data-quality control and review, and stored on a nine track magnetic tape in a modified NRZI SEG Y format.

The recording method used was the The Mini-SOSIE<sup>1</sup> technique developed by the Geophysical Research Center of Societe Nationale Elf Aquitaine (Production)[SNEA(P)] in PAU, FRANCE. This method allows impact rates of up to 18 per second from the surface energy source. Up to 36 energy pulses were stacked<sup>2</sup> together during each record length of two seconds.

At each receiver group, 12 geophones were connected together. Each geophone was a Mark Products, Inc. L-25D, with a natural frequency of 30 Hz and a coil resistance of 710 OHMs. Response curves for a single geophone with zero and 60 percent damping are given in figure 7.

The energy source used was a 151Y Wacker rammer<sup>3</sup> with a accelerometer mounted on the base of the rammer to produce time breaks for the recording system. The short source-time signature and its frequency spectrum (figures 8 B and A ) demonstrate that the high frequency energy required for high-resolution is supplied by this source.

By field testing, a conventional split-spread, six-fold reflection survey was determined to produce high quality results. Receiver geophone groups were placed 16 m apart. The energy source was centered between channels six and seven at the middle of the twelve recording

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<sup>1</sup> Trademark of SNEA(P)

<sup>2</sup> Recording technique that allows multiple shots or energy pulses to be vertically added together. This method improves the data quality by building up signal above the background noise level and by statistical destructive interference of random noise energy.

<sup>3</sup> The Wacker rammer is a hand-operated, small gasoline-engine driven compaction tool.

groups. The nearest recording geophone groups were 32 m from the energy source. This produced a symmetrical recording pattern with six channels (1-6) behind the source; three dead (non receiving) groups between channels six and seven with the source centered at the center dead group; and six channels (7-12) ahead of the source. The distance from the rammer to the near channels (six and seven) was 32 m and to the far channels (one and 12) was 112 m. The total spread length between channels one and 12 is 224 m. Seismic reflections can be enhanced relative to unwanted surface waves by designing arrays of geophones using the principles of antenna theory. As a result of our field testing, each geophone group consisted of 12 geophones placed inline parallel to the seismic profile with one meter between geophones. This 32 meter long geophone array was centered about each receiver group location.

Two thousand wacks from the rammer, distributed and centered along the seismic profile about each source location, were found to be optimum for the source array length of 16 m. Both the geophone and source arrays, when areally distributed, improved data quality by cancelling unwanted ground roll and other near surface-waves.<sup>4</sup> As the source locations are sequentially rammed, the proper receiver groups are selected by a rollalong switch inside the recording van. By using a 12 channel recording system and ramming at each field location, common subsurface reflections, known as common depth points (CDP), were sampled six times. This produced a six-fold or 600 percent CDP seismic survey.

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<sup>4</sup> See any current exploration geophysics text such as Dobrin, M.B.; INTRODUCTION TO GEOPHYSICAL PROSPECTING; McGraw-Hill Book Company; third edition, 1976, pp. 100-107.

### Data Processing and Plotting

The magnetic field tapes were sent to Amoco Production Company Processing Center in Tulsa, Oklahoma, to be computer processed.

Typical rock interval velocities range between 2500 meters per second (m/s) and 4000 m/s for shales and between 4500 m/s and 6000 m/s for limestones (Dobrin, 1976 pp. 46-56). An average velocity of 3000 m/s is typical for the rock column in Nemaha county based on velocity analysis of the data.

At several locations along the seismic line, time-velocity pairs were picked from computer generated velocity scans (Dobrin, 1976 p.233). The velocity functions were inaccurate because of 1) poor data quality 2) low subsurface reflection repetition 3) short horizontal receiver offsets and 4) high structural dip. The final velocity function used is graphed in figure 9.

This velocity function was used to correct reflection times from horizontal offset receiver groups to a simulated zero offset group distance. This correction, known as normal moveout, was small for short offset distances of less than 112 m. The depth-velocity function (figure 9) graphs the time velocity pairs of the normal-moveout function curve A. Any function applied to the seismic data between curves B and C will correctly remove the time delay, caused by horizontal receiver offsets, to within  $\pm 2.5$  ms. Since the normal moveout correction is small, most misalignments of seismic wavelets that occurred during stacking were due not to a poor velocity function but to uncorrected static problems.

Initial processing included utility functions such as combining several field tapes onto inhouse formatted tapes; adding field parameters; adding source and receiver elevations and locations; and computing and applying initial elevation statics. A large window (1000 milliseconds) digital automatic volume control (DAVC) scaling program was applied at this step to ensure that all field records would have a uniform average trace amplitude. For most later processing, data traces were sorted into common depth point format and saved for later input to other processing sequences.

Seismic energy is reflected from a surface when it passes into a material with a different seismic impedance (the product of velocity and density). This mismatch of acoustic impedance<sup>5</sup> determines the strength and polarity of the reflected energy. Positive polarity reflections are generated when energy flows from rock units with lower seismic impedance to higher impedance. Likewise, energy flowing from rock units of higher seismic impedance to those of lower impedance generates negative polarity reflections. Thus, positive reflections are generated by energy passing from a shale into a limestone, which usually is displayed on a seismic section as a trace swing to the right or shaded-in waveform.

The initial brute 600 percent CDP stacked section (figure 10) displays the raw seismic line with only minimum processing (as discussed

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<sup>5</sup> If  $V_b$  and  $D_b$  are the interval velocity and density of layer b, and  $V_a$  and  $D_a$  are the interval velocity and density of layer a, then the reflection coefficient  $R$  for the interface separating layer a from layer b for a wave normally incidence in the direction from layer a to layer b is:

$$R = (V_b D_b - V_a D_a) / (V_b D_b + V_a D_a)$$

above). The vertical time scale is in milliseconds. The total section covers 5.3 km (3.3 mi.) in horizontal (east-west) distance in two seismic lines. Line A starts at Mr. Crainville's farm (center of the south line of the southwest quarter of section 2, T.1S., R.13E.) and extends 147 groups to the west (200 m past Four-Mile Creek). Line B again starts at Mr. Crainville's farm and extends to the east 187 groups where it ties into the Edelman Number One oil well at group 185. The lack of reflector continuity, general poor data quality, steep reflectors (near group 25, line A), and extremely broken up reflectors (groups 100-135, line A) are phenomena typically associated with uncorrected static sections.

Data quality deteriorates when misaligned common-depth traces are stacked. Misalignment of traces is often caused by near-surface, non-homogenous rocks having anisotropic velocities. Near surface materials typically have very low velocities (commonly 1000 m/s) but may also vary greatly in short lateral distances. This velocity variation generates traces with varying time delays commonly known as statics.

In northeast Kansas, several geologic phenomena combine to produce a complicated statics problem. A slow velocity layer, known seismically as the weathering zone, is present along the entire survey line. It is commonly related to the material zone above the water table. Secondly, the geophone arrays were placed along a county road with its aggregate fill of sand and gravel varying in thickness from less than a meter to seven meters. Along the line, several Recent valleys have alluvial fill varying in thicknesses from zero at the edges to perhaps more than 20 m near the valley centers. Adding to the diversity, a Pleistocene Kansan

till layer ranges from zero thickness near the center of the survey to over 20 m at the east end. All four of these statics-producing layers may have different velocities, which may also vary greatly laterally. No practical field methods were available to determine this complicated two-dimensional velocity-anisotropic statics problem.

Automatic trimming programs can determine and remove time delays caused by static problems. Excellent results were obtained from the Nemaha seismic line by selecting several trimming reflectors, closely maintaining only allowable dips, and carefully determining the optimum number of CDPs to trim across. Care was taken not to remove geologic structure in the data processing. After several runs, three sections illustrate the trimming improvement (figures 11,12,13). The optimum-trimmed stack section (figure 12) used 49 CDPs to compute the statics. Using only five CDPs (figure 11) did not smooth out the reflectors while 99 CDPs (figure 13) did not significantly improve the data quality above the 49 CDP section.

Several factors improve data quality when reflection points are repeated and stacked together. First, improvement of the signal to noise ratio is proportional to the square root of the number of traces summed together. Thus stacking six traces improves the signal to noise ratio two and one-half times. Second, random noise is eliminated by destructive interference. Third, many statistical tools may be applied to improve seismic data quality. To demonstrate the improvement, three sections were generated simulating 200, 300, and 600 percent CDP coverage. All processing, except that necessary to simulate the different coverages, was identical for the 200 (figure 14), 300 (figure 15), and

600 percent (figure 16) stacked sections. As seen in these three sections, data quality improves with increasing fold.

Another interesting display is distance-limited sections. Commonly, certain trace distance offsets or ranges have better quality data because of the lack of ground roll or other unwanted energy arrivals. Three sections were generated by stacking traces from three different ranges. The near range (figure 17) is between 32 and 96 m, the middle range (figure 18) is between 96 and 128 m, while the far range (figure 19) is between 112 and 144 m. Since the far group offset is short, only 114m. away from the source, all three ranges show generally the same quality.

In some field areas seismic energy is reflected more than once producing undesirable multiple reflections. These multiples are usually attenuated by CDP processing. The extent to which they are present in the final CDP section can be displayed by generating an autocorrelogram (figure 20). Multiples are evident between groups 15 and 70 of line B and groups 70 and 144 of line A. While multiples are certainly present in the trimmed 600% CDP section, there are several events that are not multiples as shown by the autocorrelogram (figure 20). In addition, there are continuous reflectors that run through areas of multiples into areas where no multiples are present. This indicates that the basic interpretation of the line is valid and that multiples are not a serious problem, even though multiples are present along some portions of the line.

Multiples may also be attenuated by deconvolution techniques. The deconvolved section (figure 21) is the optimum-processed seismic section

of the Nemaha data set. It has the best velocity function applied, the optimum statics removed, unwanted energy and noise eliminated, and multiples attenuated. The highest degree of resolution and data quality are present in this section.

The Wacker rammer produces high frequency energy as seen in the amplitude spectrum (figure 22) of a typical data trace. Peak frequency is at 80 Hz and the bulk of the energy recorded is between 30 and 100 Hz. The lack of frequencies below 30 Hz is due to attenuation by the geophones and low cut recording filters.

High frequency source energy improves the resolution of the seismic sections by allowing definition of thinner beds and more precise depth determination. High frequencies are also attenuated more rapidly with distance than lower frequencies, which makes high-resolution seismic surveying practical only for shallow targets. Two sections were generated to simulate typical lower frequency Vibroseis industry seismic data. The first section (figure 23) was filtered with a bandpass of one to 50 Hz while the second, more typical of industry energy-frequencies (figure 24) has a bandpass of one to 30 Hz. A comparison of these filtered sections with the high frequency section (figure 16 or 12) clearly demonstrates the improved resolution of the Wacker rammer source, although the filtered sections had much of the low frequencies eliminated by the geophones and recording filters.

#### Well Control and Stratigraphy

The subsurface stratigraphic section, corresponding to the seismic reflections, was determined from electrical logs (figure 25) of the

McCulloch Oil Company, Venus Oil Company, and Alex W. McCoy and Associates, Inc. Edelman Number One wildcat oil well drilled in 1971. This well is located in the southwest corner of Section 6, T.1S., R.14E. of Nemaha county and ties the east end of the seismic line at group number 185.

Interval velocities were estimated from the bulk density log (Gardner and others, pp. 770-780). A sonic log was then computed from the interval velocity log. Finally, a 40, 80, and 120 Hz synthetic seismograms were generated from the sonic log.

The 80 Hz synthetic seismogram (column C) in figure 26 corresponds well with the field data (column B). The 40 Hz synthetic seismogram (column A) is comparable to the lower frequency industry seismic data while the 120 Hz synthetic seismogram (column D) indicates the possible improvement in bed resolution with a higher frequency source. Interval velocities are plotted in column E.

#### Additional Geological and Geophysical Data

Although oil wells penetrating the Precambrian granite are sparse and widely distributed in Nemaha County (figure 2) they provide enough control to map 1200 m of throw on the Humboldt Fault close to the Nebraska-Kansas line. The Precambrian surface, down the axis and near the center of ridge (between Seneca, Kansas, and Tecumseh, Nebraska), is uniformly near an elevation of 150 m (500 ft). Burchett (1980, personal communication) has generally found continuous rock sequences in the upper 100 m along strike in Richardson and Pawnee counties in Nebraska.

At Stevens and Vhri Number One Robert Harlow oil well (drilled April of 1939, SE,NE,Sec.32,T.1N.,R.13E, Pawnee county, Nebraska), the top 33 m of the Cherokee Group rests on the Precambrian granite surface at an elevation of 111 m (362 ft). This well is about one and one-half miles north and one-quarter mile west of the west end of the seismic line. The Precambrian surface would be near 200 milliseconds on the seismic section, suggesting that events later than 200 milliseconds on the west end of the seismic line A (figure 21) are due to either multiple reflections, geologic structure or low dip.

Steep gradients across the seismic line on both the aeromagnetic (figure 27) and Bouguer gravity maps (figure 28) indicate a possible fault.

DuBois (1978) interpreted a fault based on stratigraphic evidence:

The highest dip observed in the area mapped is 19 degrees NE in the southcentral portion of Section 3, where Permian rocks of the Council Grove Group are exposed. Alluvial and glacial deposits cover the area west of these outcrops for several hundred meters, at which point gently dipping (2 degrees E) ledges of Reading and Wakarusa limestone are found on the knob in the southwest corner of Section 3. A post-Permian throw of 53-74 m (180-250 ft.) is estimated, depending on the exact location of the fault.

Between the top of the Reading limestone and the bottom of the Council Grove Group there is 123 m (403 ft) of stratigraphic section (based on a typical section).

#### Geological Subsurface Interpretation

Geological interpretation is constrained by the geophysical limitations of the seismic data. Interpretative limitations are influenced by source penetration, frequency content, record quality, processing tech-

niques, velocity control, and even surface, near-surface and deep geology.

On the Nemaha County seismic line, the maximum depth of penetration for the Wacker source is about 600 m, which corresponds with a time of about 350 ms. From the amplitude spectrum (figure 22) and from any of the seismic sections, the highest useful frequency is 100 Hz, which (assuming average velocity of 3000 m/s) corresponds to a wavelet with a wavelength of 30 m (98 ft.). With this wavelength, bed thicknesses of 15 m and vertical fault offset of six meters or more can be detected.

With poor velocity control, identification of individual rock units is at best an educated guess. Useful aids for identifying the units are approximate depth, average velocity, rock type (for determining reflection coefficient), relationships with surrounding rocks, and synthetic seismograms.

Much unwanted seismic information cannot be eliminated or attenuated. Complicating the geological interpretation may be reflections out of the vertical plane of the survey; complex energy ray paths; focusing problems associated with complicated geologic structures; diffractions from fault surfaces; residual effects of ground roll and first energy interference, processing techniques; and recording equipment limitations.

The geological interpretation can be divided into three sections: the Forest City Basin, the Humboldt fault, and the Nemaha Ridge. In the Forest City Basin, four major reflections (figure 21) are recognized at the east end on the seismic line near receiver location 185: 1) Admire Group at 105 ms; 2) Tecumseh Shale Group at 180 ms; 3) the Drum-Dennis

Limestones at 285 ms; and 4) top of the Cherokee Group at 375 ms. In addition, nearly 40 other limestone and shale units are resolved on the section. Generally the units are about 15 m thick. The rock units are uniformly flat (less than one degree) between receiver group 187 and group 35. A small monocline, with 12 m of vertical displacement, is seen between groups 35 and 25. The rock units are essentially flat between group 25 (line B) and group 25 (line A) at the west edge of the basin.

The Humboldt Fault region begins at group 25 on line A and ends at group 95 on line A. For the 1120 m between groups 25 and 95, the rock units above the Basal Kansas City dip at an average of 11 degrees eastward. At the east edge of the region, between groups 40 and 50, a relatively steep slope of 23 degrees permeates the entire section, cropping out at the surface where DuBois (1978, p.16) measured 19 degrees of dip on Permian rocks in the Council Grove Group.

A nearly flat bench extends west for 80 m between groups 50 and 55. At the west end of this bench, at group 55, the easterly dipping slope of 12 degrees continues smoothly up to the crest of the ridge to group 95, interrupted only by a small vertical fault. At the crest of the ridge, low dips are observed throughout the section, including at the surface where DuBois (1978, p.16) measured dips of two degrees on ledges of the Reading and Wakarusa limestones.

The one small fault is located at group 62 with 7 ms of vertical offset corresponding to 12 m of throw estimated from the seismic section. A post-Permian throw is estimated at 32 m on the fault if the average dip of 11 degrees observed on the seismic section is used in-

stead of the 19 degrees used by DuBois from surface dip observations. Thus the fault throw estimated directly from the seismic section and the throw estimated from the combination of dip and stratigraphic thicknesses measured at the surface now agree within 20 m.

Above the Nemaha Ridge, beyond group 95 (line A), the Pennsylvanian rocks lie unconformably on the granite surface of the Nemaha ridge. The rocks dip slightly eastward over this section although the seismic line seems to show westward dip (this was introduced by the trimming technique in the processing). At 235 ms (group 140), the upper section of the Cherokee Group overlies the Precambrian granite surface at a depth of 353 m. At this location, the Drum-Dennis Limestones are at 145 ms (207 m deep).

Post-Pennsylvanian draping over the Humboldt Fault was observed 150 to 200 km. to the south in Chase and Butler Counties by Berendsen (1980, personal communication).

The observed fault throw of 12 m on the seismic line is now in closer agreement with the missing stratigraphic rock section of 53-74 m estimated by DuBois (1978). A detailed drilling program across the Humboldt Fault is needed to remove the differences between the geologic (DuBois, 1978) and the seismic interpretation of the post-Pennsylvanian faulting and draping.

### Conclusions

The initial goal of determining the location and nature of the Humboldt fault 1.6 km (1 mi) south of the Nebraska-Kansas line in Nemaha County was accomplished by conducting a 5.3 km. long six-fold CDP seis-

mic reflection survey. High seismic data resolution was obtained by using short group spacings (16 m) and high frequency source energy (Wacker rammer).

The eastern two thirds of the seismic survey show nearly flat beds with only a small monocline near the center of the line. Limestone and shale units with thickness between 15 and 30 m, were resolved within the upper 600 m. The four prominent reflectors are 1) Admire Group at 105 ms., 2) Tecumseh Shale at 180 ms., 3) Drum-Dennis Limestones at 285 ms., and 4) the top section of the Cherokee Group at 375 ms.

The Humboldt Fault region has four features in the upper 600 m of the rock section. First, at the east edge, a relatively steep slope of 23 degrees permeates the total vertical section. Then a nearly flat bench extends 80 m to the west. The rest of the easterly dipping slope gradually flattens from 12 to zero degrees with only the last feature (the small vertical fault) interrupting the smooth incline. The vertical fault at group number 62 has a small offset of 12 m and definitely offsets the Drum-Dennis Limestones. The observed fault throw from the seismic line and the fault interpreted from the stratigraphic section by DuBois (1978) are now in closer agreement if the average dip of 11 degrees is used to compute rock thickness.

The western fifth of the seismic line shows the Pennsylvanian-Permian rock section overlying the Precambrian granite surface. Two prominent reflectors are observed: the Drum-Dennis Limestones at 145 ms. and the top section of on the Cherokee Group at 235 ms. resting unconformably the Precambrian granite.

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MAJOR TECTONIC FEATURES ASSOCIATED WITH THE NEMAHA RIDGE

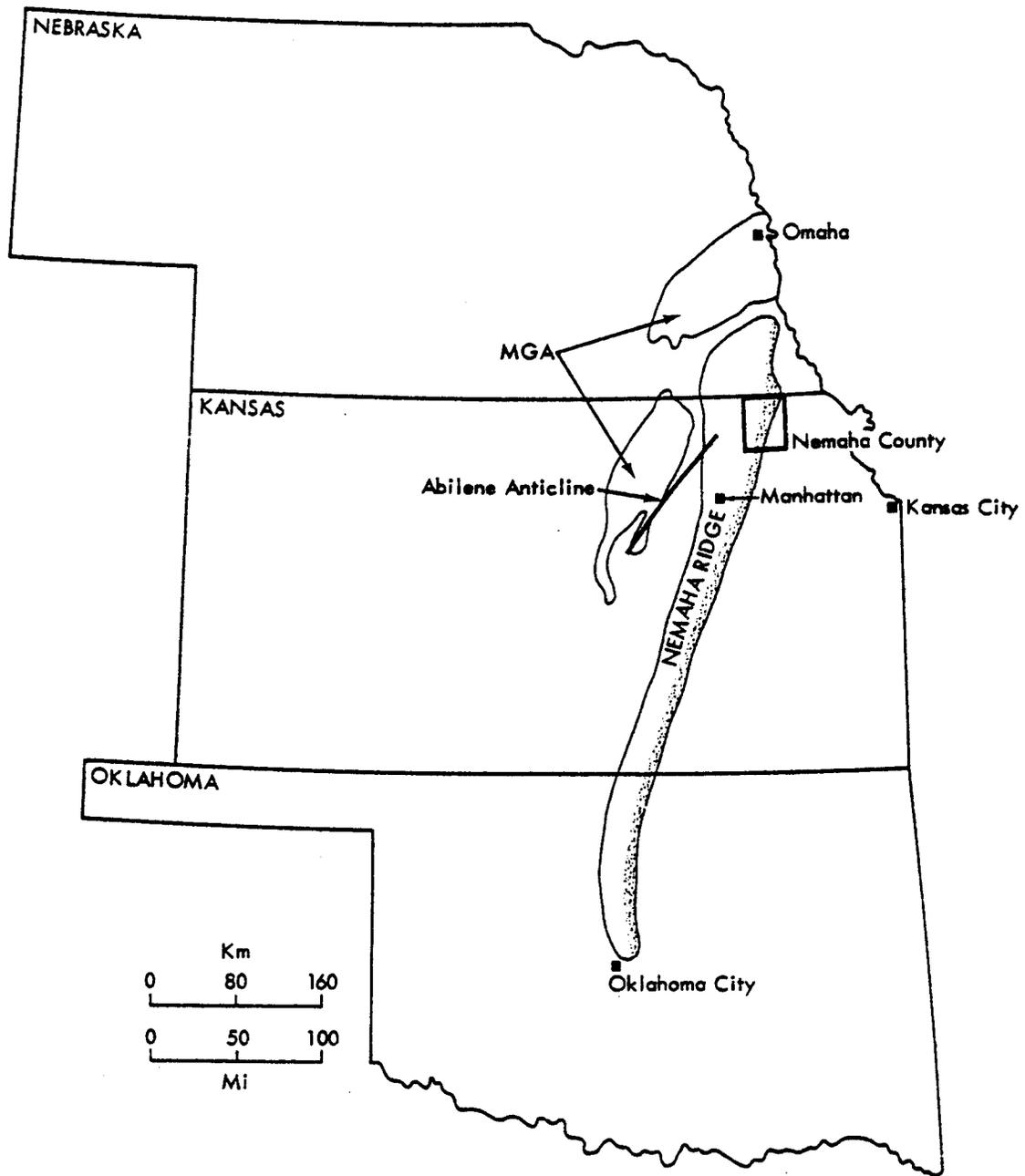


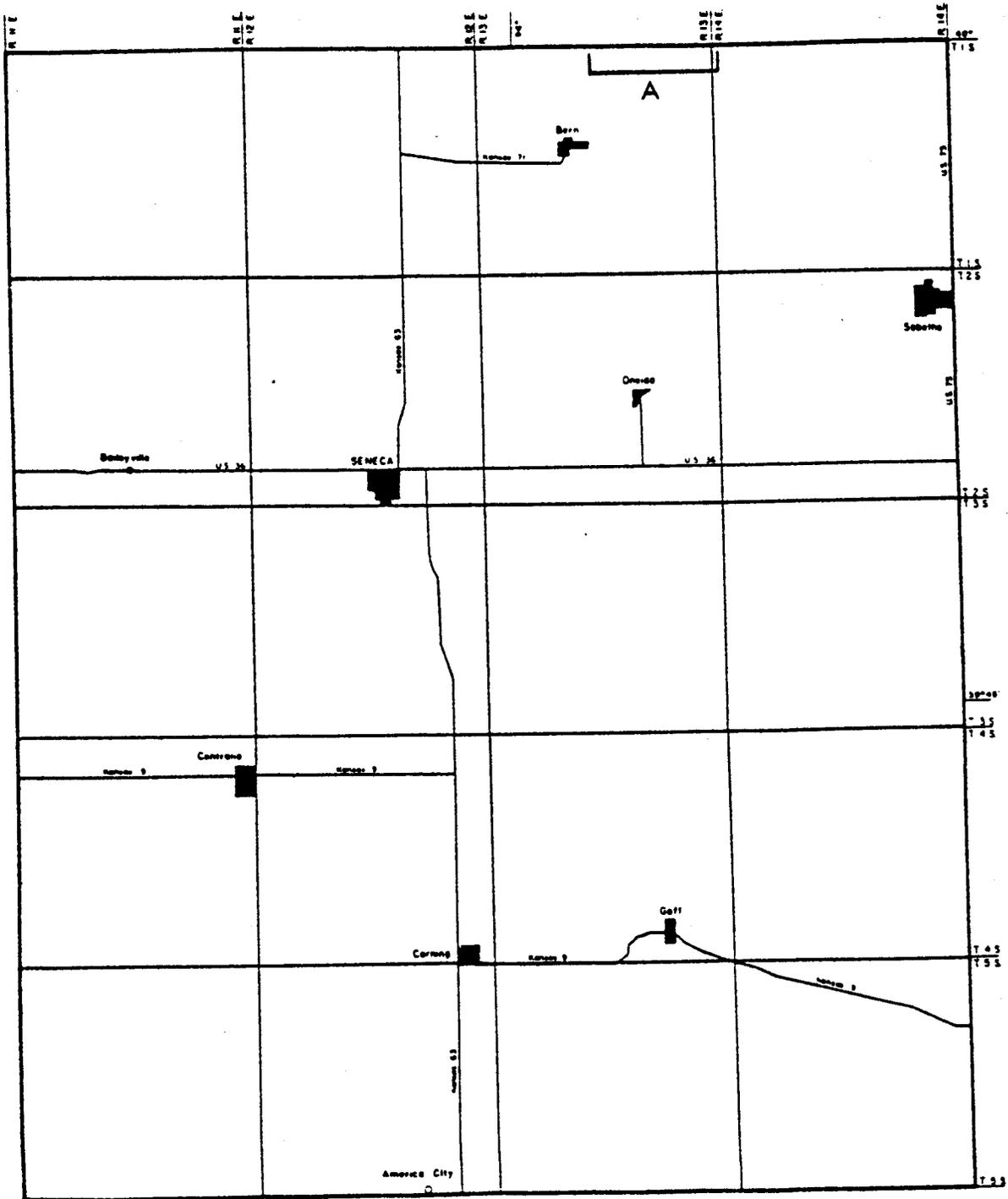
FIGURE 1



● Well to the Precambrian  
Precambrian Surface (Cole, 1976)

FIGURE 2

# BASE MAP OF NEMAHA COUNTY, KANSAS

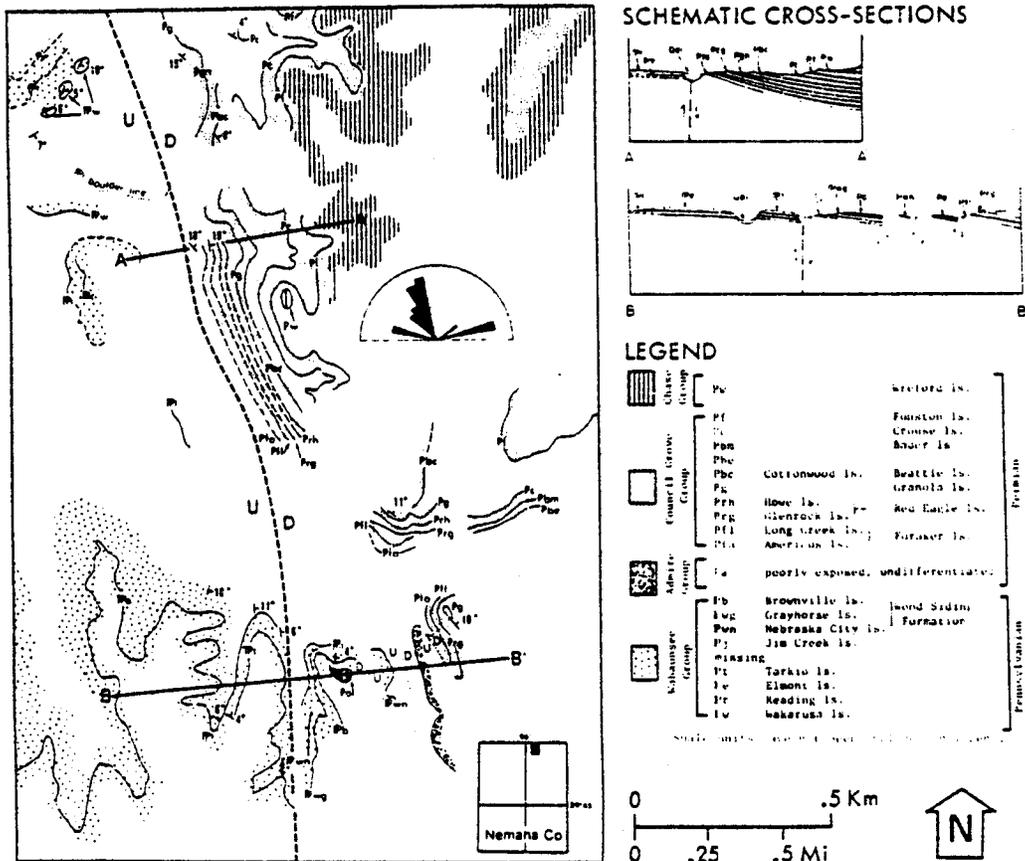


A - Seismic Line

(DuBois, 1978)

FIGURE 3

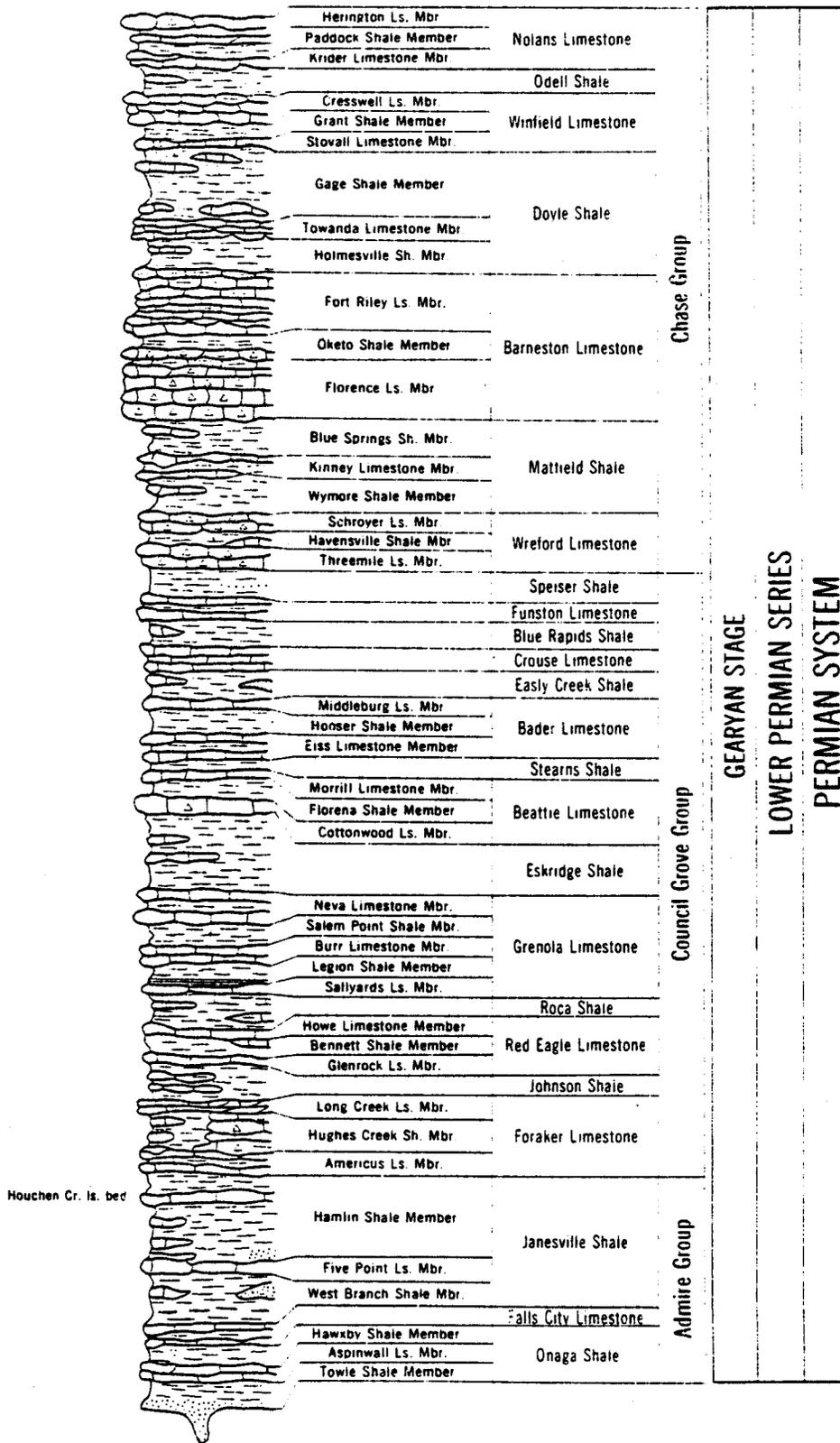
# GEOLOGY NORTHEAST OF BERN



(DuBois, 1978)

FIGURE 4

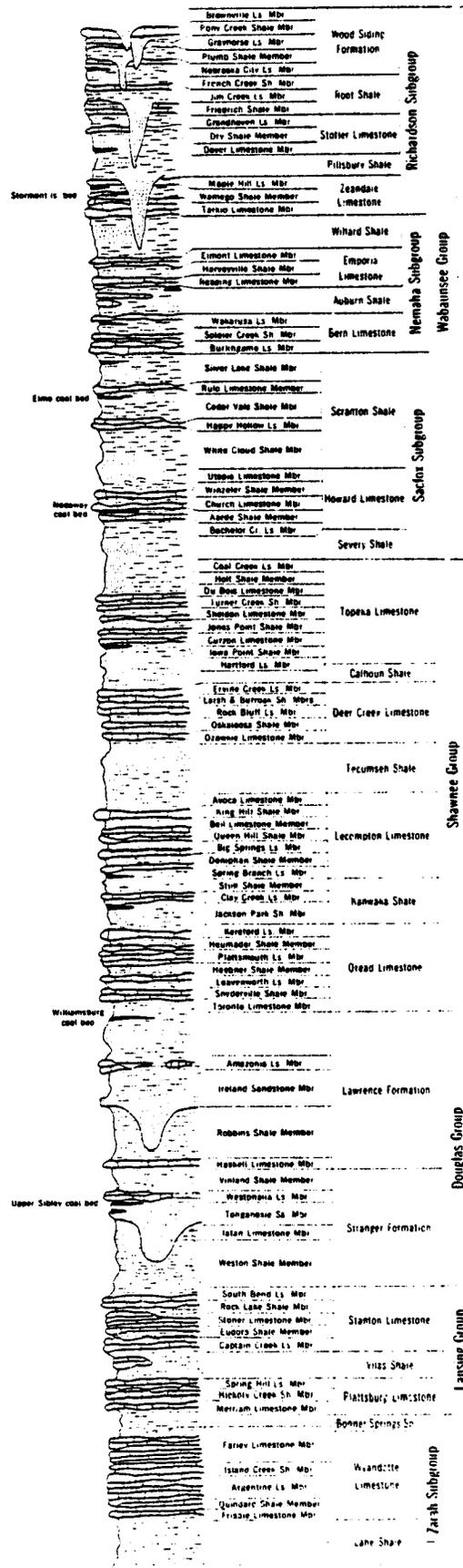
# STRATIGRAPHIC SECTION REPRESENTED BY SEISMIC SECTION



(Kansas Geological Survey Bulletin 189, Doris Zeller, ed., 1968)

FIGURE 5A

STRATIGRAPHIC SECTION REPRESENTED BY SEISMIC SECTION

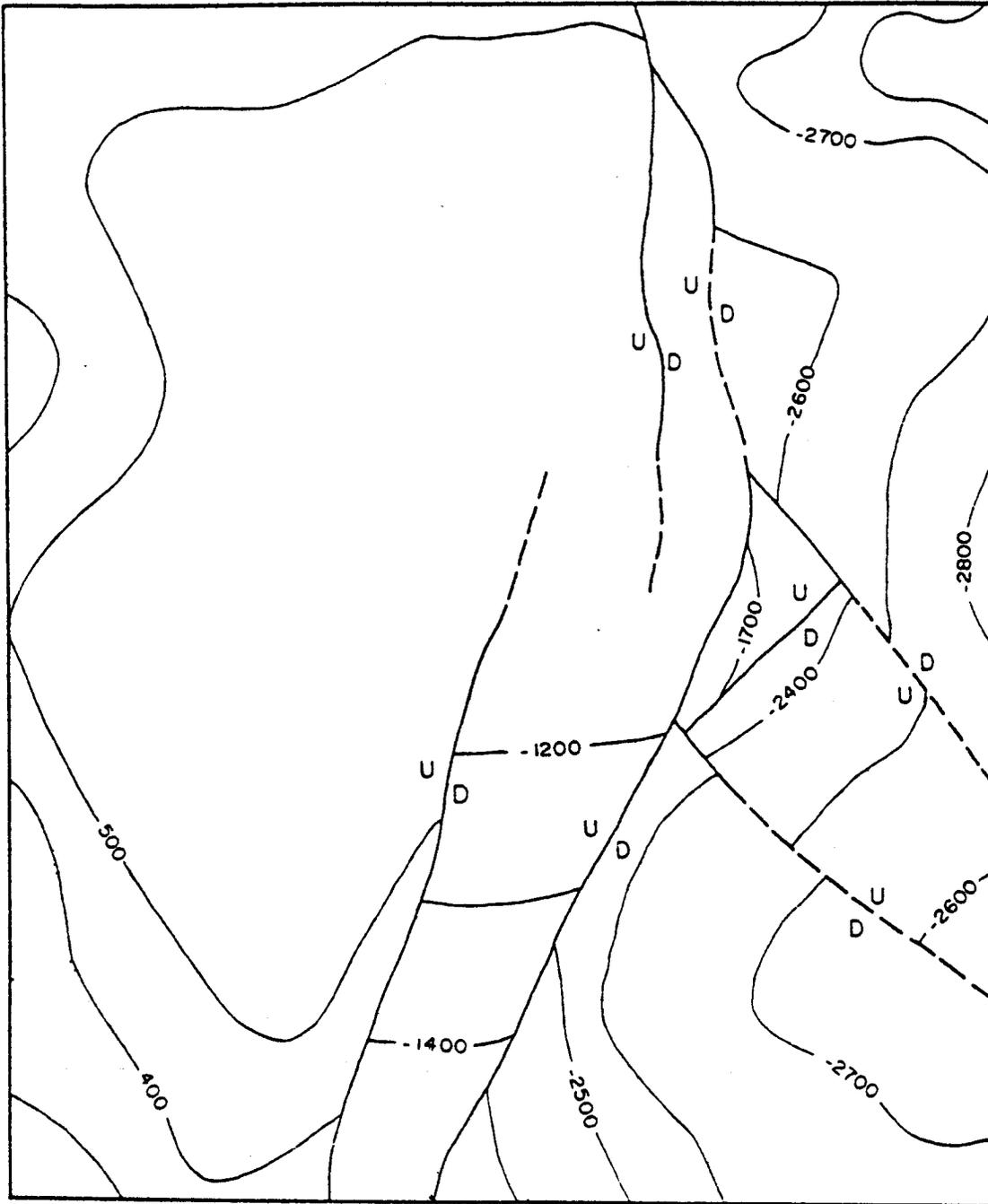


VIRGILIAN STAGE  
 UPPER PENNSYLVANIAN SERIES  
 PENNSYLVANIAN SYSTEM  
 PALEOZOIC ERA  
 MISSOURIAN STAGE

(Kansas Geological Survey Bulletin 189, Doris Zeller, ed., 1968)

FIGURE 5B





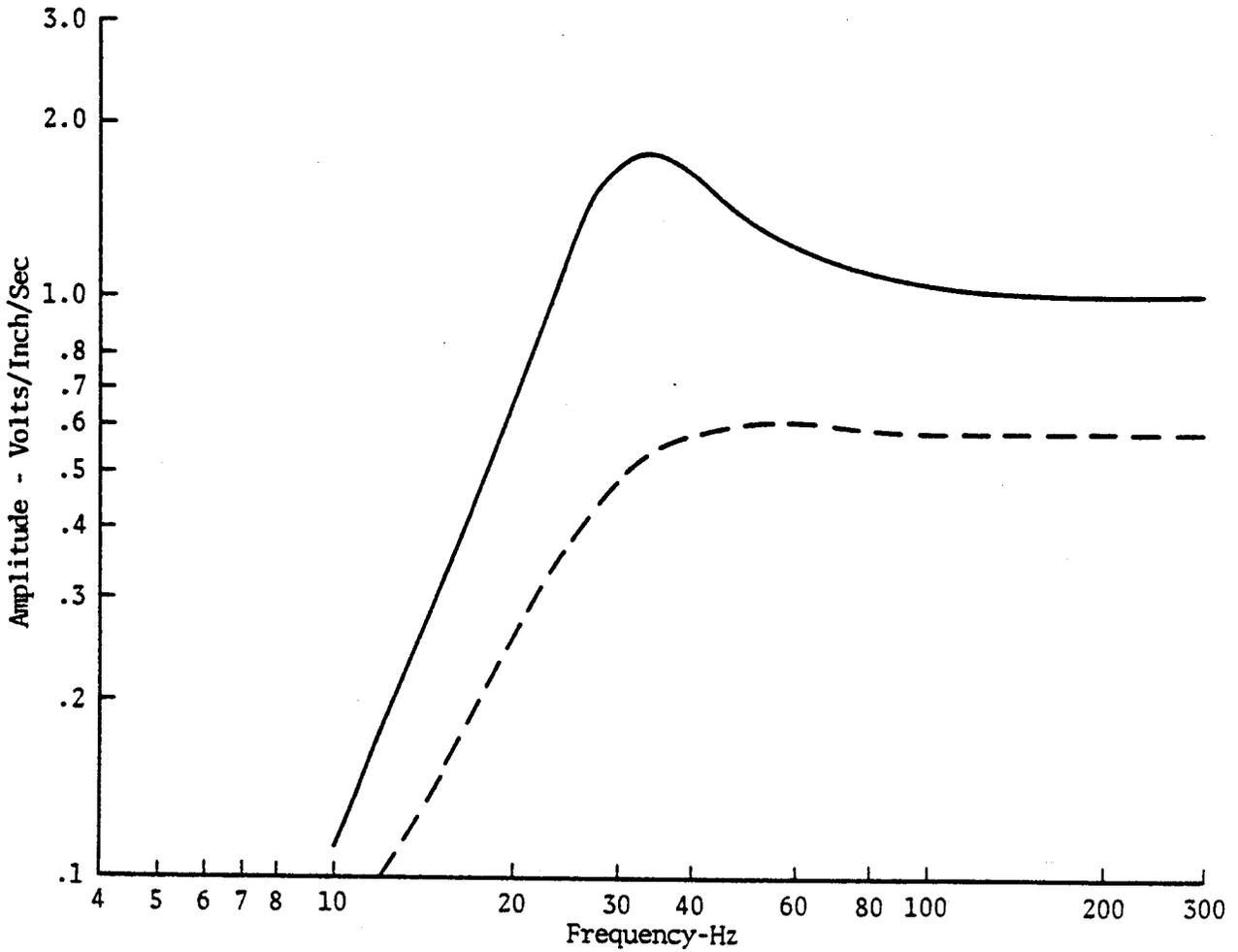
Precambrian Surface Inferred from  
Surface, Subsurface, and Geophys-  
ical Data

( DuBois, 1978 )

Contour Interval: 100 feet

FIGURE 6

GEOPHONE RESPONSE CURVE



Explanation

— Open-Circuit      - - - 985 Ohm Load  
(0.6 Damping)

FIGURE 7

MINI-SOSIE WACKER GVR - 151Y (RECORDED WITH 30 Hz GEOPHONE)

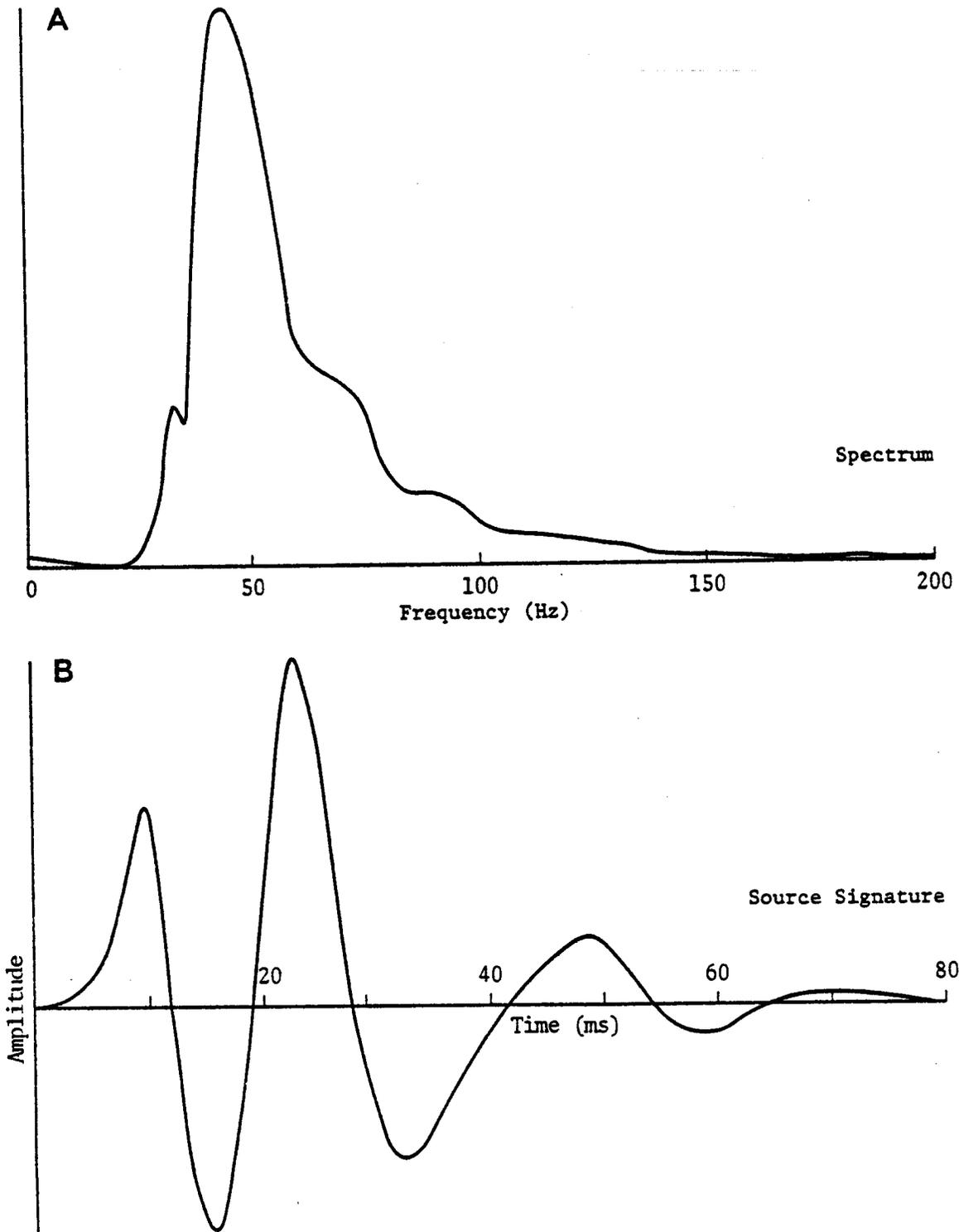
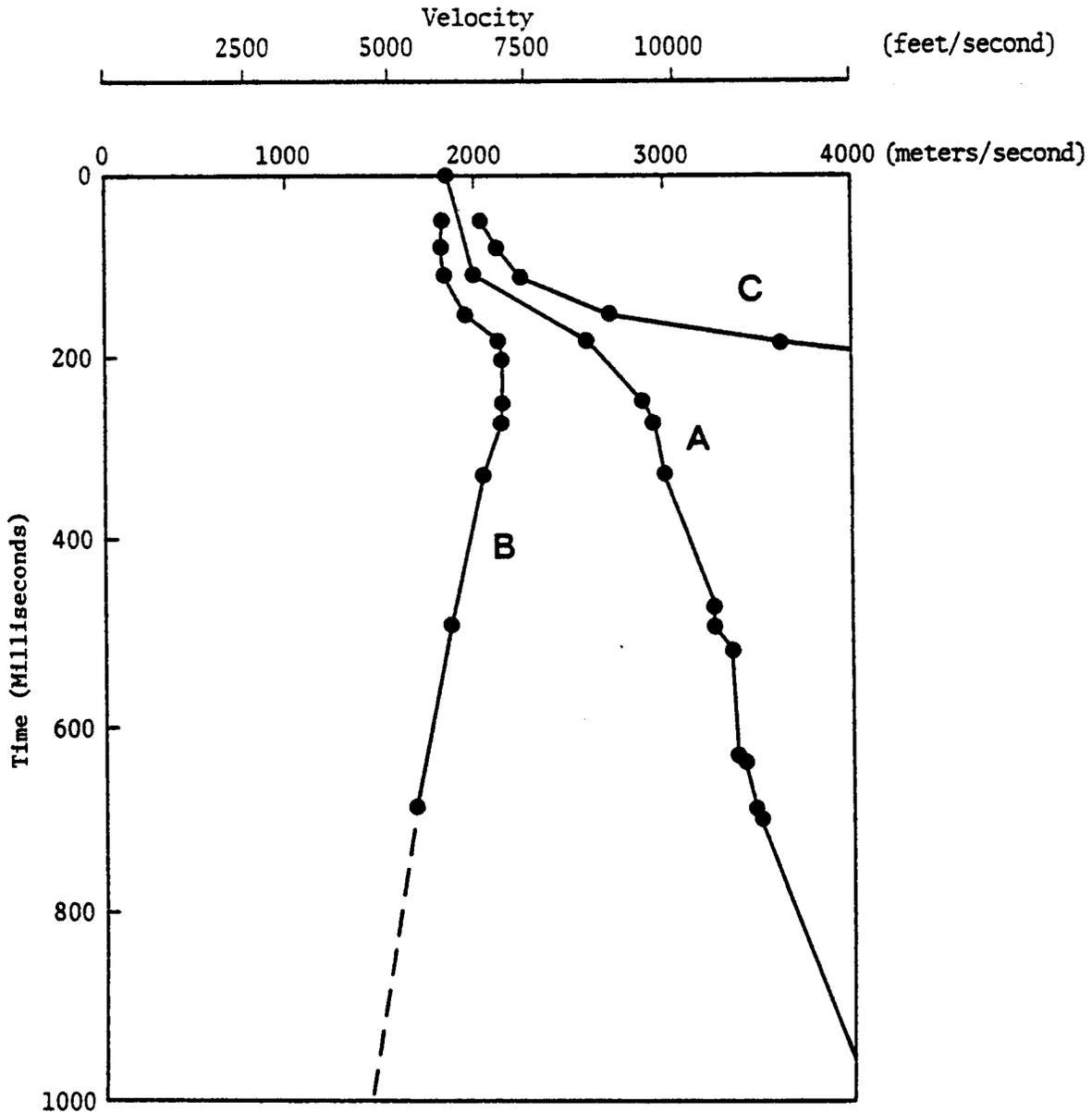


FIGURE 8

DEPTH - VELOCITY FUNCTION USED ON SEISMIC LINES



- A Time-Velocity Function Determined By Velocity Analyses.
- B +2.5 ms. Error Curve.
- C -2.5 ms. Error Curve.

Note: Any Time-Velocity Function Between Curves B and C Will Properly Correct For Normal Moveout With Less Than  $\pm 2.5$  ms. Of Error Of Curve A.

FIGURE 9

Selsmic Section Of The East Flank Of Nemaha Anticline

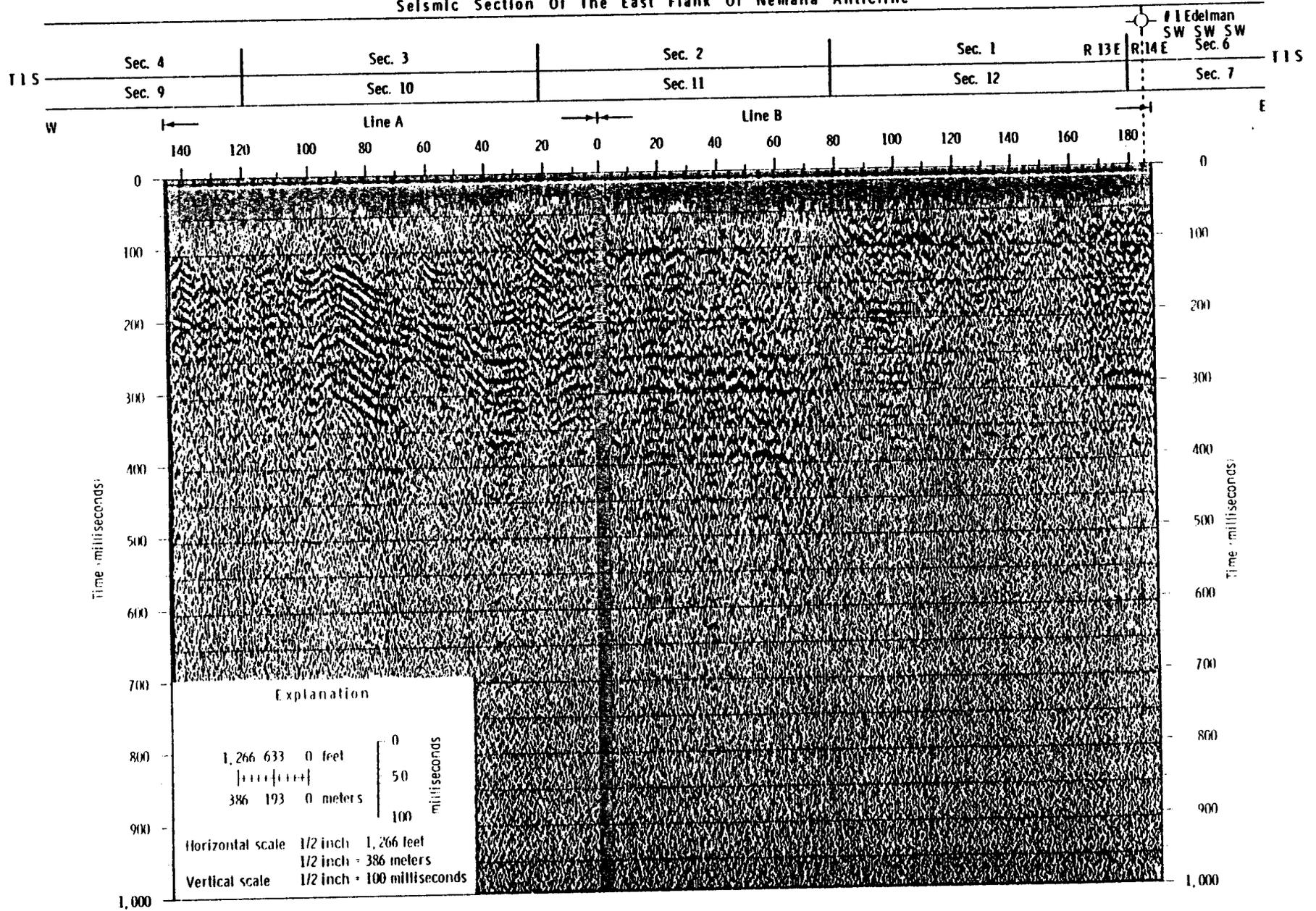


FIGURE 10: INITIAL 600% C.D.P. STACK SECTION

# Seismic Section Of The East Flank Of Nemaha Anticline

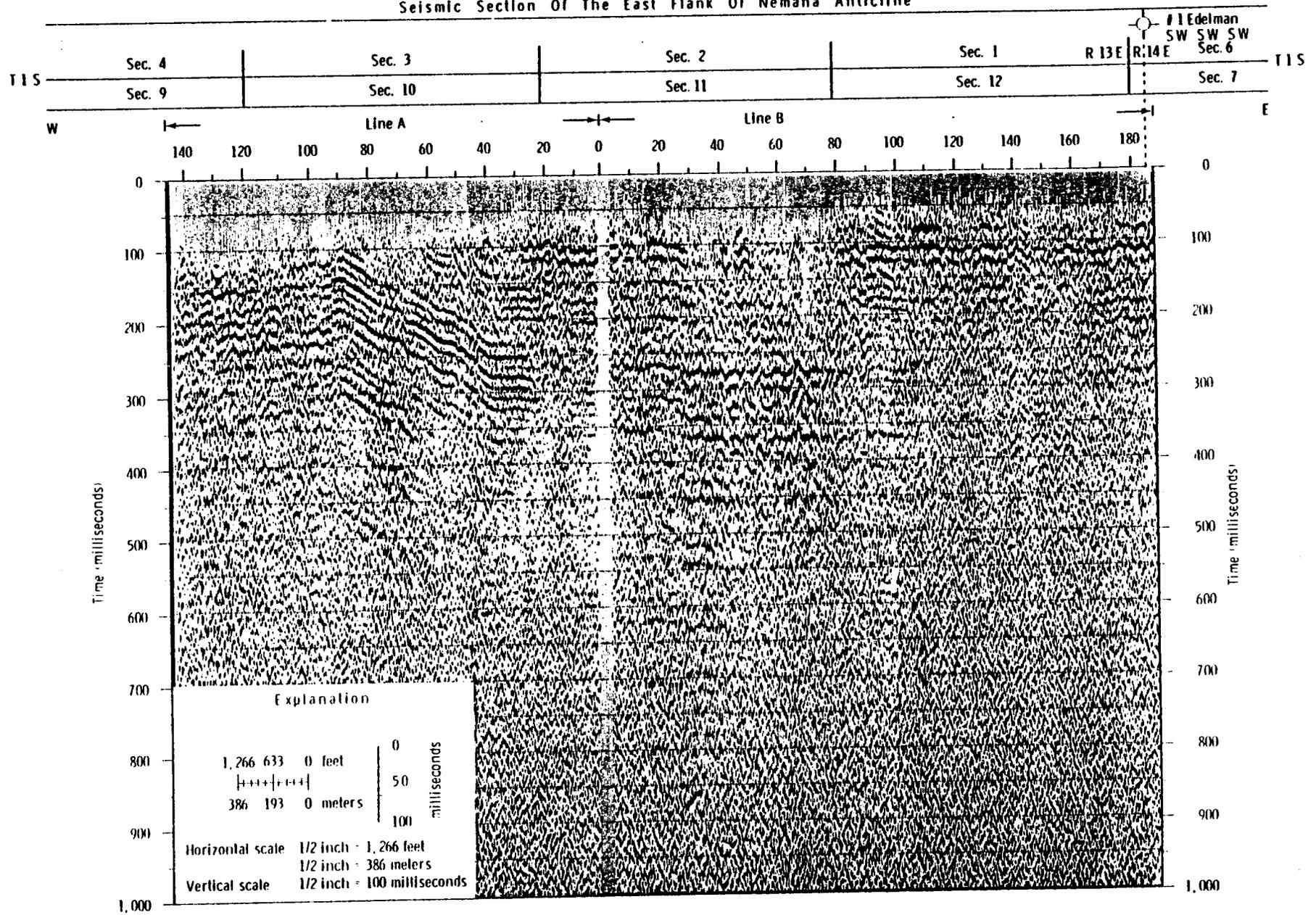


FIGURE 11: FIVE C.D.P. TRIMMED SECTION

# Seismic Section Of The East Flank Of Nemaha Anticline

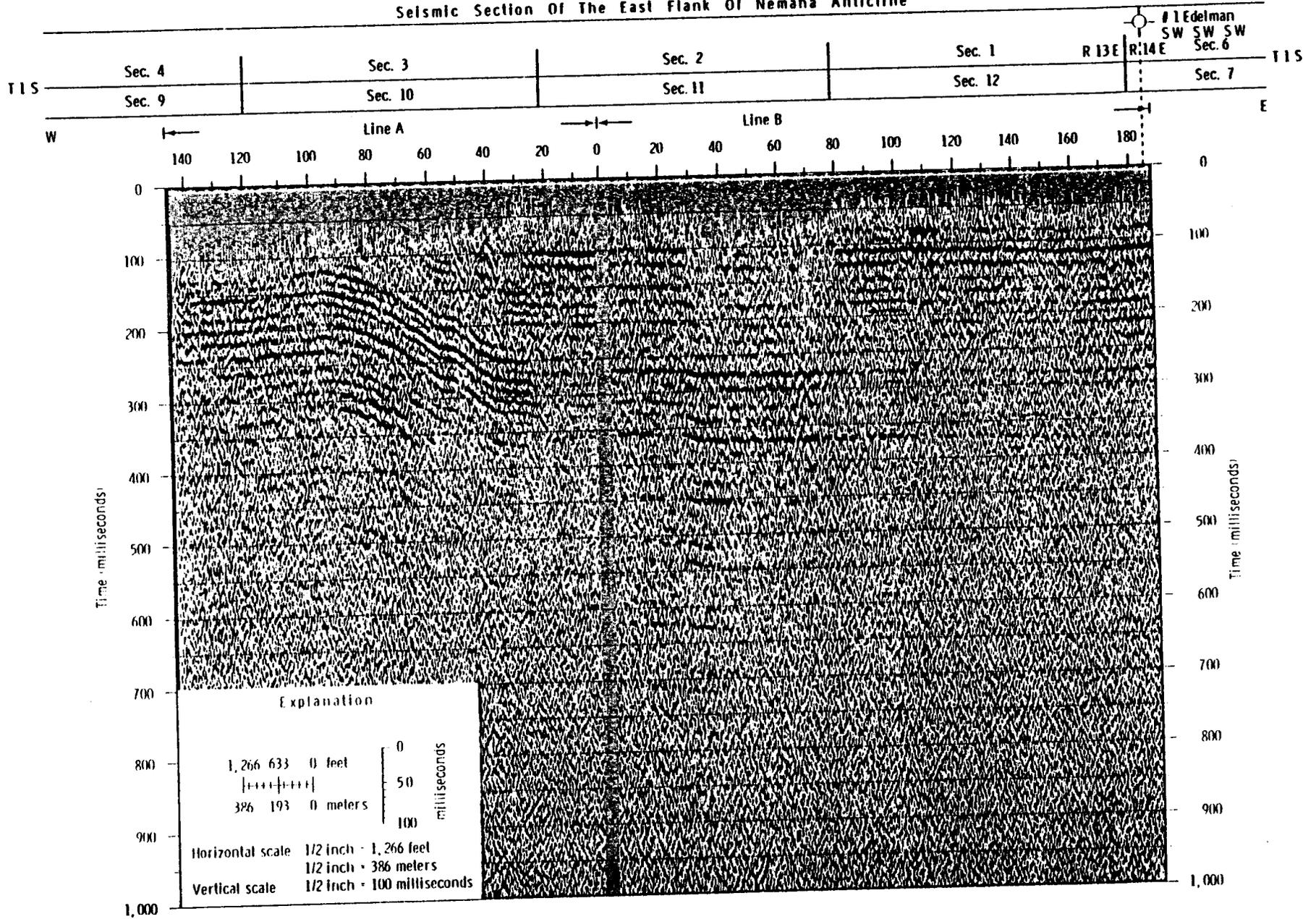


FIGURE 12: FORTY-NINE C.D.P. TRIMMED SECTION

# Seismic Section Of The East Flank Of Nemaha Anticline

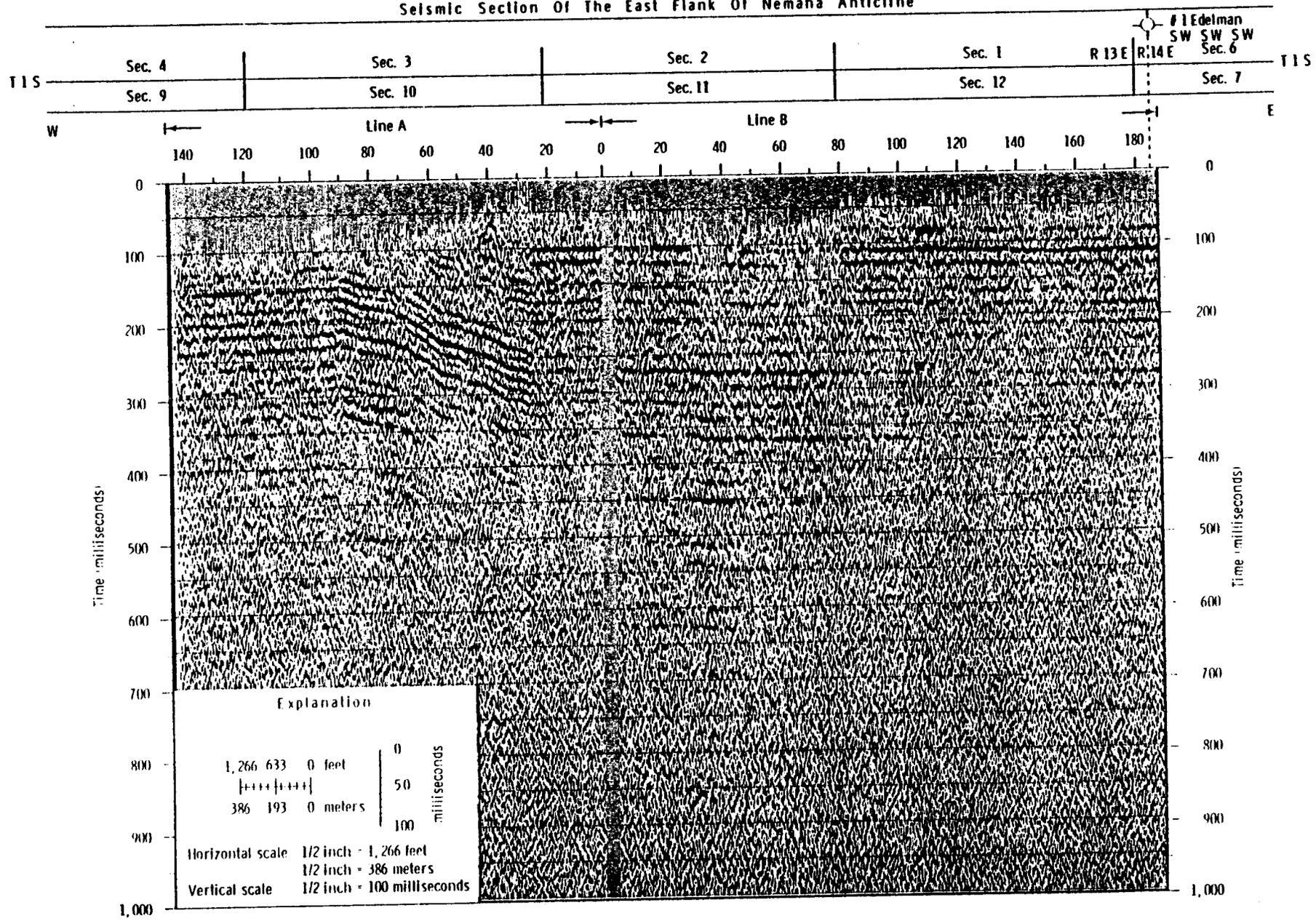


FIGURE 13: NINETY-NINE C.D.P. TRIMMED SECTION

# Seismic Section Of The East Flank Of Nemaha Anticline

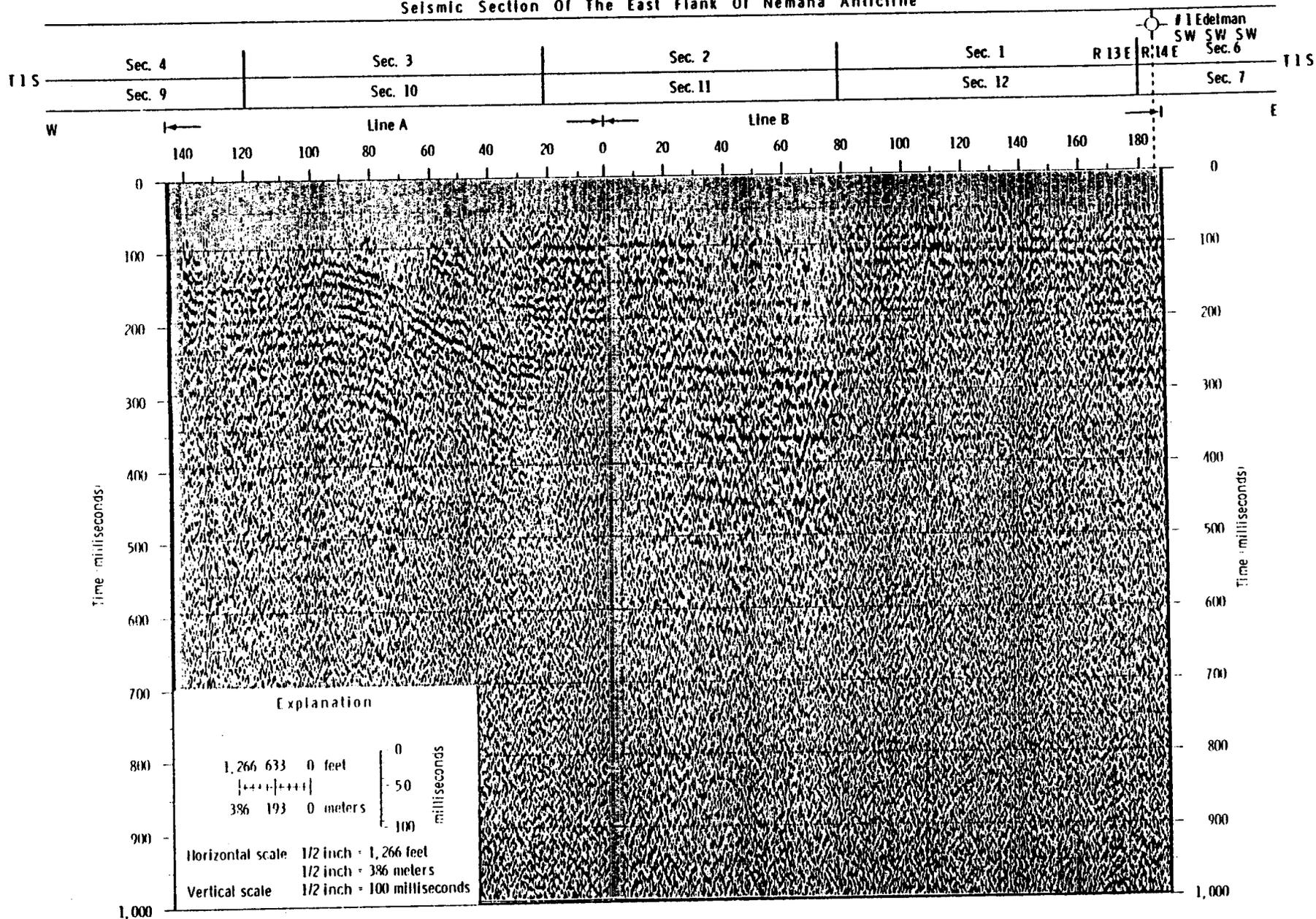


FIGURE 14: 200% C.D.P. SECTION

Selsmic Section Of The East Flank Of Nemaha Anticline

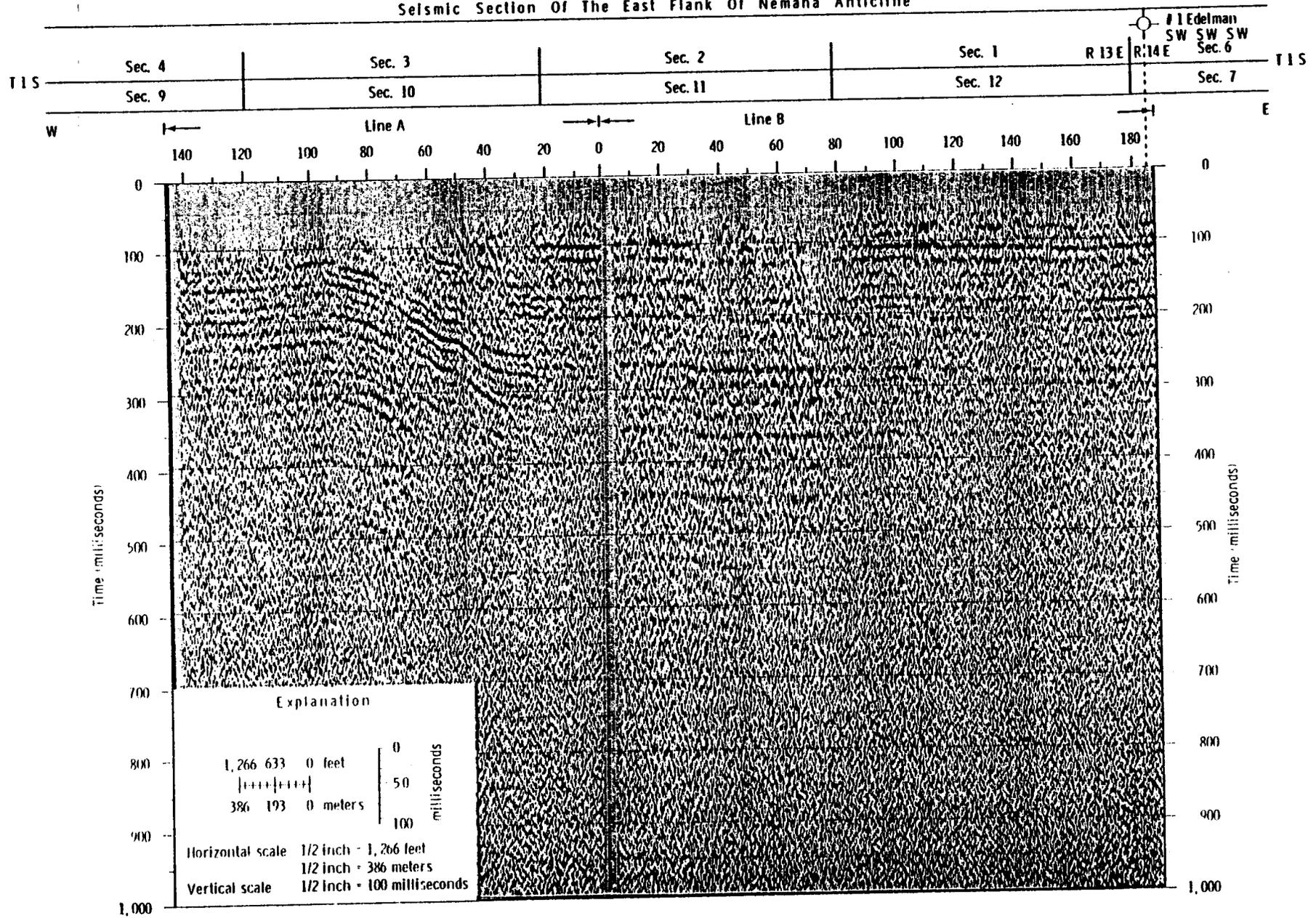


FIGURE 15: 300% C.D.P. SECTION

Seismic Section Of The East Flank Of Nemaha Anticline

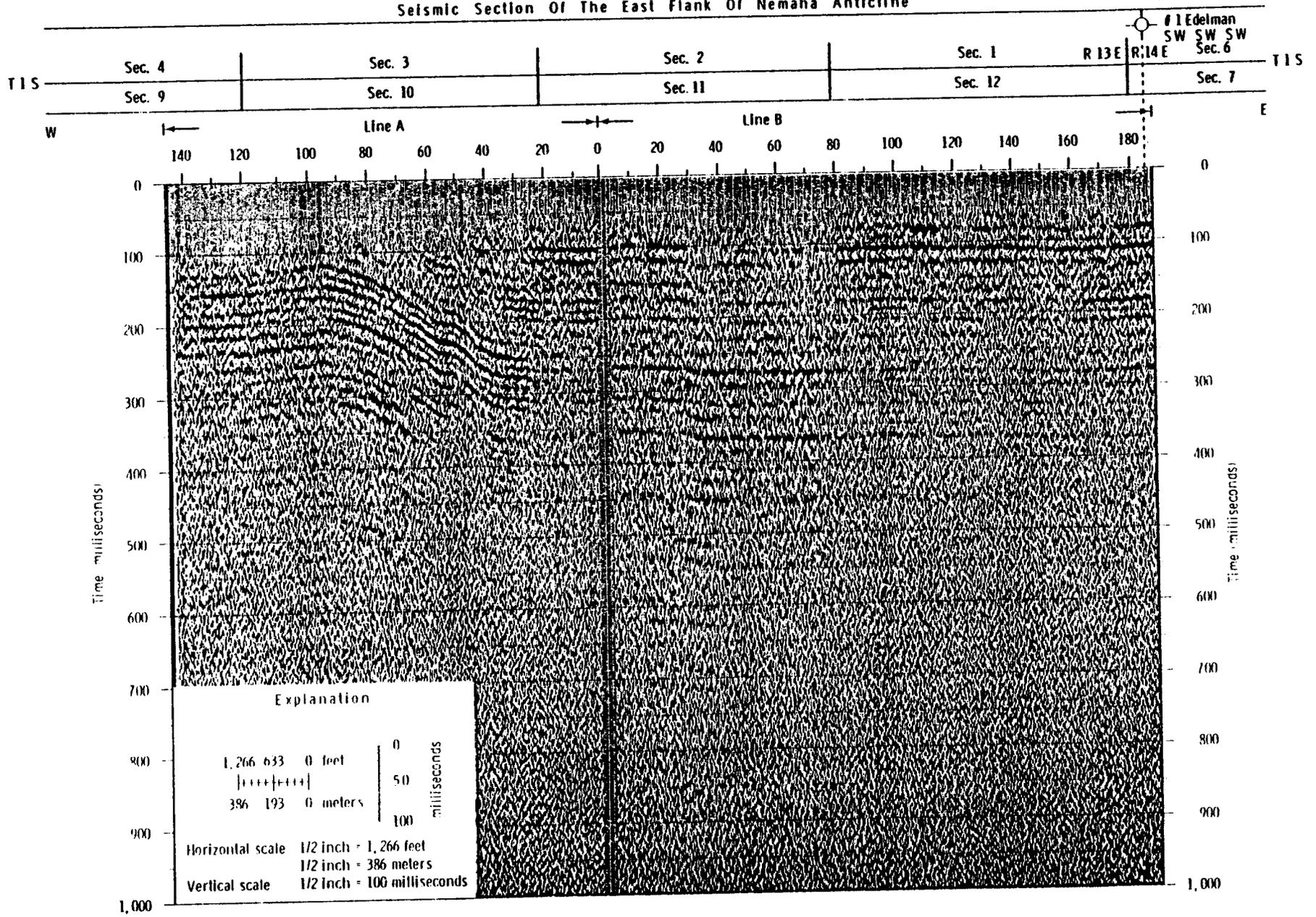


FIGURE 16: 600% C.D.P. SECTION

Seismic Section Of The East Flank Of Nemaha Anticline

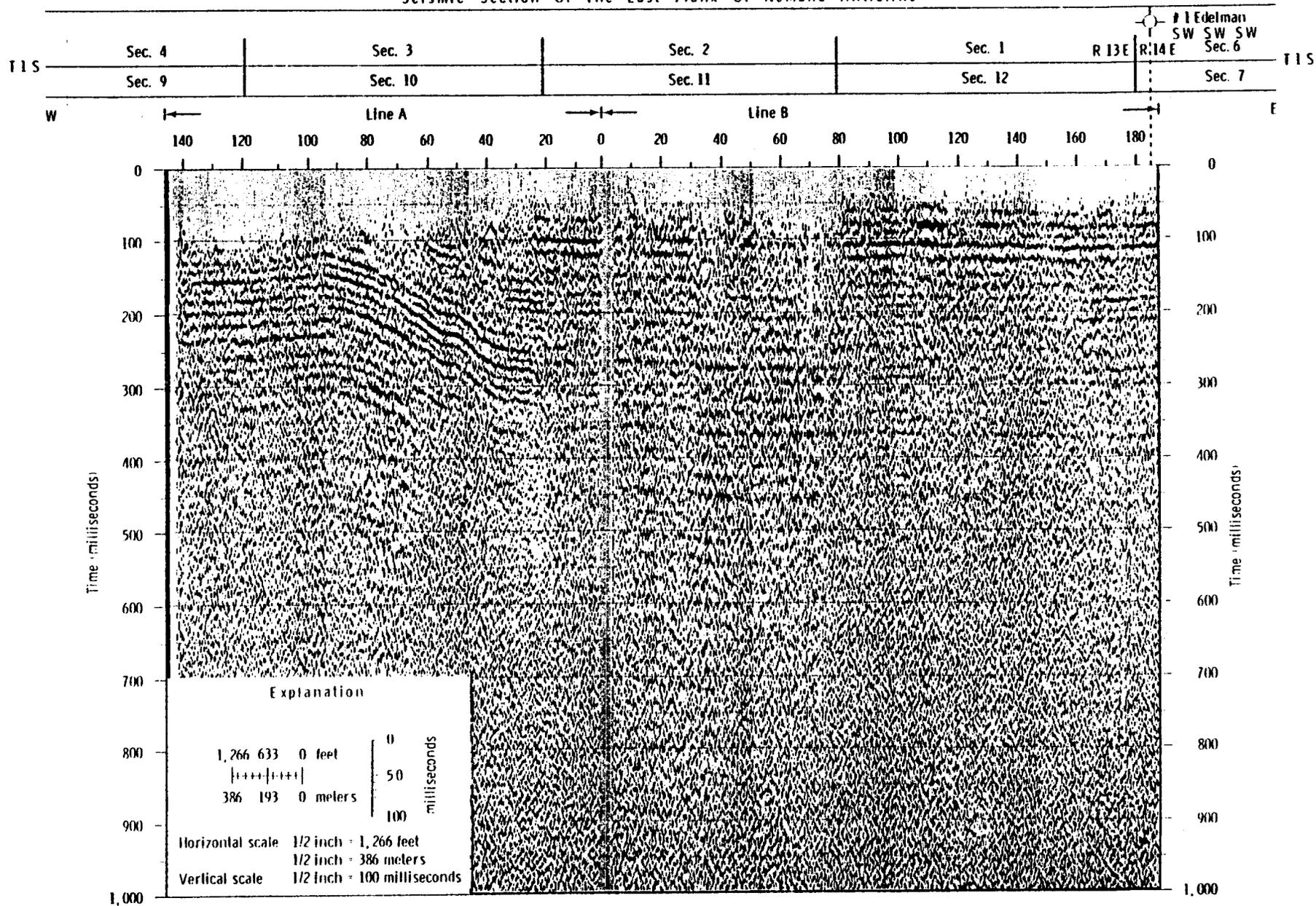


FIGURE 17: NEAR-RANGE C.D.P. SECTION

# Seismic Section Of The East Flank Of Nemaha Anticline

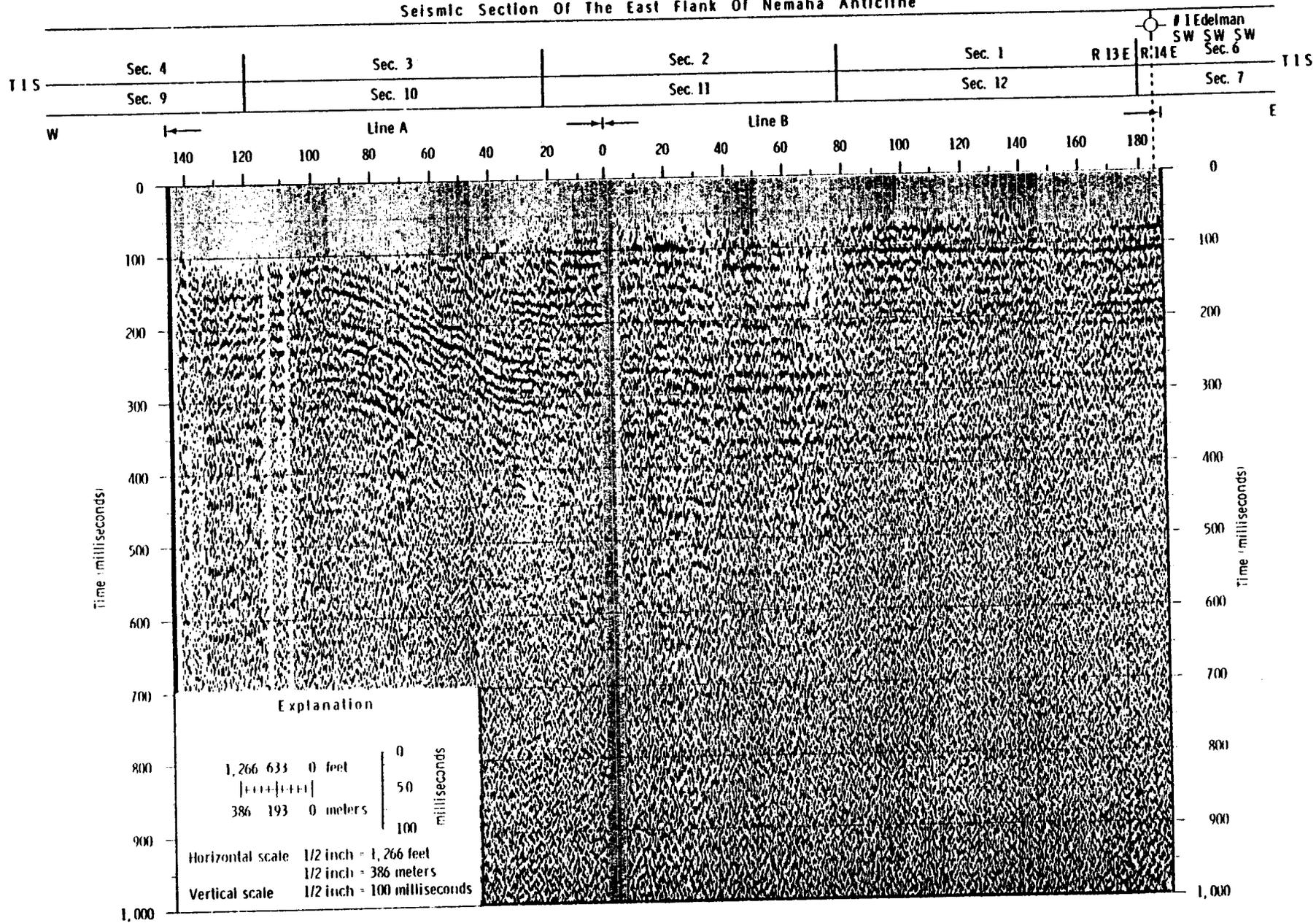


FIGURE 18: MIDDLE-RANGE C.D.P. SECTION

# Seismic Section Of The East Flank Of Nemaha Anticline

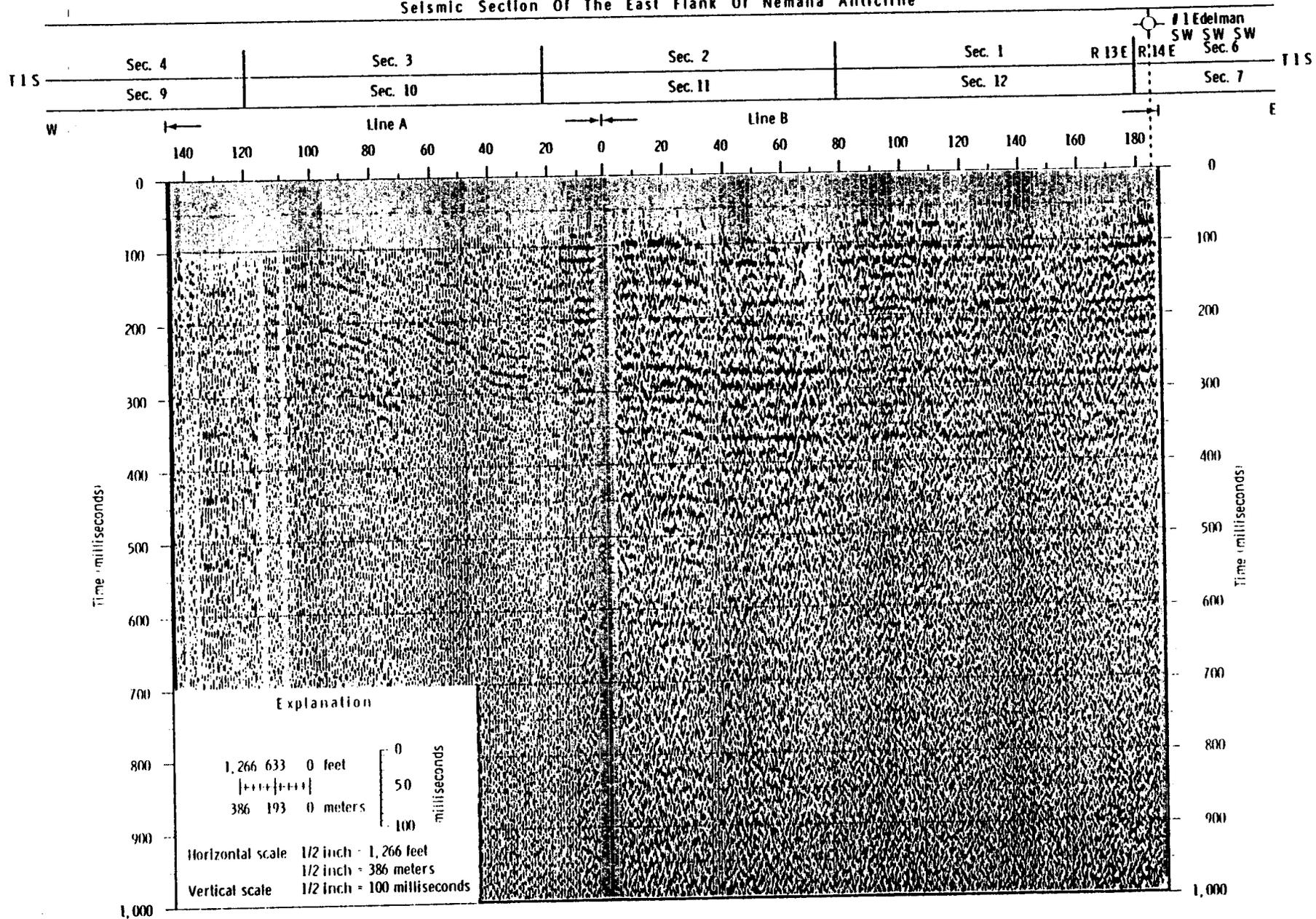


FIGURE 19: FAR-RANGE C.D.P. SECTION

Seismic Section Of The East Flank Of Nemaha Anticline

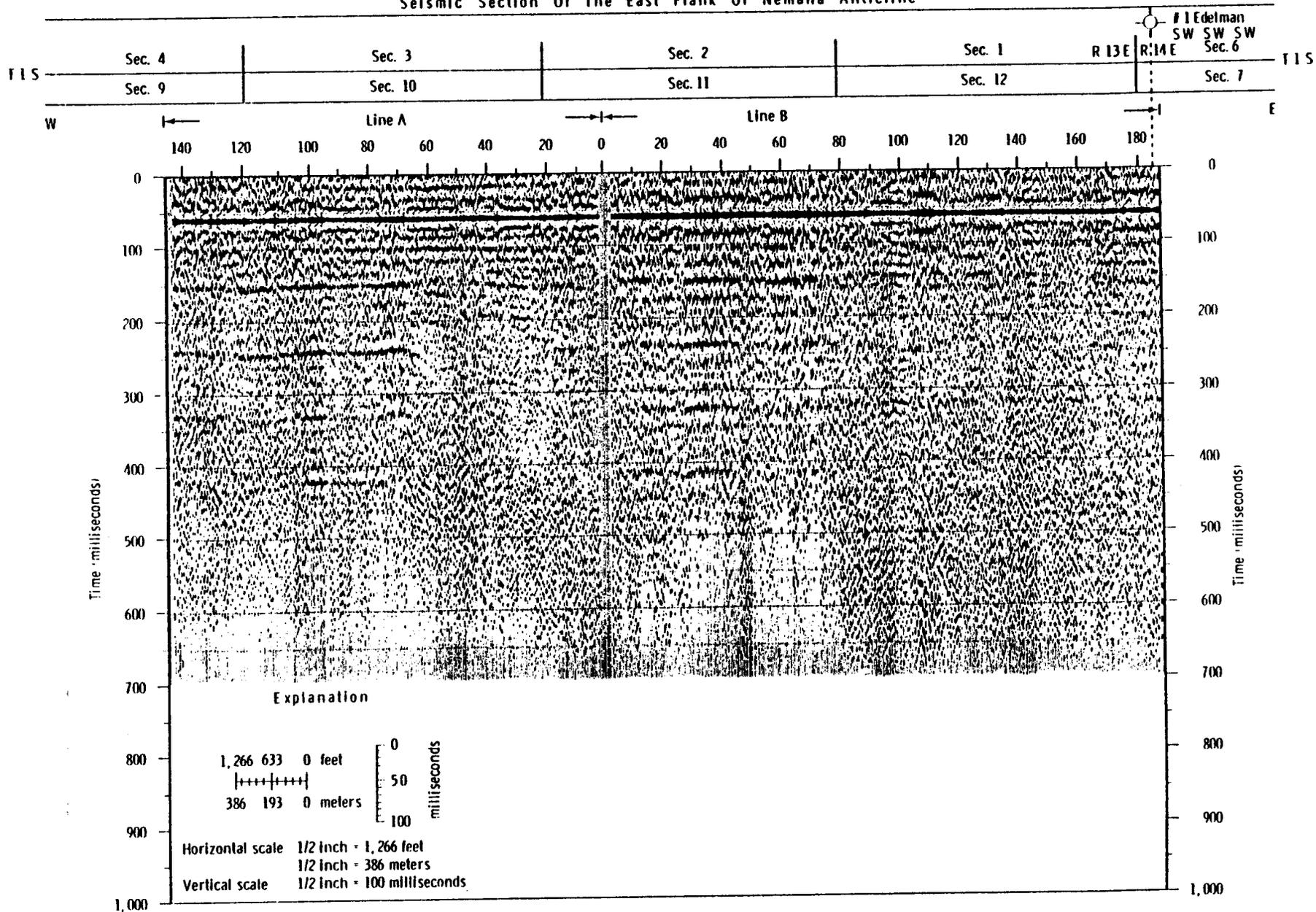


FIGURE 20: AUTOCORRELOGRAM OF C.D.P. SECTION

Seismic Section Of The East Flank Of Nemaha Anticline

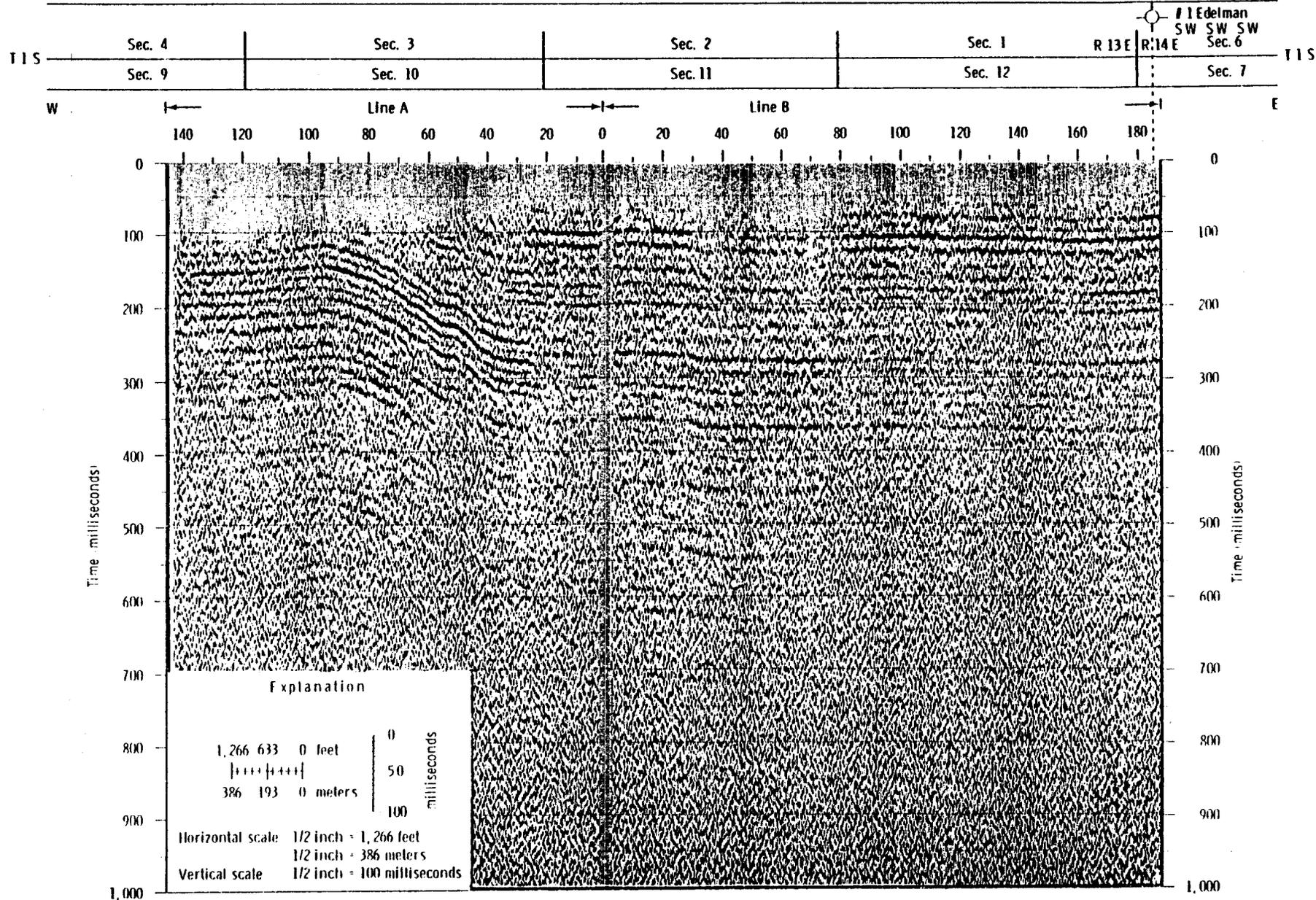


FIGURE 21: DECONVOLVED C.D.P. SECTION

AMPLITUDE SPECTRUM OF ONE SIX-FOLD STACKED TRACE AT GROUP 176 (LINE B)

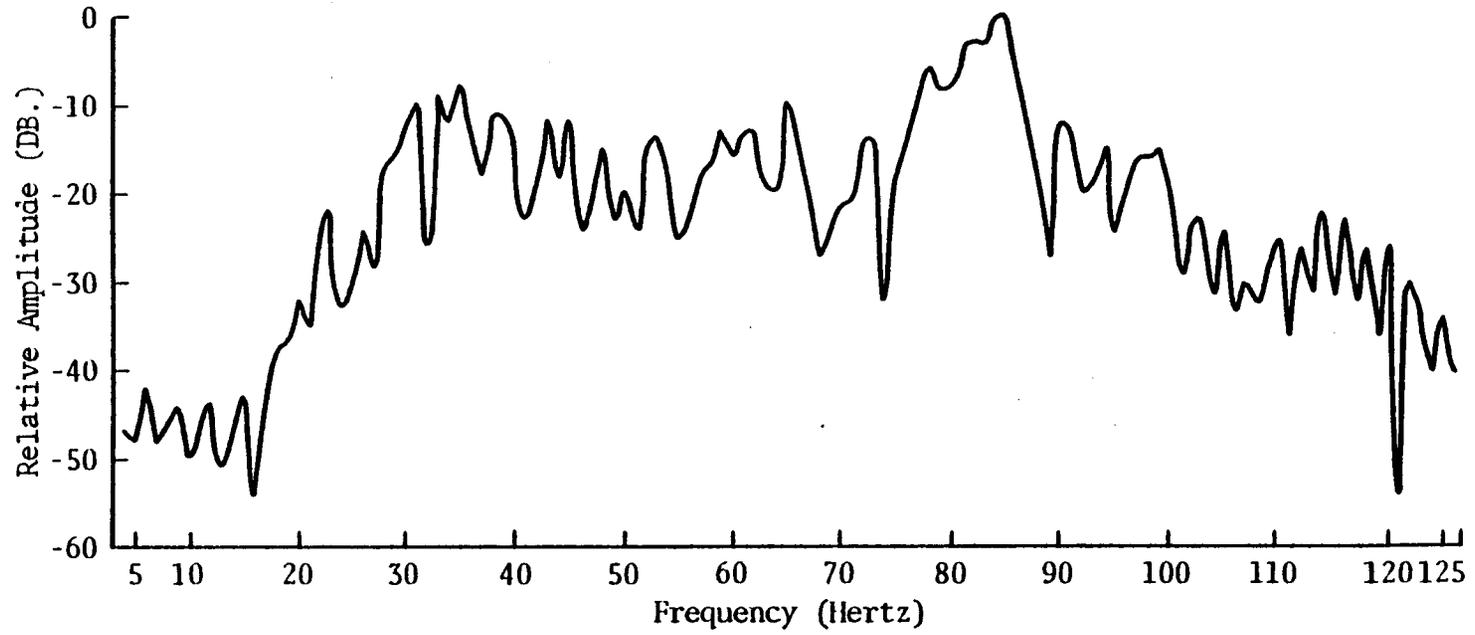


FIGURE 22

Seismic Section Of The East Flank Of Nemaha Anticline

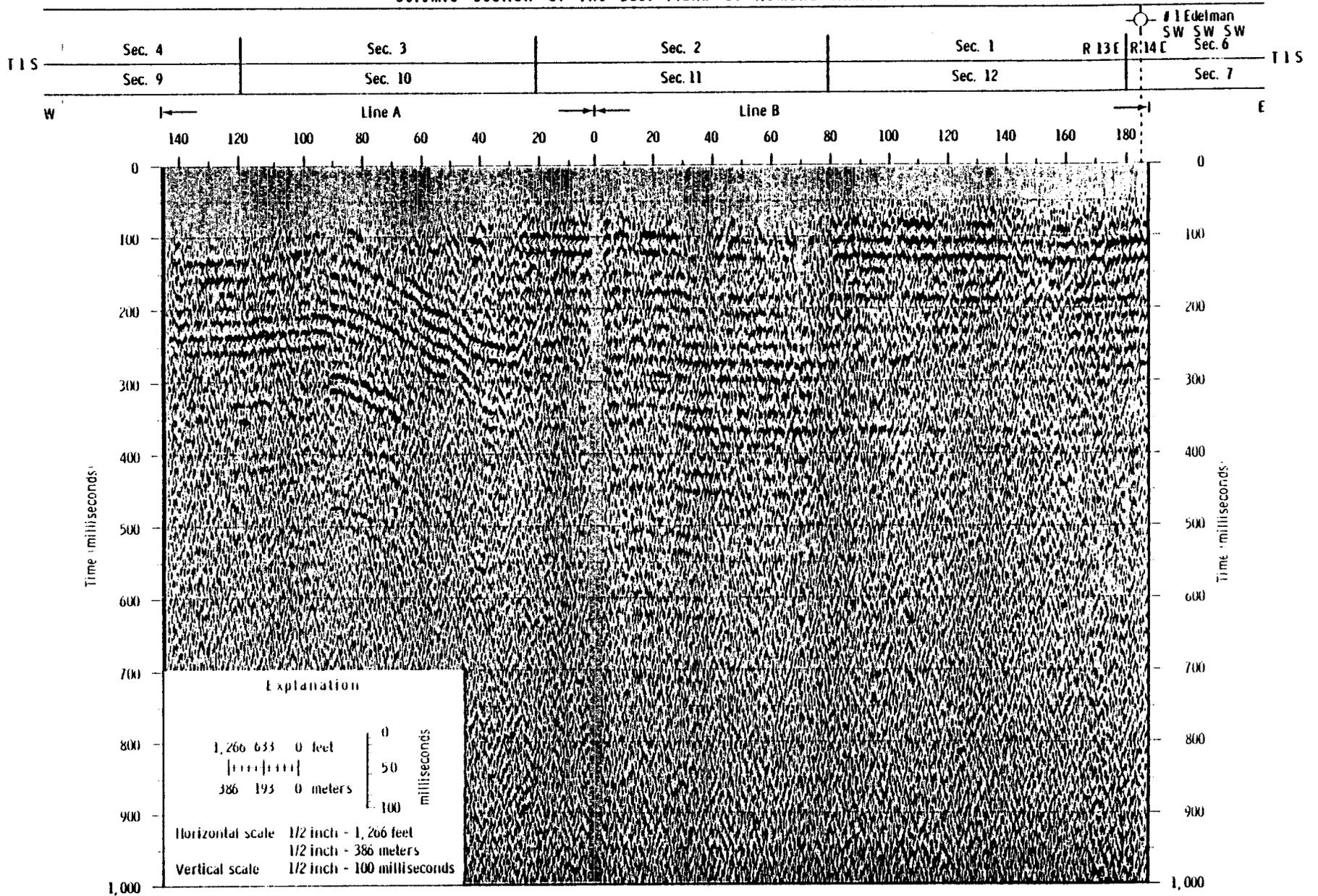


FIGURE 23: ONE TO THIRTY HERTZ FILTERED C.D.P. SECTION

Selsmic Section Of The East Flank Of Nemaha Anticline

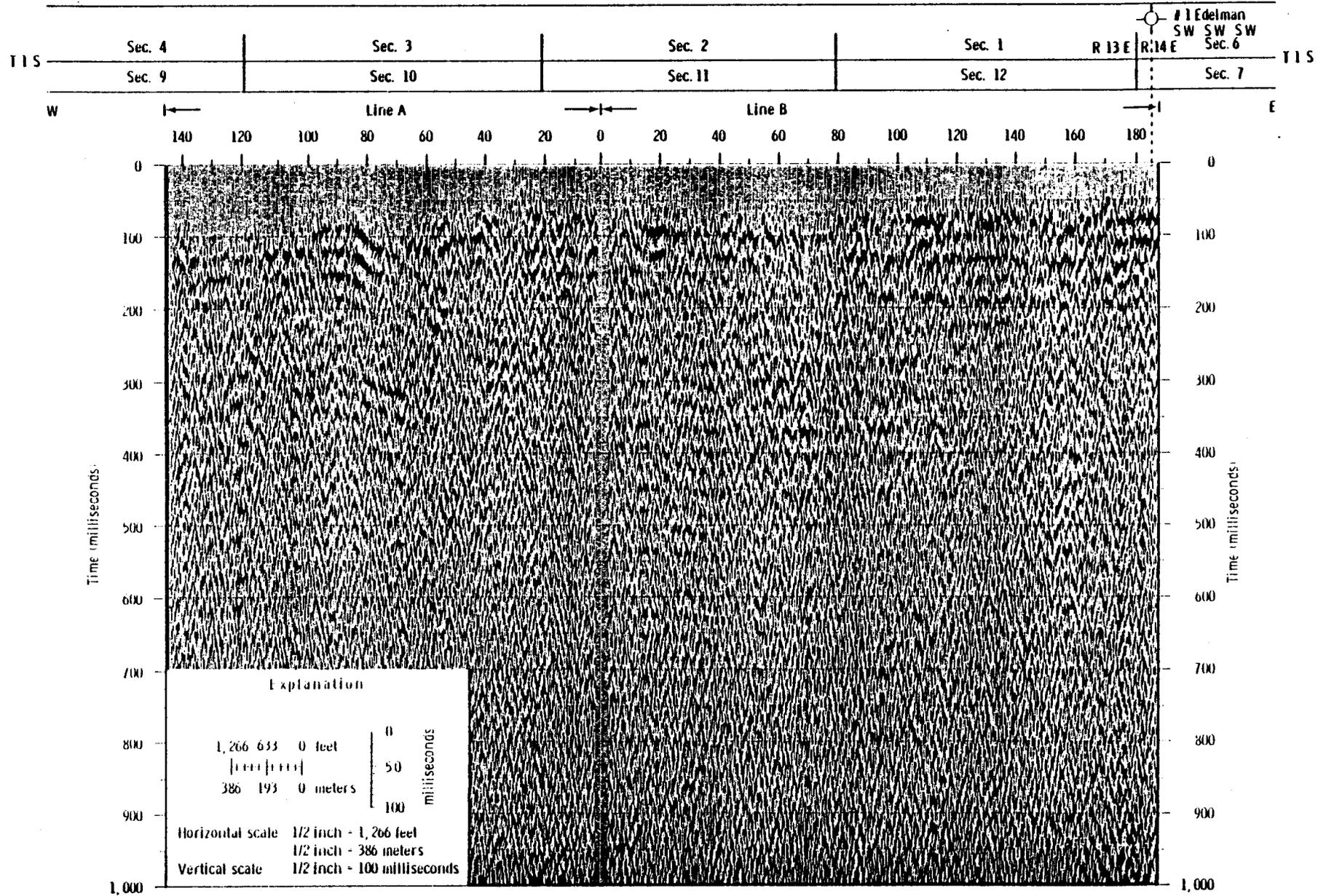


FIGURE 24: ONE TO FIFTY HERTZ FILTERED C.D.P. SECTION

EDELMAN #1 WELL ELECTRIC LOGS AND SYNTHETIC SEISMOGRAMS

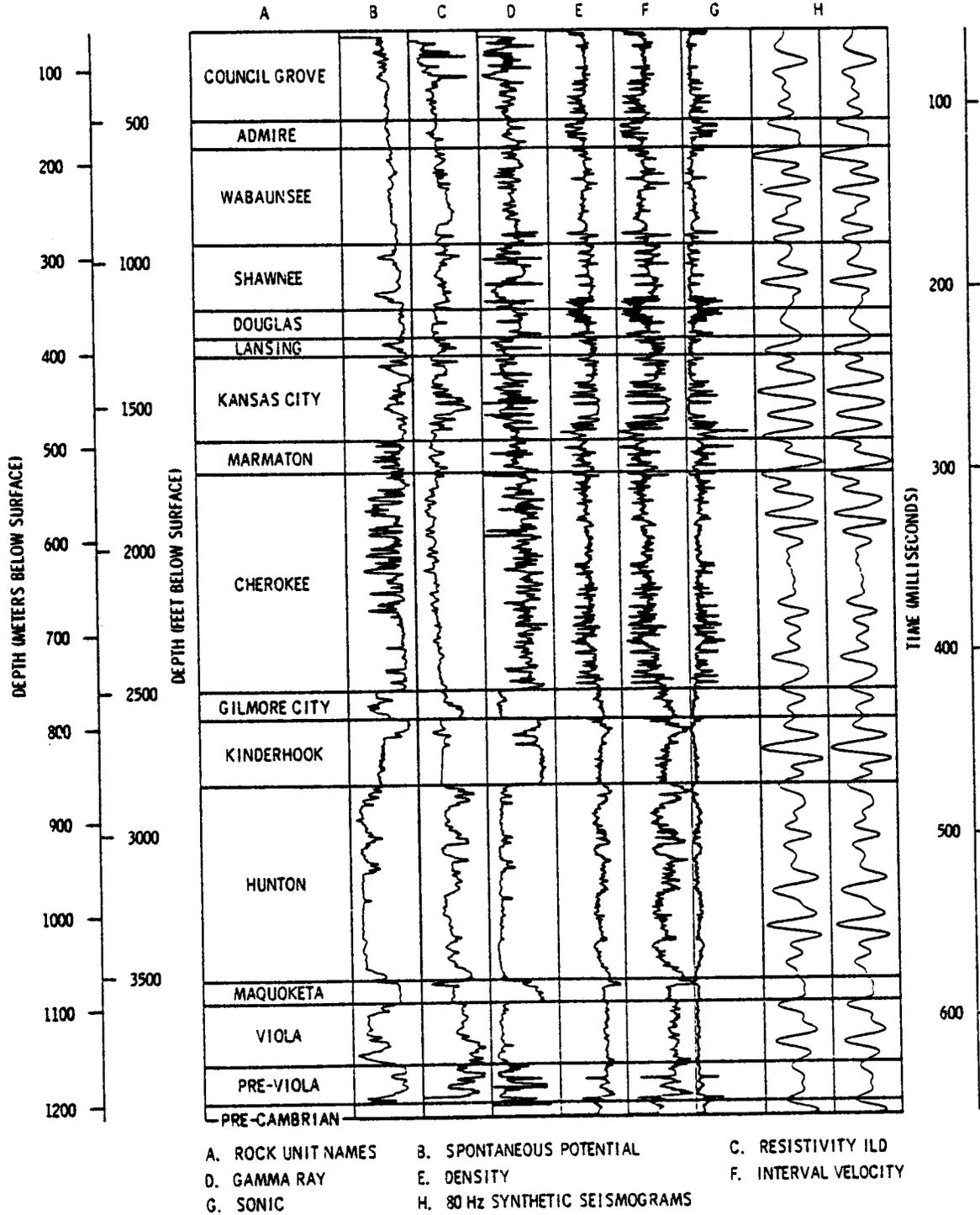
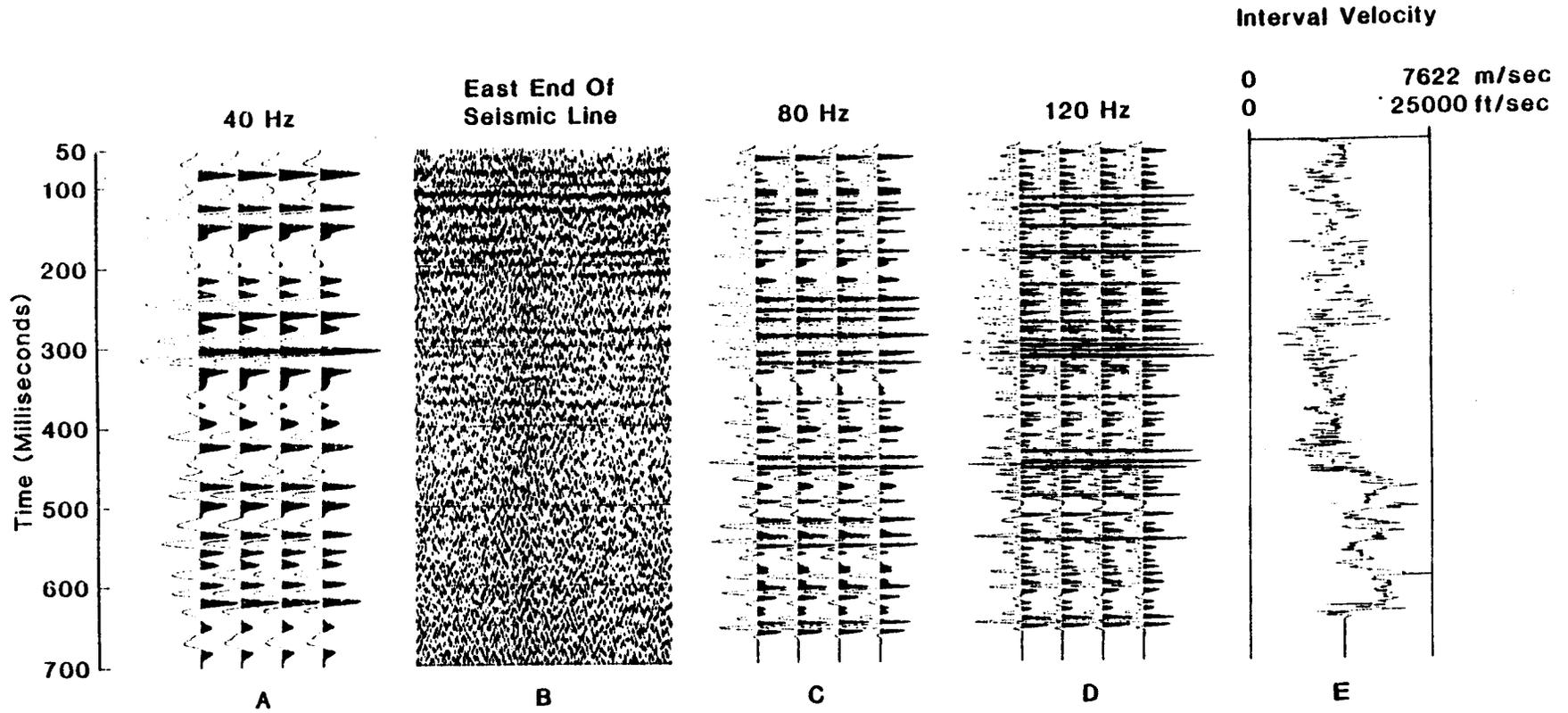


FIGURE 25

# SYNTHETIC SEISMOGRAMS



Source Function On A, C, And D Is A Ricker Wavelet.

FIGURE 26

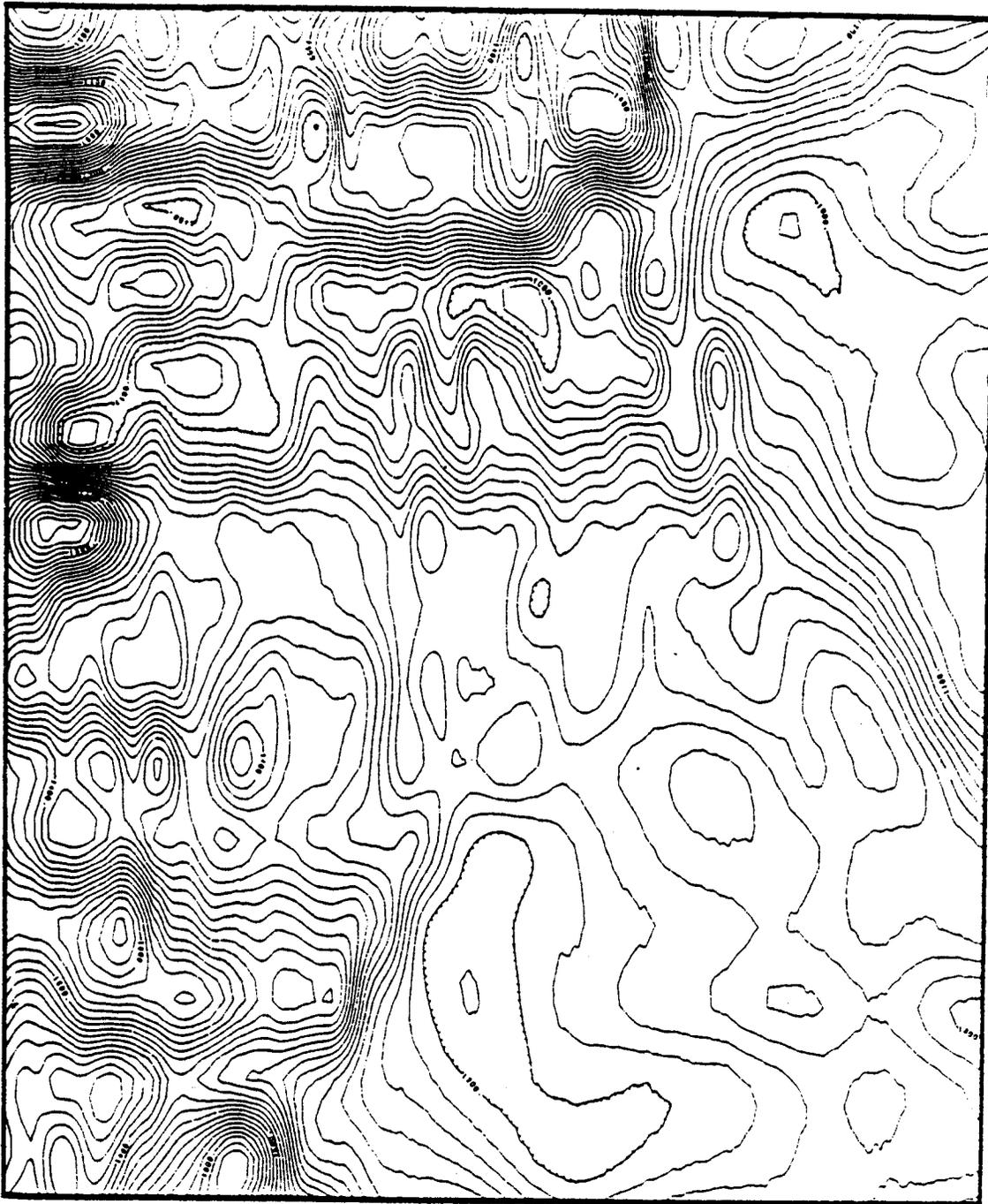
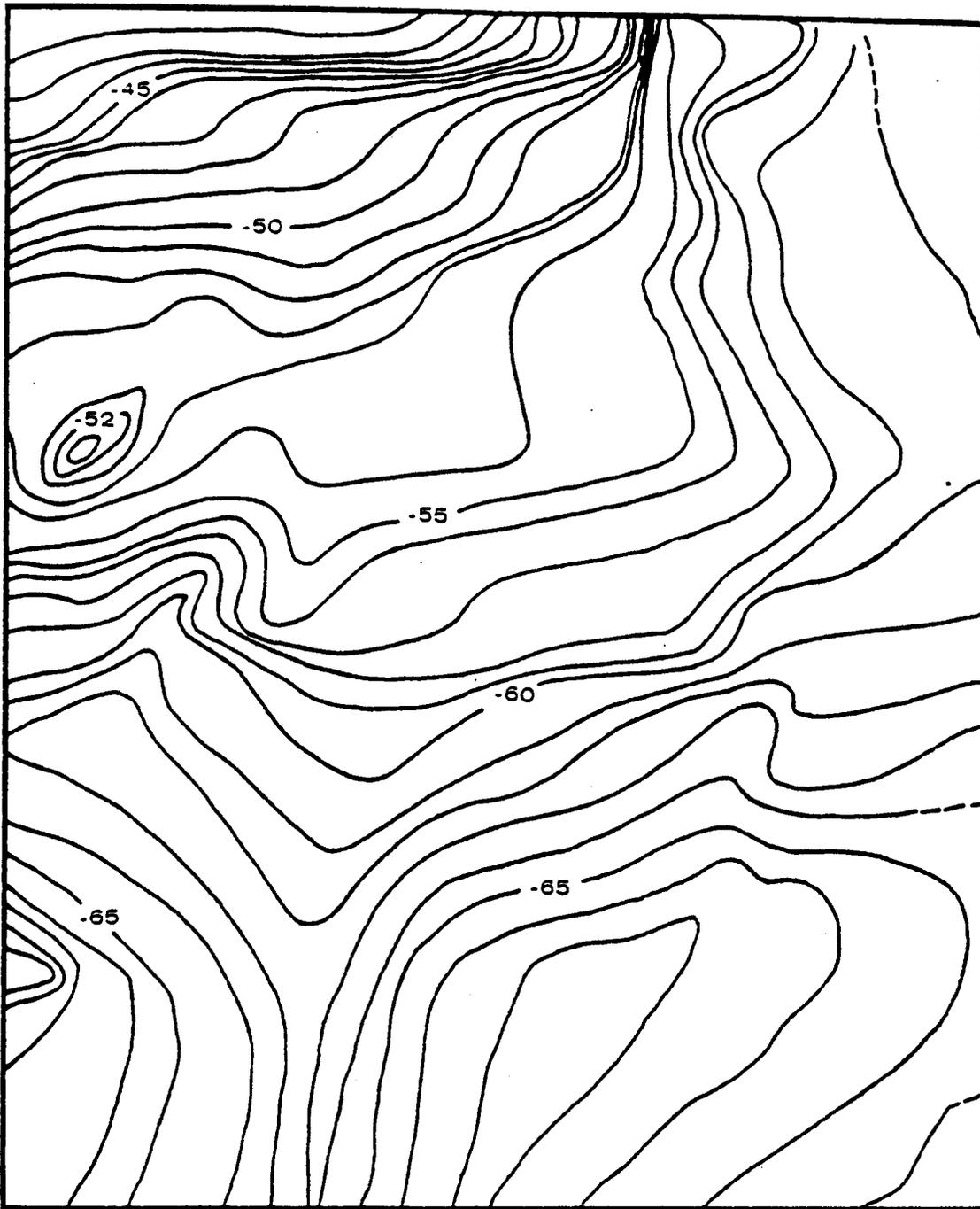


FIGURE 27

Aeromagnetic Map (Compiled by Randy Robertson)  
Contour Interval: 20 gammas  
Flight Elevation: 750m (2500 ft) above sea level



Bouguer Gravity Map  
Contour Interval = 1 milligal

(DuBois, 1978)

FIGURE 28

INTERPRETED GEOLOGIC CROSS SECTION

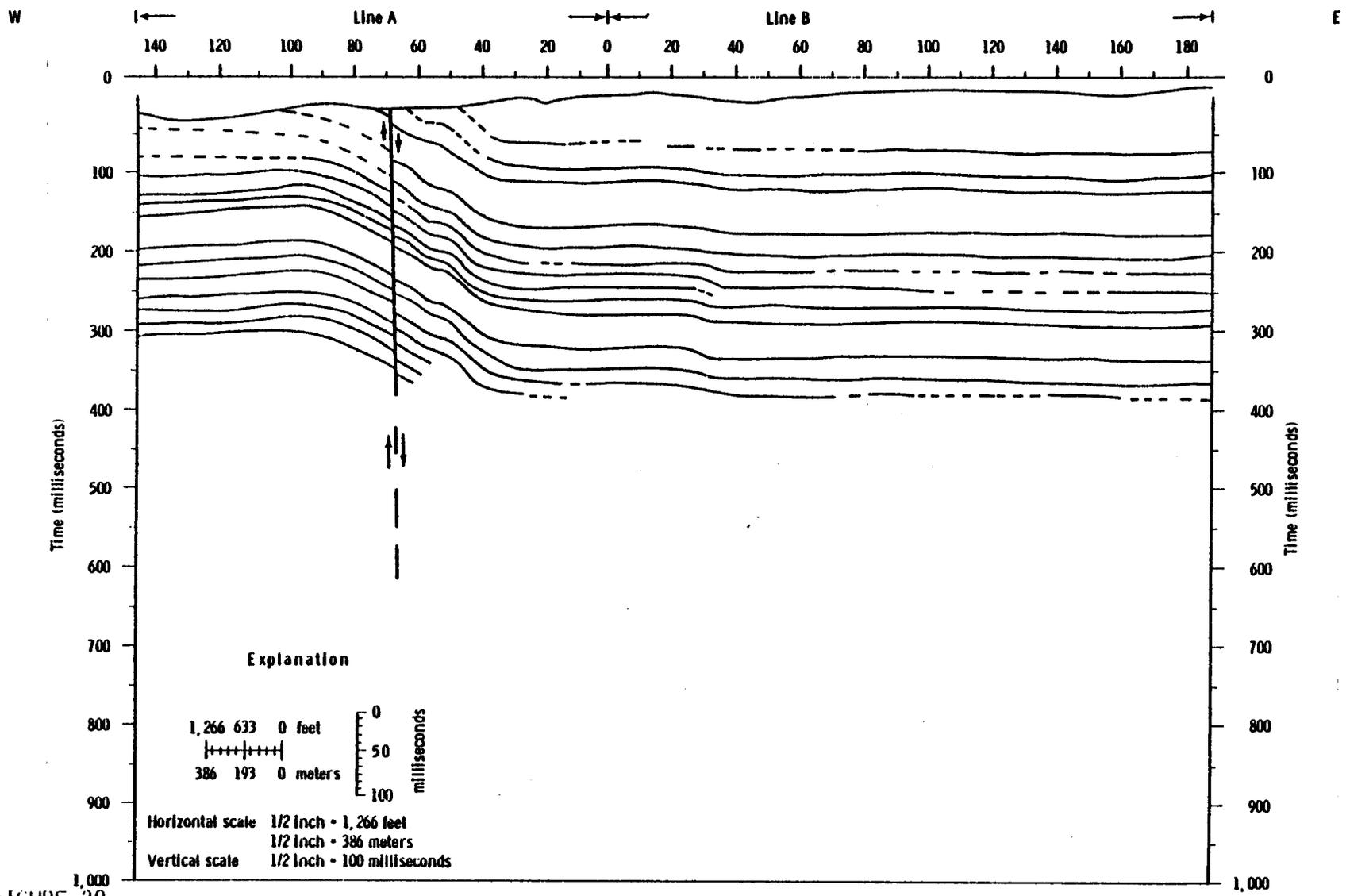


FIGURE 29