

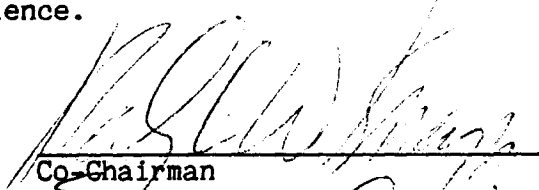
A HIGH RESOLUTION SEISMIC STUDY
MIAMI COUNTY, KANSAS

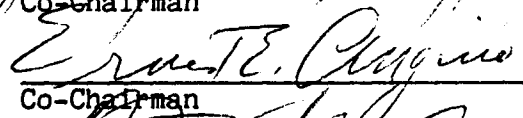
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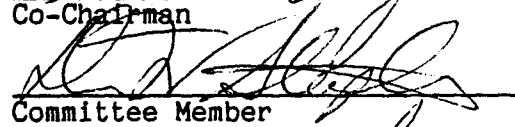
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B.A., Boston University, 1978

Submitted to the Department of
Geology and the Faculty of the
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of Master of Science.


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ABSTRACT

Two high resolution seismic lines were shot by the Kansas Geological Survey near Wellsville, Kansas during 1981 and 1982. Two different seismic surface sources were used for each line: Betsy Seisgun and MiniSosie. The study site is located near the southeast margin of the Forest City basin. The stratigraphic column consists of strata deposited discontinuously since the Precambrian.

The purpose of the study was to determine if either of two surface sources of high frequency seismic energy was capable of resolving the presence of thin sandstone bodies, 'squirrel' sands, located at the top of the Cherokee Group of the Upper Pennsylvanian. The sandstone bodies are located within strata deposited under cyclic conditions associated with the rise and fall of sea level.

The seismic data were recorded using both source and geophone arrays to attenuate the contribution of non-vertical seismic waves. Severe low-cut (110 Hz, 24 dB/octave) and high-cut (220 Hz, 24 dB/octave) filters were used to enhance the high frequency information. After editing and muting, the seismic data from both sources along each seismic line were identically processed. The final conventional stacks revealed that the MiniSosie produced a more coherent record of the subsurface than did the Seisgun. In addition, the resolution of the MiniSosie data was superior than the Seisgun data. This is most likely due to higher frequency content and the superior attenuation of noise during vertical stacking. In some regions of the seismic records, especially below 200 milli-

seconds, it appears that the Seisgun produced a more coherent record of the subsurface. Information from each Seisgun common-depth-point data set was added to the corresponding MiniSosie common-depth-point data set. Generally, this enhanced the MiniSosie data and aided the seismic interpretation.

Due to the lack of sonic well log data, an algorithm relating neutron porosity to seismic velocity was established for northeastern Kansas. The algorithm was used to produce a pseudovelocity log for a well near the seismic lines. Synthetic seismograms were created from the pseudovelocity log to aid in the interpretation of the seismic data.

Analysis of the synthetic seismic data reveals that primary energy is severely attenuated by the cyclothem of the Upper Pennsylvanian. There is a 12 dB decrease in transmitted energy at the top of the Cherokee Group due to the effects of transmission loss. As a result, it appears that the multiply-reflected signal becomes the dominant reflected energy.

The seismic record sections are divided into 10 seismic sequences. These zones represent depositional sequences composed of genetically related strata.

The seismic data reveals the presence of an anticline as well as several faults in the pre-Mississippian strata. It appears that it is possible to seismically locate 'squirrel' sands that have been deposited in channels using MiniSosie. The presence of these channels in the subsurface apparently results in a dimming of the overlying Fort Scott composite reflection due to interference.

I dedicate this thesis to:

DeAnn DuVall Ready.

ACKNOWLEDGMENTS

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a) reflection coefficient series;	
b) seismic wavelet (15-30-100-150, -90 degree phase shift);	
c) synthetic with primary energy only;	
d) synthetic with primary energy plus transmission losses;	
e) synthetic with primary and multiple energy (transmission losses included).	

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INTRODUCTION

In the petroleum industry, as the frequency of discovery of structural traps has declined, greater emphasis has been placed on the search for stratigraphic traps. This has led to the development of new surface sources of seismic energy which are capable of producing high resolution data. The purpose of this study is to determine if either of two high frequency seismic sources is able to detect the presence of "squirrel" sands in Miami County, Kansas. These sands are thin stratigraphic traps located at the top of the Cherokee Group of the Upper Pennsylvanian.

In 1981 and 1982, the Kansas Geological Survey collected high resolution seismic data along two field lines in the Paola-Rantoul oil field, Miami County, Kansas (Figures 1 and 2). The data were acquired using both Betsy Seisgun and MiniSosie earth compactor seismic sources for each line. The seismic data from both seismic sources were identically processed for each line. The processing was accomplished using Sytech, Inc. geophysical software available on the Data General MV/8000 computer at the Kansas Geological Survey. In order to enhance data deep in the seismic section, the Seisgun and MiniSosie data were summed together in a combo-stack. In order to generate the combo-stack, the Seisgun data for each common-depth-point was scaled, time shifted, and added to the corresponding MiniSosie data.

As an aid during interpretation, synthetic seismograms were produced for a well near the study site. Since no sonic logs were

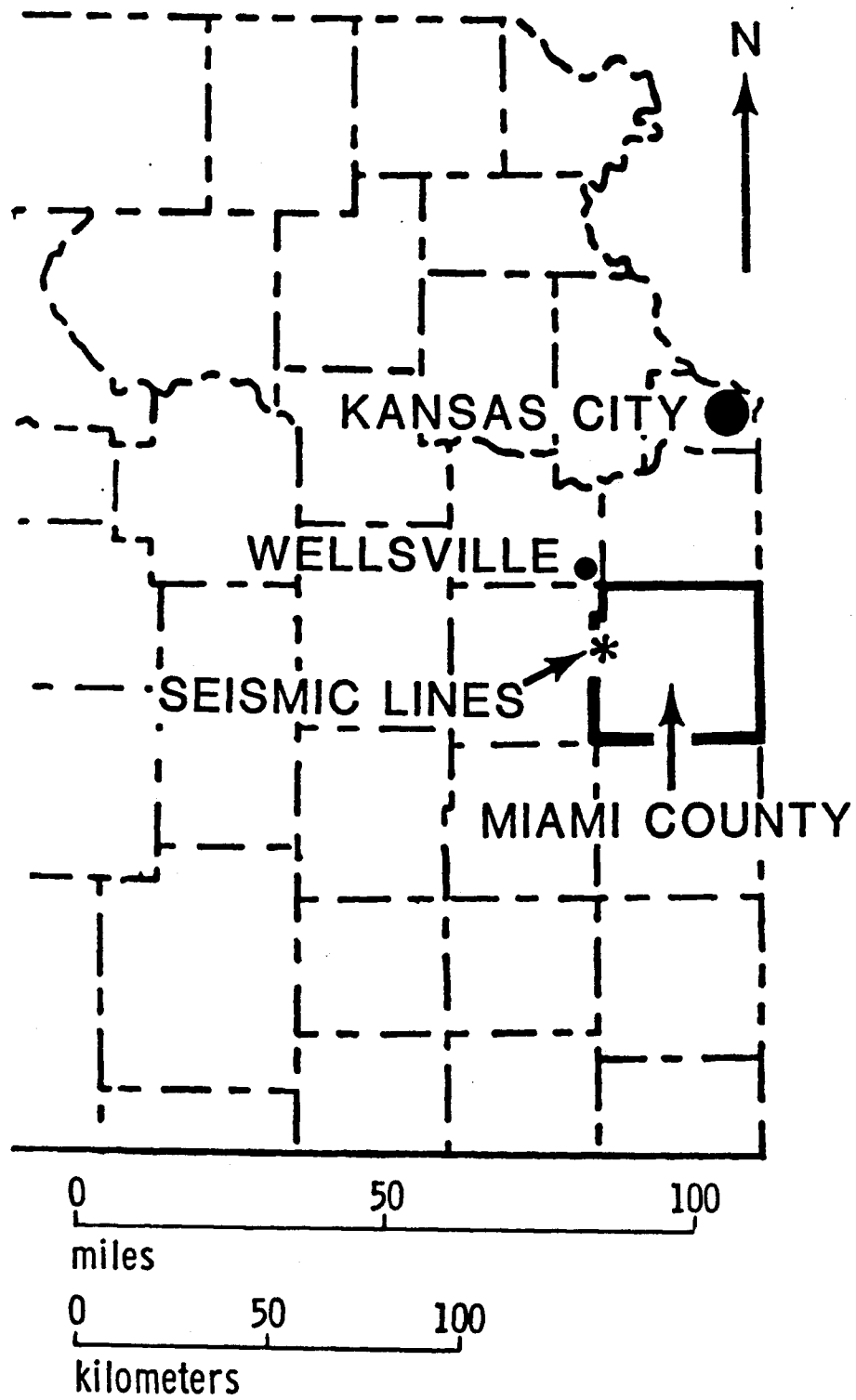
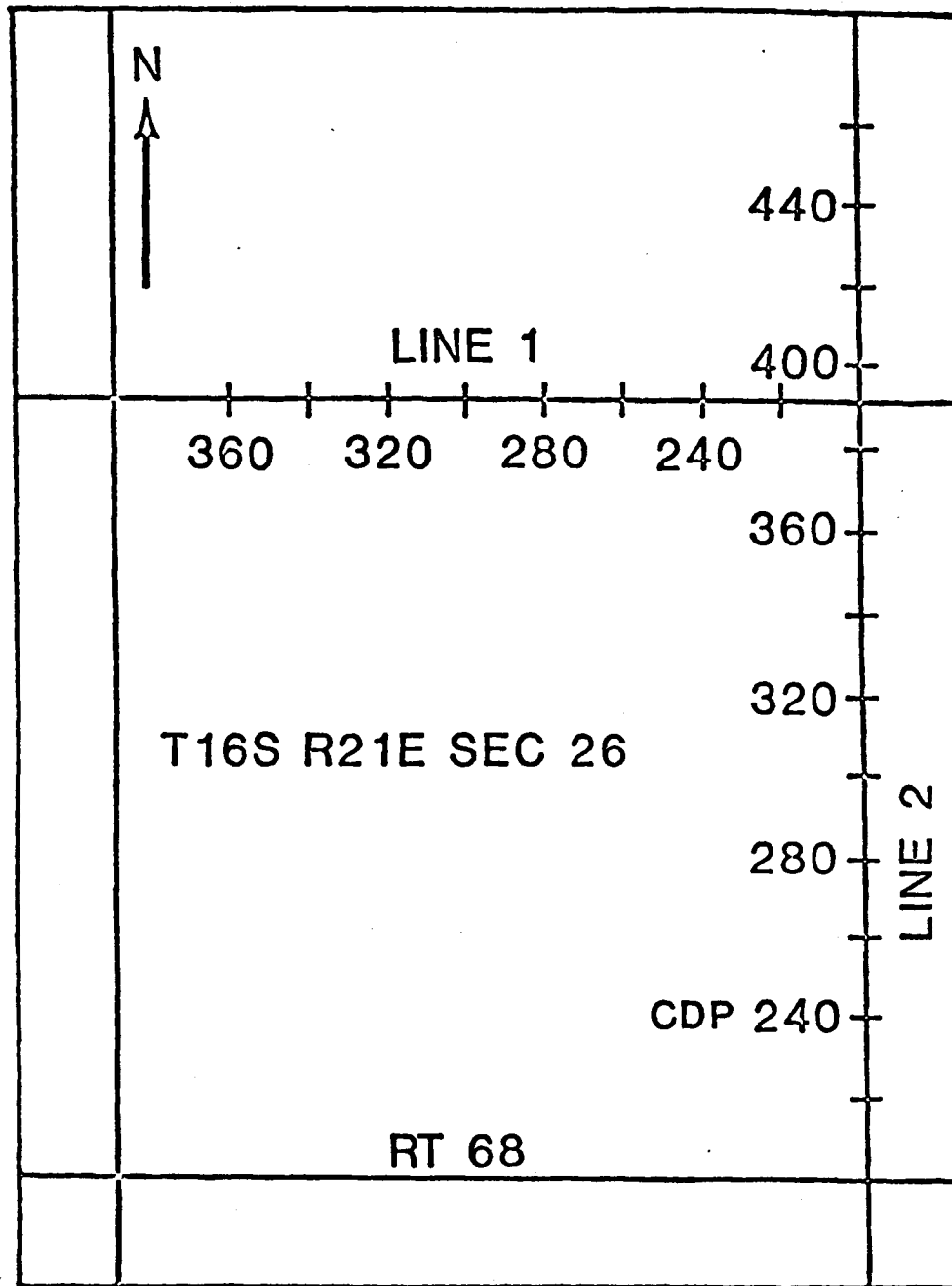


Figure 1.- Location of seismic lines.



0 1000 2000 3000 4000 5000

feet

0 250 500

meters

Figure 2.- Orientation of seismic lines with common-depth-point locations.

available in the immediate study area, an algorithm was empirically derived to convert neutron porosity to interval transit time for wells in Miami County, an area where sonic logs are scarce. A neutron count log from a well on one of the seismic lines was converted to neutron porosity using the 40:1 method. The 40:1 method consists of assigning porosities of forty percent and one percent to a shale and a tight limestone, respectively. Porosities are then calculated using these two control points (Wood, et al., 1974). The conversion algorithm was then used to help generate a synthetic sonic log for the well. Synthetic seismograms were subsequently created from the synthetic sonic log.

BACKGROUND GEOLOGY

The study area is located on the southern edge of the Forest City basin in eastern Kansas. This basin is both structural and topographic in nature. The sedimentary column has an approximate thickness of 2350 feet in Miami County and is shown in Figure 3.

STRATIGRAPHY

The Precambrian rock underlying the study area is believed to be primarily granite (Bickford, et al., 1979). These rocks are unconformably overlain by Lamotte Sandstone of Upper Cambrian age. Generally, the Lamotte is arkosic in character at the base. Quartzose, dolomitic, quartz-glaucconitic and feldspathic sandstones are also present in the Lamotte (Merriam, 1963). This unit grades conformably into Bonneterre Dolomite, a glauconitic, noncherty dolomite of Upper Cambrian age (Zeller, 1968). Arbuckle Group encompasses all of the pre-St. Peter Ordovician and Cambrian rocks above the Bonneterre. Bonneterre, though indistinguishable on the well log from Arbuckle, is separated from the Arbuckle on the basis of stratigraphic consideration (Lee, 1943).

Arbuckle Group at the study site includes Eminence Dolomite, Gasconade Dolomite, Roubidoux Formation, and Jefferson City and Cotter Dolomites. There are unconformities between each of these lithologic units (Lee, 1943). The Arbuckle Group consists mainly of crystalline dolomite deposited under shallow water conditions. Chert is common in the upper part (Merriam, 1963).

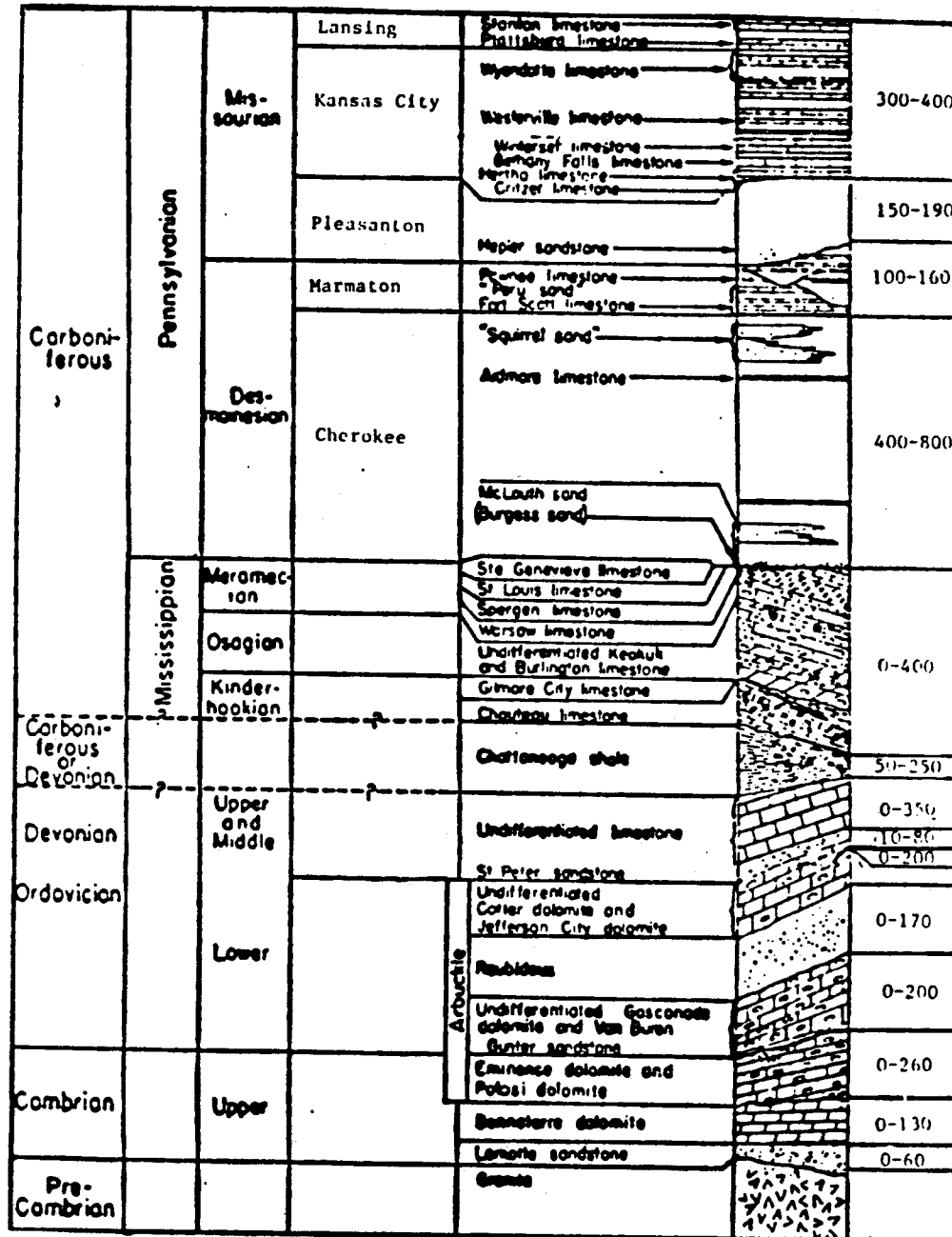


Figure 3.- Columnar section of rocks in Miami County, Kansas (from Lee, 1943, Figure 1).

At the study site, Arbuckle is overlain unconformably by St. Peter Sandstone of Ordovician age. The St. Peter is associated with the sandy part of the Simpson Group.

Undifferentiated rocks of the "Hunton Group" unconformably overlie St. Peter Sandstone. These rocks are composed of limestone and dolomite and are Devonian in age. Apparently, the Silurian component of the "Hunton Group" and the Viola Limestone were eroded at the end of Silurian time (Merriam, 1963).

The "Hunton Group" is overlain by Chattanooga Shale which was deposited during Kinderhookian time. These rocks are believed to be of Devonian or Mississippian age. They are separated from the "Hunton Group" by an unconformity. Chattanooga Shale in the study area is overlain conformably by Mississippian rocks deposited during Osagian and Meramecian time. These rocks consist primarily of limestone and dolomite deposited in an epicontinental sea. Low relief of the nearby land surfaces resulted in clear water conditions on the continental shelf which facilitated the widespread deposition of calcium carbonate associated with marine organisms (Moore, 1957).

Pennsylvanian rocks deposited during Desmoinesian and Missourian time, overlie those of Mississippian age in the study area. The Pennsylvanian rocks consist of cyclothems. Cyclothems are cyclic terrigenous clastic and carbonate strata deposited under cyclic conditions associated with transgressive-regressive marginal seas (Heckel et al., 1979). Each cyclothem is associated with a cycle of deposition consisting of, in ascending order: a transgres-

sive carbonate, a marine shale, a regressive carbonate and a regressive shale. The environments of deposition, as determined by Watney (1980), are shown in Table 1.

The Cherokee and Marmaton Groups were deposited during Desmoinesian time. Relatively clean sandstones found at the top of the Cherokee have been referred to as "squirrel" sands. The presence of these lenticular and discontinuous "squirrel" sands is due to the influx of sediment associated with the repeated extensions of alluvial deltaic complexes from the east (Ebanks and James, 1974). Evidently, each extension resulted in lobes or belts of sandy deposits that prograde into marine environments. Within the Paola-Rantoul oil field in Miami County, these sands are the principal hydrocarbon-bearing units.

Younger cyclic sequences of the Marmaton Group and of the Pleasanton, Kansas City and Lansing Groups, which were deposited during the Missourian stage, contain more limestone and smaller amounts of coal. This supports the concept of "...increasingly widespread marine invasion of the area throughout Middle and Late Pennsylvanian time, with variations in environmental conditions as the interplay of sea level, sediment supply and basin subsidence changed" (Ebanks, 1979, p. 69).

Descriptive Facies	Thickness (Ft.)	Genetic Facies	Depositional Environment
Upper Shale	<5-30	Regressive Shale	Oxidized, continental clastics
Upper (upper) Carbonate (lower)	<1-15	Regressive Carbonate	shallow, clear-water carbonate; tidal flat lagoon, and open marine; high and low energy
Carbonate (lower)	5-25		Subtidal, low-energy, clear-water, open-marine carbonate grading downward to mixed turbid argillaceous carbonate
Lower Shale	2-20	Marine Shale	Subtidal, low energy, marine; restricted, anoxic conditions prevalent to south and to north locally shallow water
Lower (upper) Carbonate (lower)	0-15	Transgressive Carbonate	Subtidal, low energy, open marine; clear to turbid water conditions
Carbonate (lower)	0-8		Sandy or silty reworked shoal water, intermittent restricted to open marine

Table 1.- Description of facies and environments of deposition for Pennsylvanian cyclothems in northeastern Kansas (from Watney, 1980).

STRUCTURAL EVOLUTION AND SEISMIC DISCONTINUITIES

In Miami County, tectonic forces acting upon the surrounding area since the Precambrian have had an important role in the development of the geologic column. Deformation of the earth's crust in this region has produced long periods of both deposition and erosion. A review of the regional tectonics since the Precambrian provides an opportunity to predict which geologic events that affected the stratigraphic column might result in primary reflections on the seismic record section.

The primary reflections on a seismic section approximate the chronostratigraphic patterns of the subsurface. These reflections may be produced by stratal surfaces or unconformities (Mitchum et al., 1977a). Stratal surfaces are associated with bedding surfaces and are chronostratigraphic because they represent time-synchronous surfaces of deposition. Unconformities are chronostratigraphic because they separate older rocks from younger ones.

A primary reflection is produced if there is a significant acoustic impedance contrast across a chronostratigraphic surface. The acoustic impedance (Z) of a rock is equal to the product of the density (ρ) and seismic velocity (V) of the rock. For vertically incident seismic waves, the amplitude of the reflection, or reflection coefficient (R), is equal to the change in acoustic impedance across the surface divided by twice the average acoustic impedance (Sheriff, 1977):

$$R(i) = \frac{Z(i) - Z(i-1)}{Z(i) + Z(i-1)}$$

Since the seismic velocity of sedimentary rock varies by a factor of 3.3 while density varies by a factor of 1.4 (Telford et al., 1976), the acoustic impedance contrast is primarily dependent upon velocity. Therefore, density information is often considered constant when calculating the reflection coefficients. Consequently, using a sonic log alone, it may be possible to relate primary reflections with particular tectonic events. Figure 4 is a sonic log of the strata overlying the Arbuckle in the ABC No. 1 well. This well is located seven miles southeast of the study site (Figure 5, Appendix I). Reflections on the seismic section may be expected when there are large changes in interval transit time over short depth intervals.

During Cambrian and Lower Ordovician time, Miami County was affected structurally by the presence of the subsiding synclinal Ozark basin. Contemporaneous and structurally related to the development of the basin was the rise of the Southeast Nebraska arch (Figure 6). Unconformities associated with structural uplift, the tops of the Bonneterre and Eminence Dolomites, and with eustatic changes in sea level, the top of the Roubidoux Formation, are both present in the geological column.

From St. Peter time to the beginning of deposition of the Mississippian limestones, the strata in Miami County were uplifted and tilted toward the North Kansas basin. It is widely believed

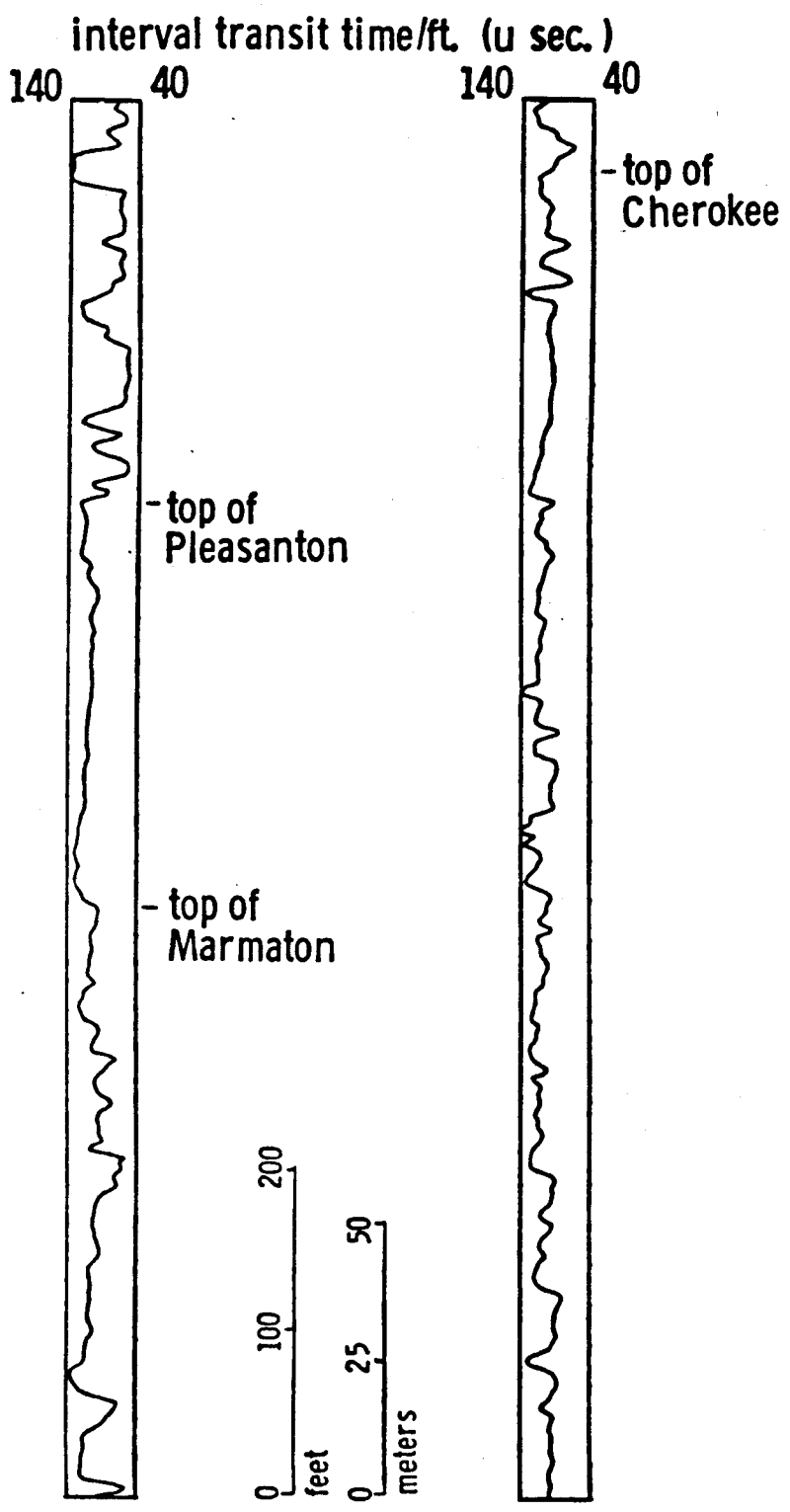


Figure 4.- ABC velocity well log.

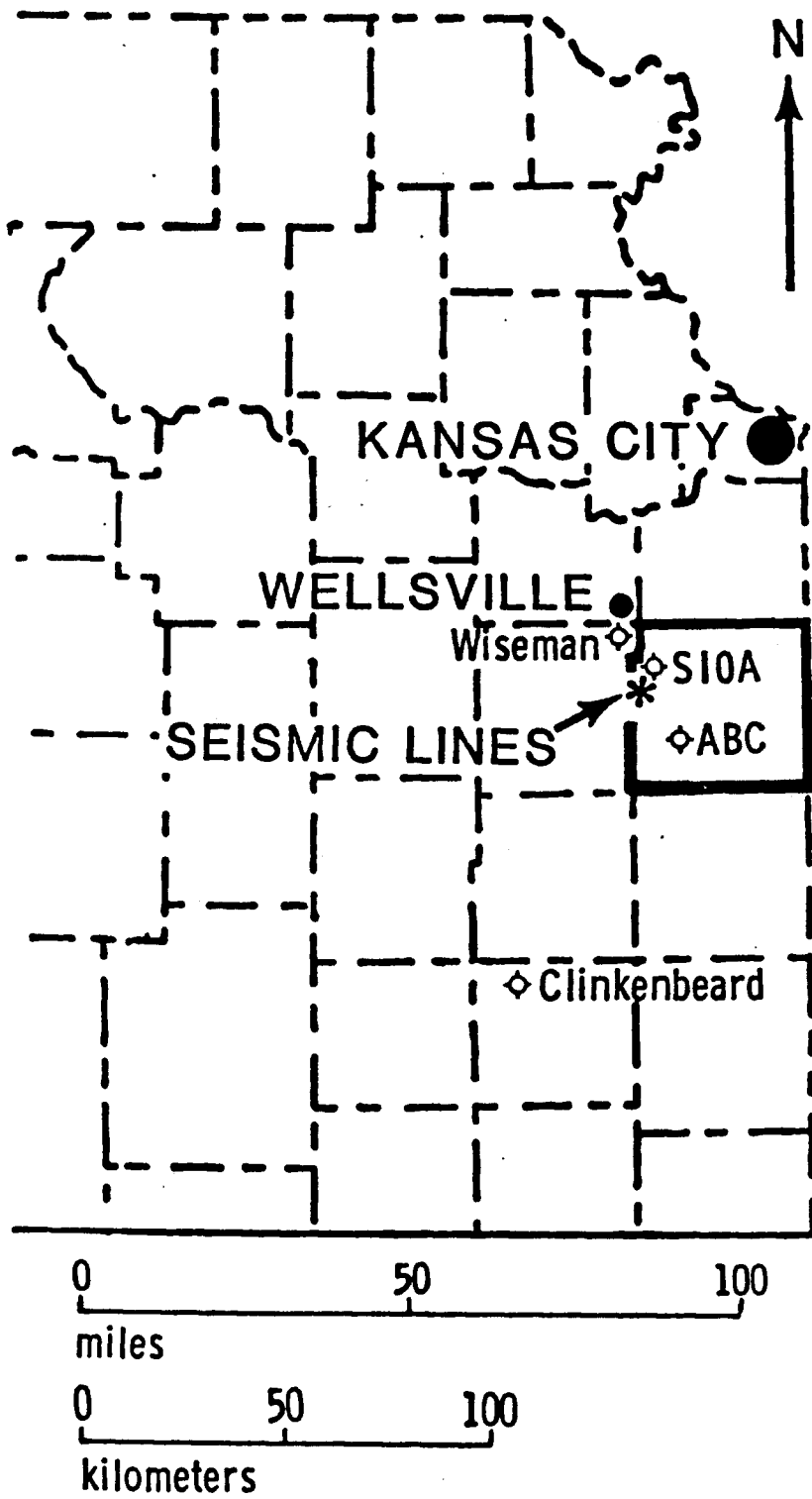


Figure 5.- Location of wells used in the study.

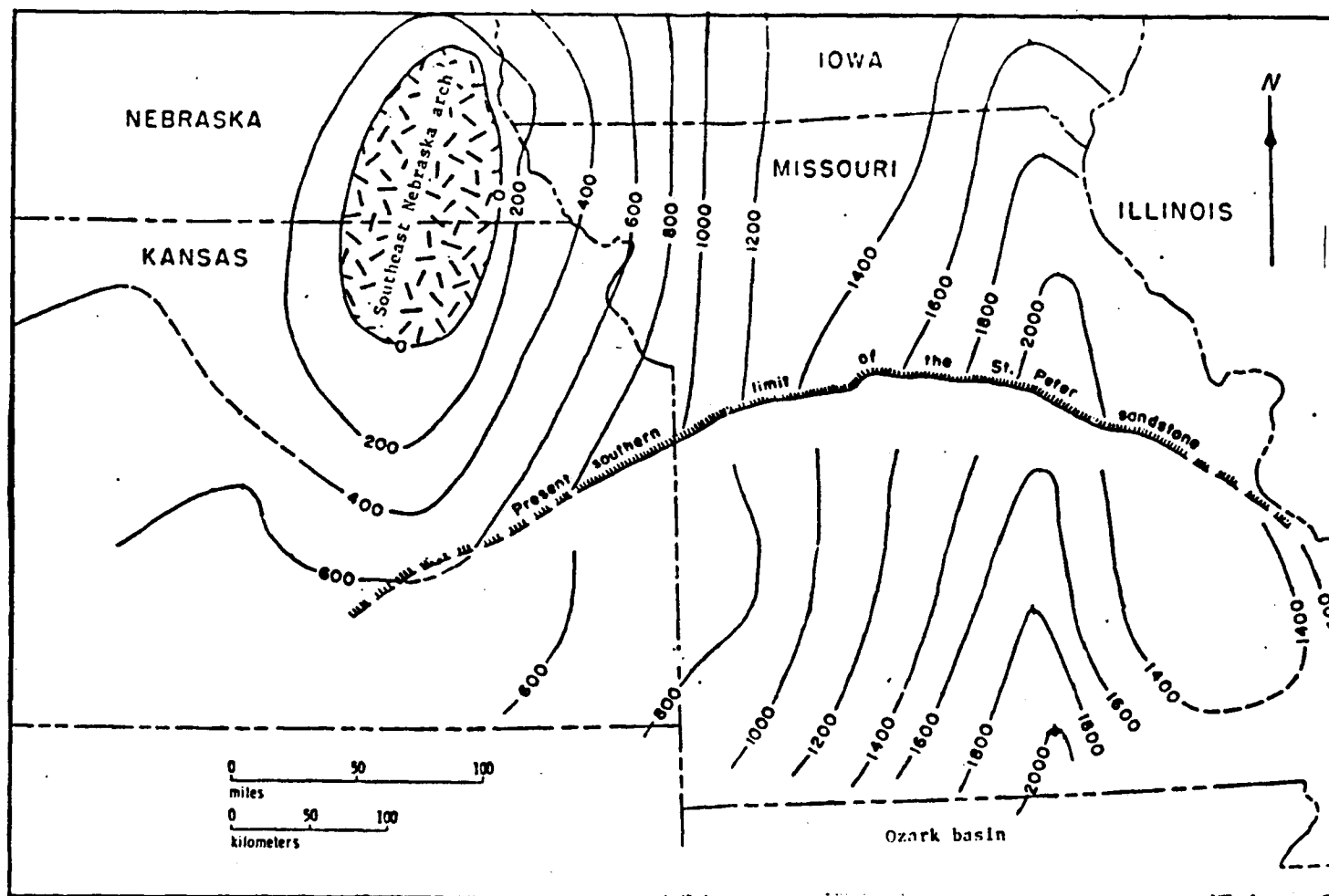


Figure 6.- Location of Southeast Nebraska arch and Ozark basin based on thickness of sedimentary rocks below the top of the St. Peter Sandstone north of its southern limit, and on thickness of rocks between the top of the Roubidoux Formation and the top of the Lamotte Sandstone (from Lee, no date, Figure 5).

that subsidence of this basin is associated with upward movement of the Ozark uplift as well as the formation of the Chautauqua arch and the Central Kansas uplift (Figure 7). The unconformity at the top of the St. Peter Sandstone is related to the erosion of pre-Devonian sediments deposited within the basin. This contact, between the Devonian "Hunton Group" and the Middle Ordovician St. Peter Sandstone, is a distinct seismic discontinuity. The seismic discontinuity at the top of the "Hunton Group" is due to an unconformity between the "Hunton Group" and the overlying Chattanooga Shale (Lee, 1943). The seismic discontinuity at the top of the Chattanooga Shale is due to a conformable stratal surface between the Chattanooga and the overlying Chouteau Limestone (Merriam, 1963).

During Mississippian time, deformation along the Nemaha anticline resulted in the formation of a broad syncline in northeastern Kansas (Figure 8). According to Rascoe and Adler (1983), the uplift of the Nemaha anticline was due to the collision between the North American craton and the northern margin of the South American plate during Mississippian time. Lee (1943) considered this syncline to be the ancestral Forest City basin (Figure 8). Sediments were deposited into this basin during Mississippian time. Evidently, these sediments were eroded near the end of Mississippian time due to continued uplift of the Nemaha anticline. Of lesser importance was uplift of the Ozark region to the east (Lee, 1943; Lee, no date). The erosional surface between Mississippian rocks and overlying Pennsylvanian strata is one of the most distinctive discontinuities on the sonic log shown in Figure 4.

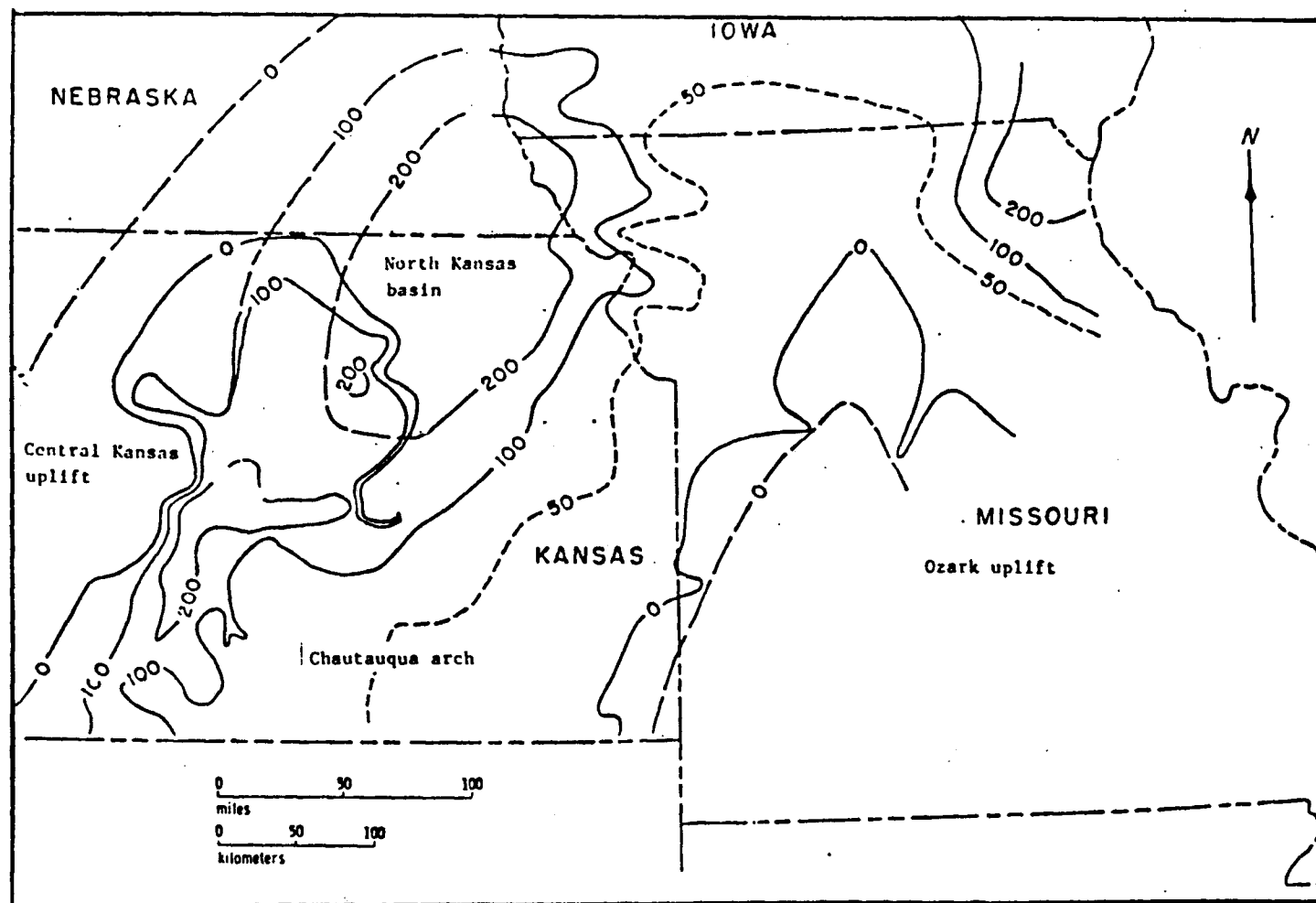


Figure 7.- Location of Ozark uplift, Chautauqua arch, and North Kansas basin based on present or pre-Mississippian thickness (long dashes) of Boice and Chattanooga Shales (from Lee, no date, Figure 17).

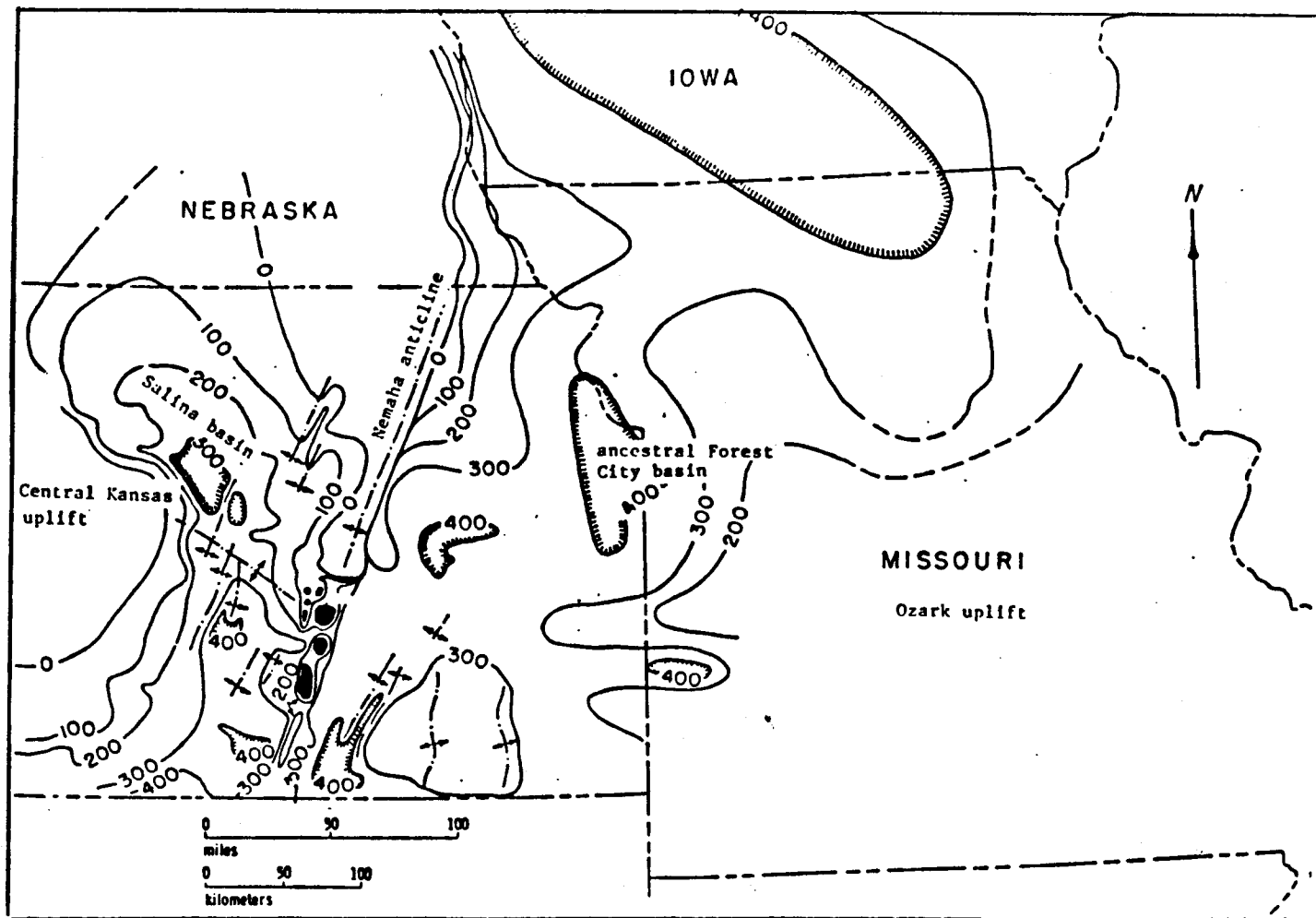


Figure 8.—Location of Nemaha anticline and ancestral Forest City basin based on thickness of Mississippian limestones (from Lee, no date, Figure 20).

During early Pennsylvanian time, the eastern flank of the Nemaha anticline subsided relative to the western flank. To the east of the study area, this resulted in large scale block faulting along the Humboldt fault. As a result of the subsidence, two basins were formed to the east of the ridge. These were the Forest City basin in northeast Kansas (including the study area), northwest Missouri, and southwest Iowa, and the Cherokee basin in southeast Kansas (Figure 9). The basins are separated by the Bourbon arch, a low, broad anticline. During Pennsylvanian time, the center of subsidence of the Forest City basin was west of the center of subsidence of the ancestral Forest City basin (Lee, 1943; Lee, no date) (Figure 10). In the study area, deposition continued throughout Permian time and possibly through Cretaceous time as well (W.L. Watney, personal communication).

During the Pennsylvanian, the entire Kansas shelf was subjected to repeated cycles of marine transgression. Changes in sedimentation were due mainly to eustatic changes in sea level (Watney, 1980). A review of Figure 4 reveals that Pennsylvanian strata are characterized by rapid and repeated changes in sonic velocity. This is a direct result of cyclic sedimentation. In this region of the geologic column, strong primary seismic reflections are associated with both unconformities and stratal surfaces. An example of the latter is the boundary between transgressive limestones and marine shales.

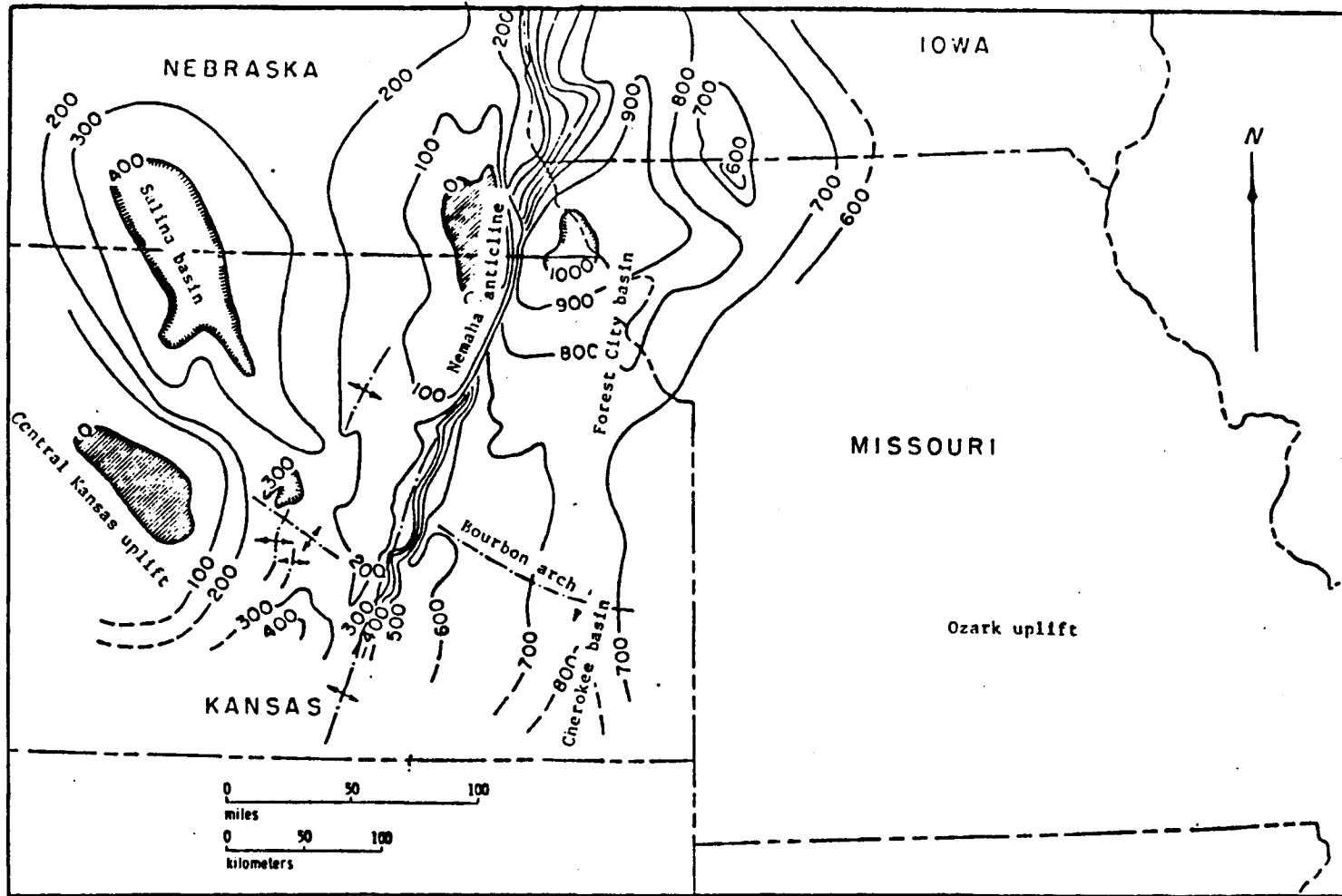


Figure 9.- Location of Forest City and Cherokee basins based on thickness of Pennsylvanian rocks below the Hertha Limestone (from Lee, no date, Figure 21).

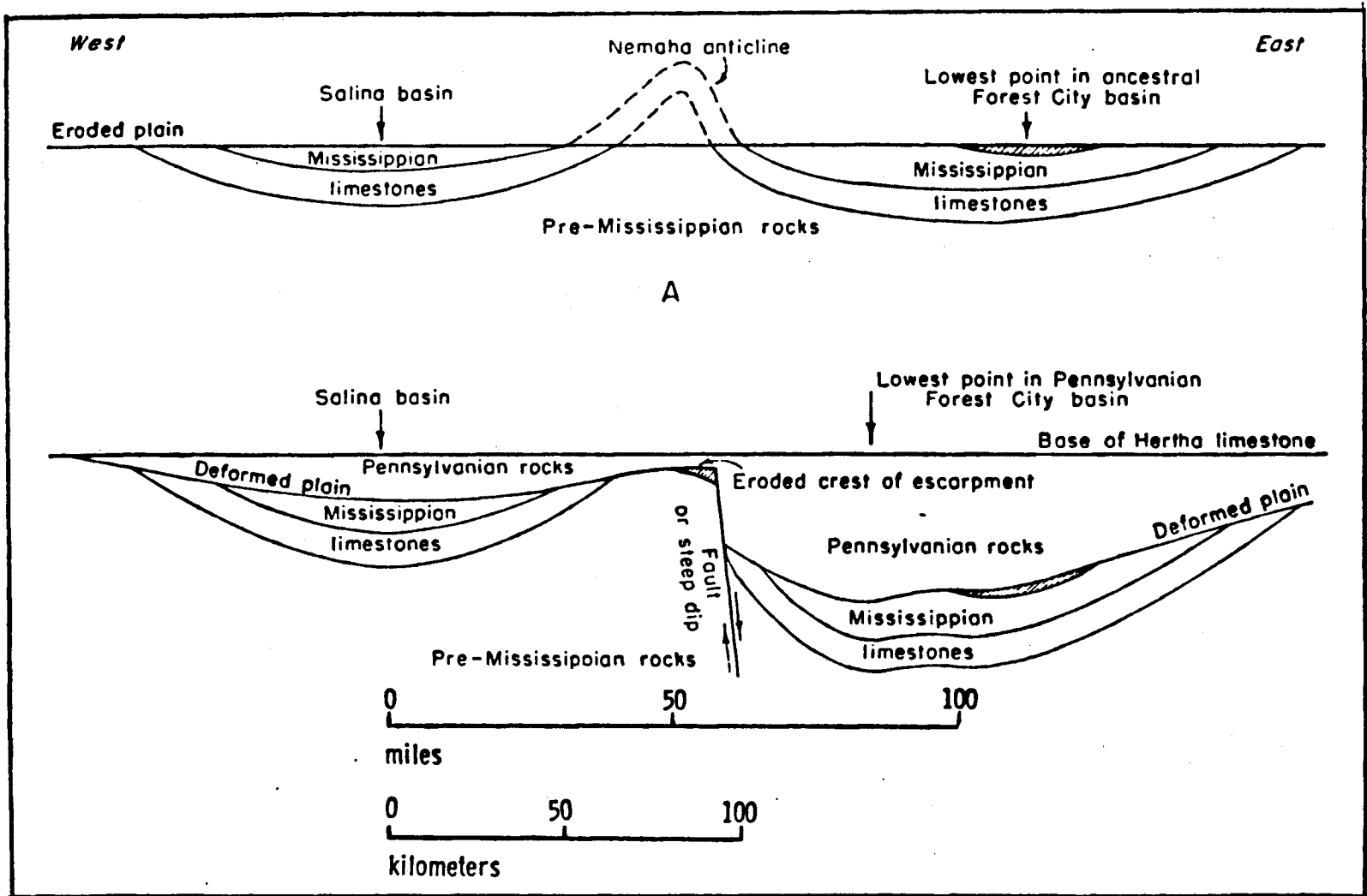


Figure 10.- Diagrammatic cross-sections, west to east, from Salina, Kansas to Kansas City showing relative location of Nemaha anticline, and ancestral Forest City and Forest City basins (from Lee, no date, Figure 22).

DATA ACQUISITION

Along each seismic line, two types of surface sources of seismic energy were used: the Betsy Seisgun and the MiniSosie earth compactor. Data acquisition parameters for each source are given in Appendix II. During acquisition, source and geophone arrays were used to provide spatial filtering. The geophone array consisted of ten 30 Hz geophones connected in series parallel to each live geophone takeout on the seismic cable. If seismic waves approach the surface vertically, then all of the geophones of the array are, theoretically, stimulated simultaneously and their outputs combine constructively. If the seismic waves approach horizontally, the geophones are affected at different times and their outputs combine destructively. Source arrays have a similar effect on non-vertical waves. The seismic data were filtered in the field using 110 Hz pre-emphasis lowcut and 220 Hz highcut filters. These filters have a rolloff of 24 dB/octave. This technique of pre-emphasis filtering (Sheriff, 1973) preserved the frequency content of the data between 110 and 220 Hz while severely attenuating groundroll.

SEISMIC SOURCES

The Seisgun seismic energy source is produced by Betsy Seisgun, Inc. as a portable surface seismic source. It is an 8 gauge industrial shotgun which is fitted to a wheelbarrow-type carrier. The gun barrel is mounted vertically atop a cylindrical steel platform which provides the operator with protection against blast

debris. The base of the platform is designed to minimize the air blast noise and gun recoil. The entire assembly weighs approximately 200 pounds.

Three ounce lead slugs are manually fired into the ground at each shotpoint. A strong motion geophone is attached to the side of the gun barrel to record a time break for recording purposes. Sub-surface information is then recorded for each shot. Beggs and Garriot (1979) report that they obtain significant information at frequencies between 20 and 160 Hz at depths between 2000 and 2500 feet (610 and 762 meters, respectively).

The MiniSosie technique uses a Wacker model 151 GY earth compactor energy source. A two horsepower engine is used to drive a piston which has a metal plate attached to its base. The rate at which the plate strikes the ground is governed by the operator via throttle. The earth compactor is operated continuously over the length of the source array until information from a pre-specified number of impulses are recorded. Typically, 1000 to 2000 impulses are recorded. According to Barbier and Viallix (1974), useful information up to 200 Hz has been recorded.

VERTICAL STACKING OF SEISMIC RECORDS IN THE FIELD

Vertical stacking is performed to improve the signal-to-noise ratio at a particular shotpoint. It involves multiple firing of the source and summing the data recorded from each shot. For the Seis-gun, seismic information arriving at each geophone is recorded over the entire time interval of interest for each individual impulse

before the next impulse is initiated. By recording time zero, the appropriate memory location with respect to time for each data point of the time series can be identified for each live geophone. The information is then added to the data already in memory. The output from the Seisgun can be viewed as the convolution of the source impulse, $s(t)$, with the reflection coefficient series of the earth, $e(t)$ (Figure 11a).

For MiniSosie, impulses are continuously sent into the ground as stated above. Vertical stacking occurs in real time as information from the subsurface is continuously recorded. For the initial impulse, information is recorded at each geophone group. The next impulse occurs before the recording interval of the first impulse has passed. The information from the second shot is superimposed on the information from the first shot. The information from subsequent impulses are in turn superimposed on the data from the earlier pulses to form a composite record. In order to decipher this composite record, a special 20 bit MiniSosie processor is used. The processor has a memory associated with it which has 1000 memory sample point locations per data channel.

The MiniSosie vertical stacking process is shown in Figure 11b. If the wavelet generated by the earth compactor is assumed to be constant (Barbier and Viallix, 1974), then the time function of the earth compactor input can be viewed as the convolution of the source wavelet $s'(t)$ with the earth compactor impulse time series, $y(t)$. The earth compactor input function is then convolved with the earth's reflection coefficient series $e(t)$, to produce a composite

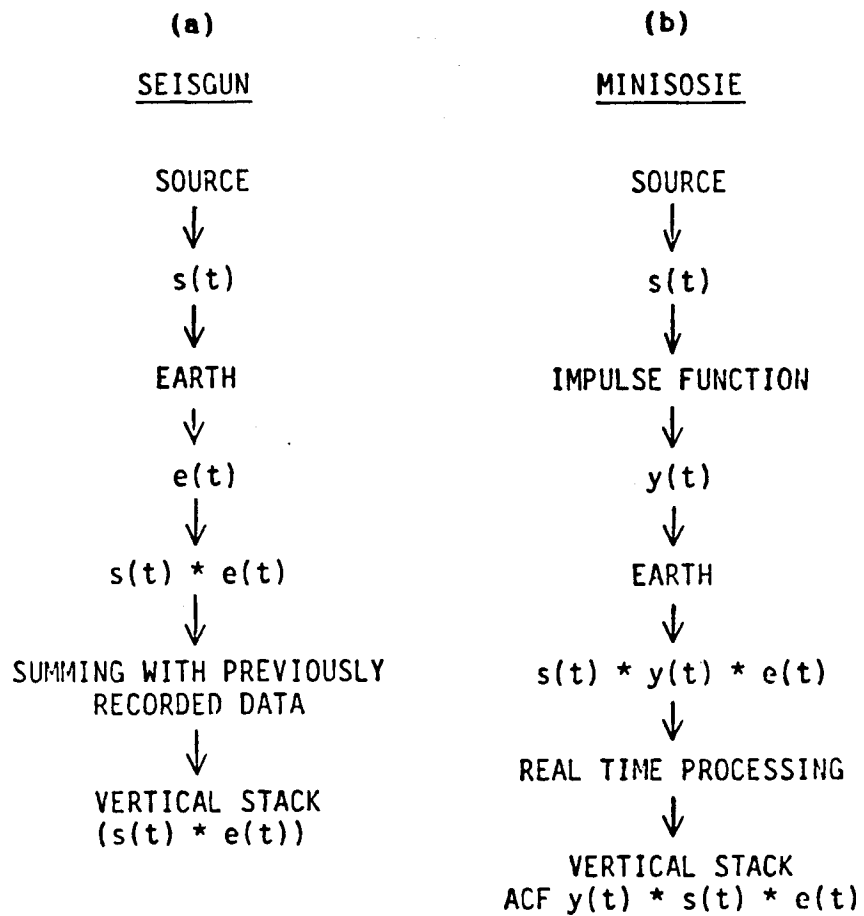


Figure 11.- Vertical stacking method of (a) Seisgun and (b) MiniSosie.

record of the subsurface. Real time processing essentially produces a cross correlation of the composite record, $s'(t) * y(t) * e(t)$, with the earth compactor impulse time series $y(t)$. In other words, the autocorrelation function of the earth compactor impulse time series, $y(t) * y(t)$ is convolved with the convolved output of the source wavelet and the earth's reflection coefficient series.

If the impulse time series of the earth compactor is random, the autocorrelation is a spike at time zero. Non-random operation of the earth compactor results in a spike or spikes at later times. This has been referred to as correlational noise (Barbier and Viallix, 1974).

At time zero, the processor begins to write the digital information from each channel into memory. Output information is continuously stored until the memory is filled. While information is being written into memory, the next impulse occurs. The MiniSosie processor adds each sample which is recorded at the time $n t$ after the second shot to the sample value which was recorded at the time $n t$ after the first shot. Data from the composite record is added to data in the memory until the 1000 samples following the second impulse have been processed. Meanwhile, a third impulse has occurred. The process continues until a predetermined number of impulse data sets have been summed. The processor is capable of time shifting and adding information from 23 impulses, contemporaneously, into memory. In other words, a particular sample of the composite record may be simultaneously added to the previously summed values in up to 23 different memory locations.

The result of vertical stacking for both the Seisgun and Mini-Sosie is a cancellation of random noises coupled with an enhancement of geologic information.

DATA PROCESSING

The raw field data were processed as shown in Table 2. First, the data were assembled from the field tapes. Traces were edited to remove "noisy" or "bad" traces and muted to remove direct and refracted seismic wave information. After common-depth-point (CDP) sorting, the traces were filtered using a 10-20-126-190 zero-phase bandpass filter to remove non-data noise from the signal. Velocity analysis was performed in order to determine the stacking velocity as a function of two-way reflection time. The velocity function is used to dynamically correct travel time in order to compensate for different shot-receiver offset distances. To determine the velocity function, common velocity stacks were produced over a range of 6000 to 14000 ft/sec (1829 to 4267 m/sec). The stacks were generated at velocity intervals of 250 ft/sec (76 m/sec). Using information from both the Seisgun and MiniSosie, a velocity function was determined and applied to correct all lines for normal moveout. Surface consistent statics were calculated and applied and the data stacked. Surface consistent statics corrects trace travel time by applying a time shift to each trace recorded at a particular location. The amount of static time shift is dependent on the thickness of the near surface weathered zone. When surface consistent statics are applied, an improved final record section is produced.

After evaluating the stacked data, additional detailed velocity analysis was performed. Surface consistent statics were recalculated and applied. The data were then stacked and residual statics

PROCESSING STREAM

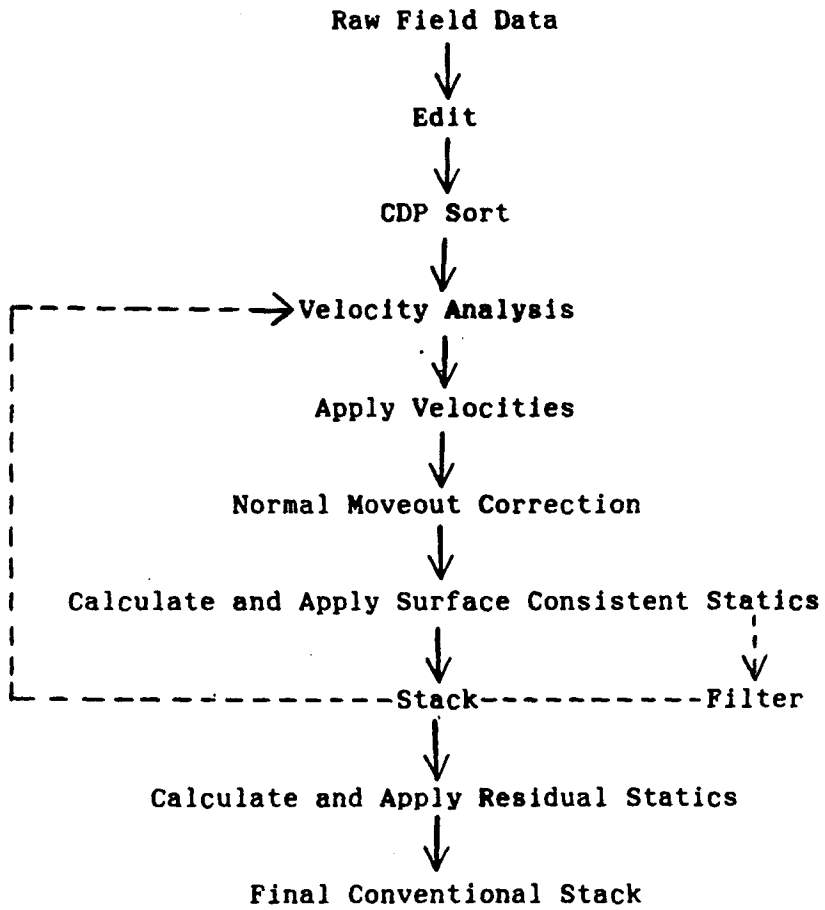


Table 2. Processing stream for final conventional stacks.

calculated and applied to achieve the final conventional record sections. The final record sections from line 1 are shown in Figures 12 and 13 for the Seisgun and MiniSosie, respectively. For line 2, the stacked record sections are shown in Figures 14 and 15 for the Seisgun and MiniSosie, respectively.

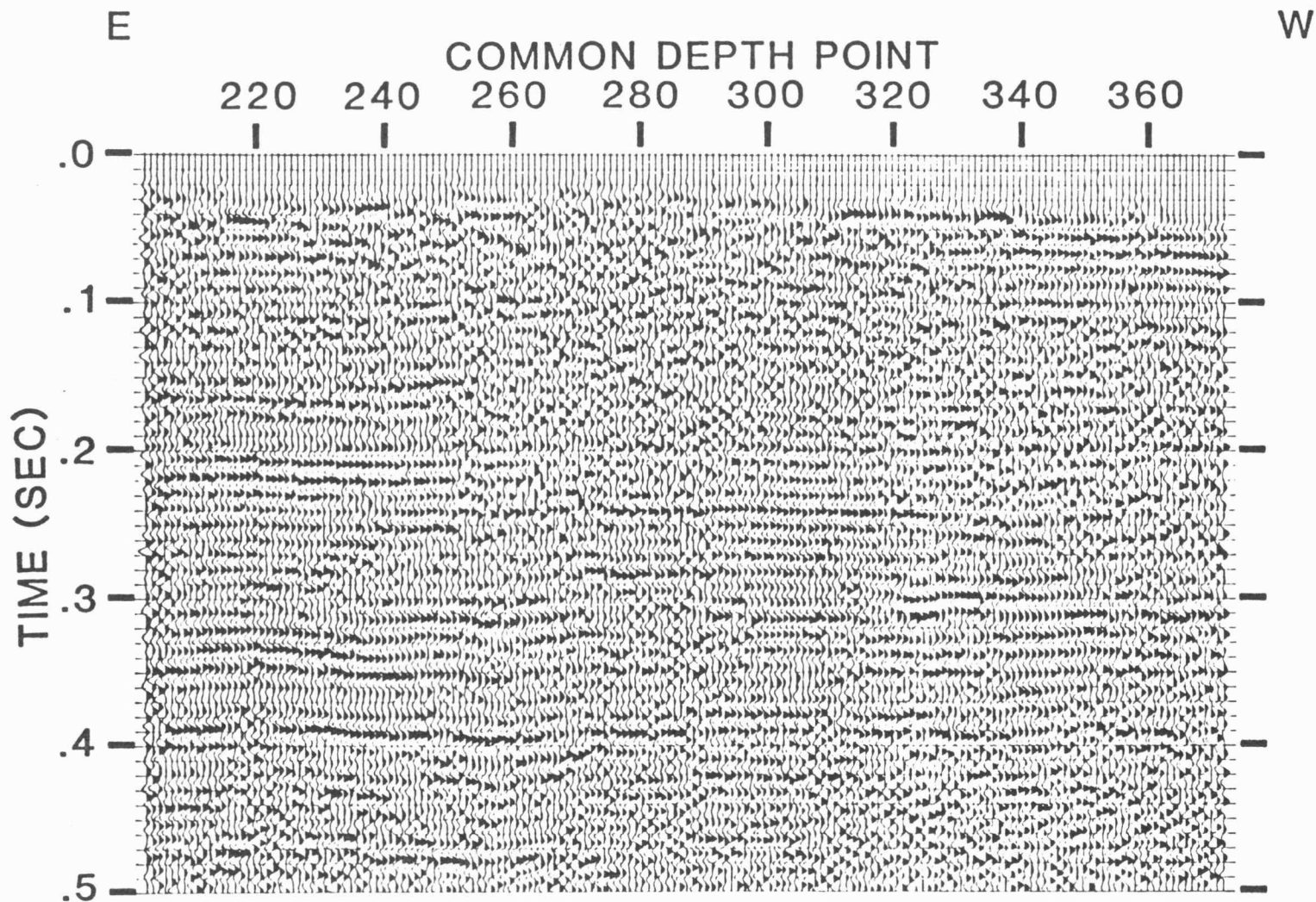


Figure 12.- Final stacked section - Seisgun line 1.

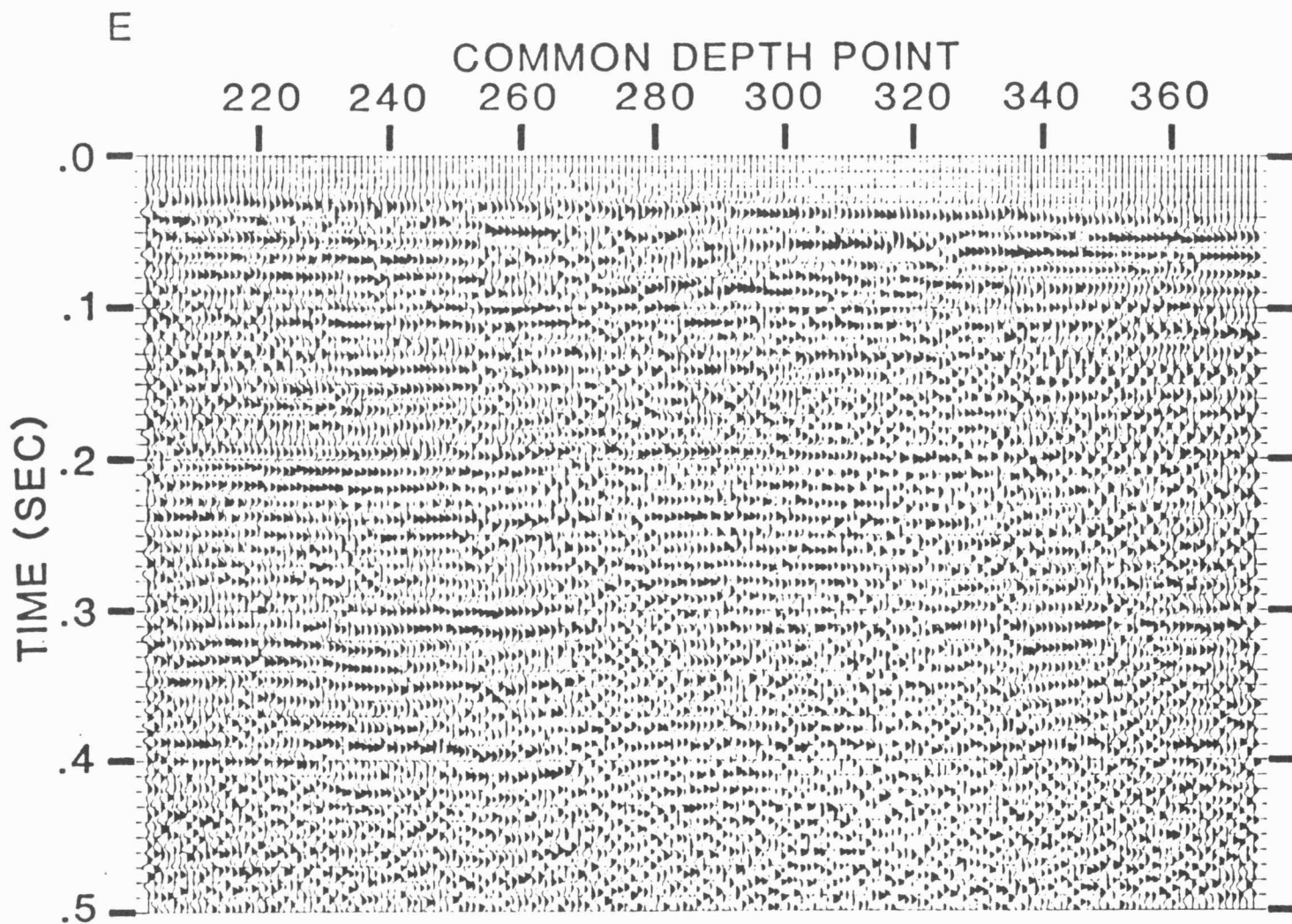


Figure 13.- Final stacked section - MiniSosie line 1.

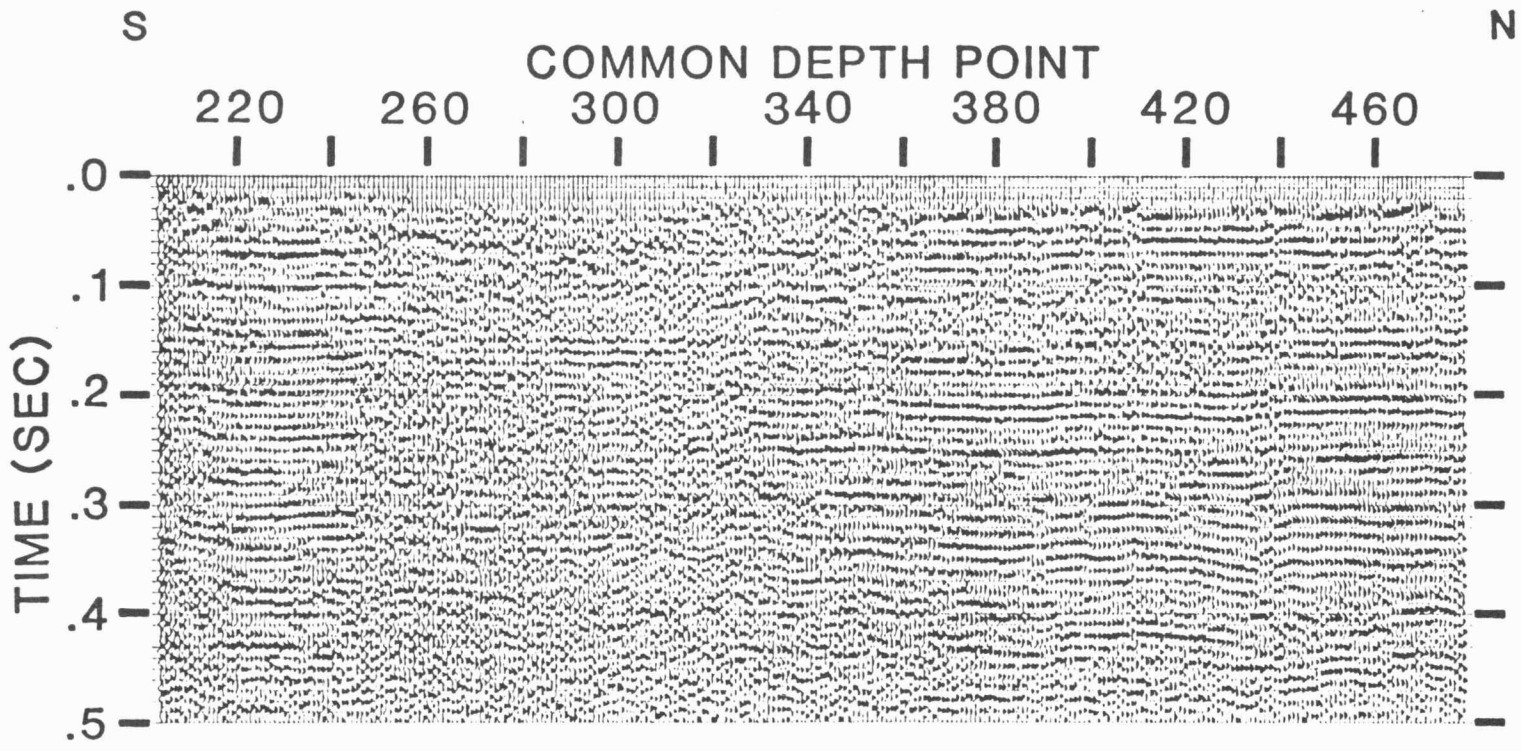


Figure 14.- Final stacked section - Seisgun line 2.

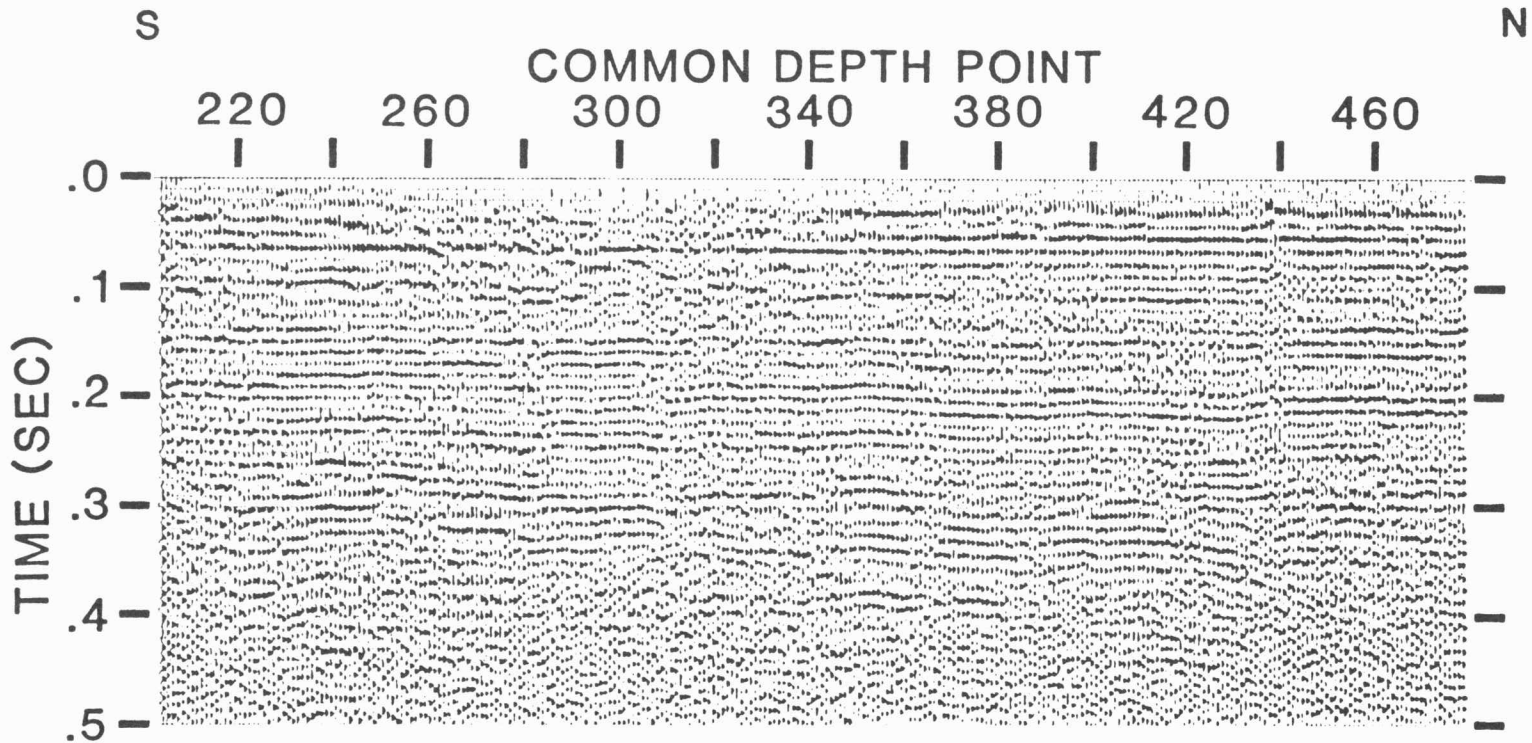


Figure 15.- Final stacked section - MiniSosie line 2.

GENERATION OF THE COMBO-STACK

Analysis of the final record sections for both sources indicates that the MiniSosie provides data superior to that of the Seisgun in the upper 200 milliseconds of the seismic record along both seismic lines; however, in comparison of the lower part of both sections the Seisgun appears to provide a more coherent record of the subsurface in some locations. Since both data sets for each line were identically processed, data from the two sources were combined along each line in an attempt to enhance the MiniSosie data. This was accomplished by scaling and time-shifting the Seisgun data and summing it with the MiniSosie data set for each line.

Analysis of the seismic data along each line revealed that the ratio of the reflection amplitudes of the two sources varies from CDP to CDP. In order to combine the data sets, it was necessary to normalize the Seisgun data relative to the MiniSosie data. This was accomplished by calculating a scaling factor for each CDP on both lines. The equation used to calculate the scaling factor at each CDP is:

$$\text{Scaling Factor} = \frac{\text{MiniSosie ACF}(t=0)}{\text{Seisgun ACF}(t=0)}$$

where $\text{ACF}(t=0)$ is the square root of the sum of the squared values of the trace. The Seisgun data at each CDP was then multiplied by its respective scaling function.

The timing of the reflection events on the Seisgun data are delayed in time relative to the MiniSosie data. A time shift at

each CDP was calculated using crosscorrelation. After calculating the time delay, the Seisgun data was time shifted. Finally, the two data sets for each line were summed together for each line. Figures 16 and 17 are the final Seisgun-MiniSosie combo-stack record sections for lines 1 and 2, respectively. There is an improvement in the continuity of the reflectors below 200 milliseconds compared with the single source final record sections. Above 200 milliseconds, the MiniSosie data is still superior. The combo-stack record sections were used to improve the interpretation of the MiniSosie record sections.

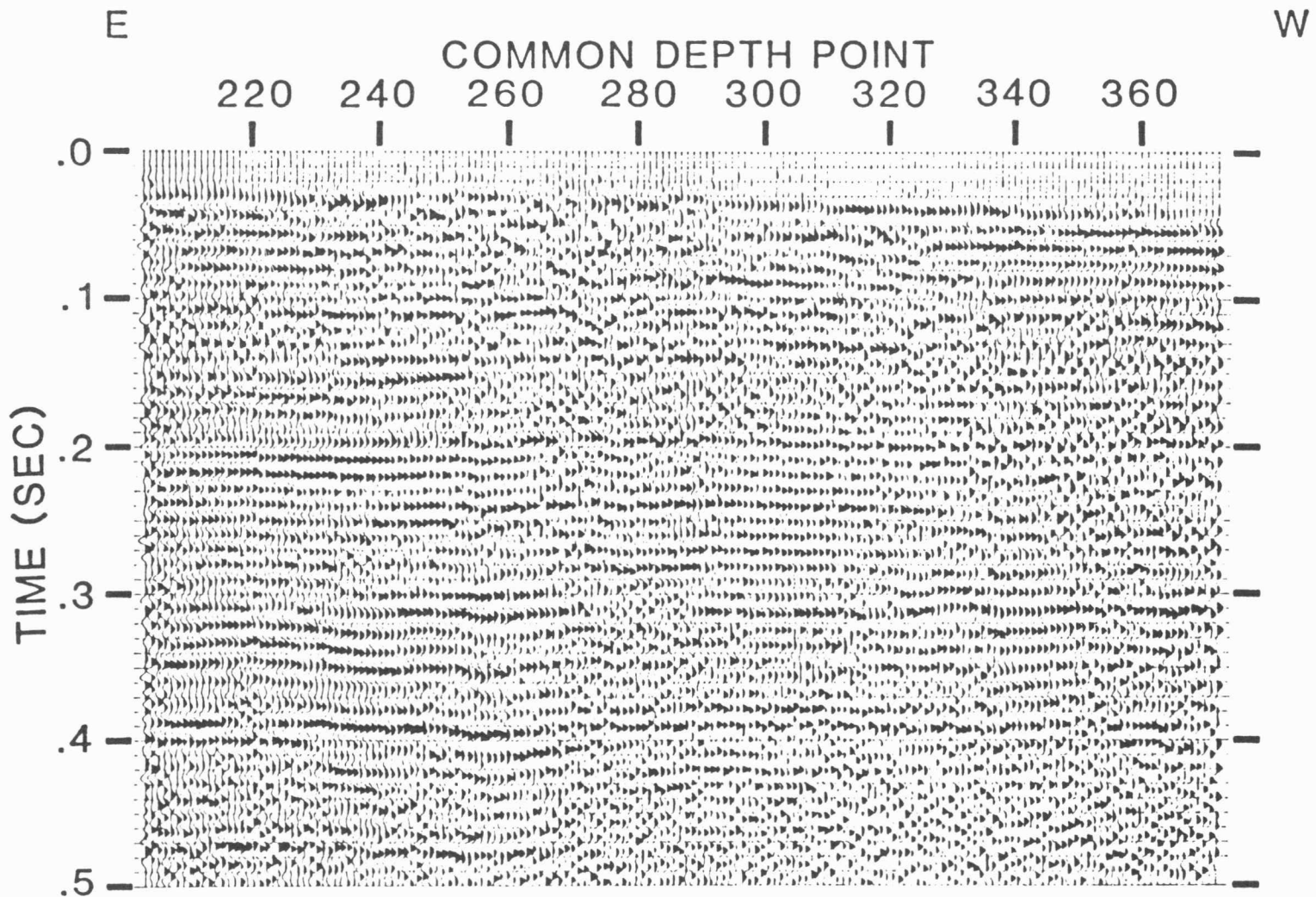


Figure 16.- Seisgun-MiniSosie combo-stack - line 1.

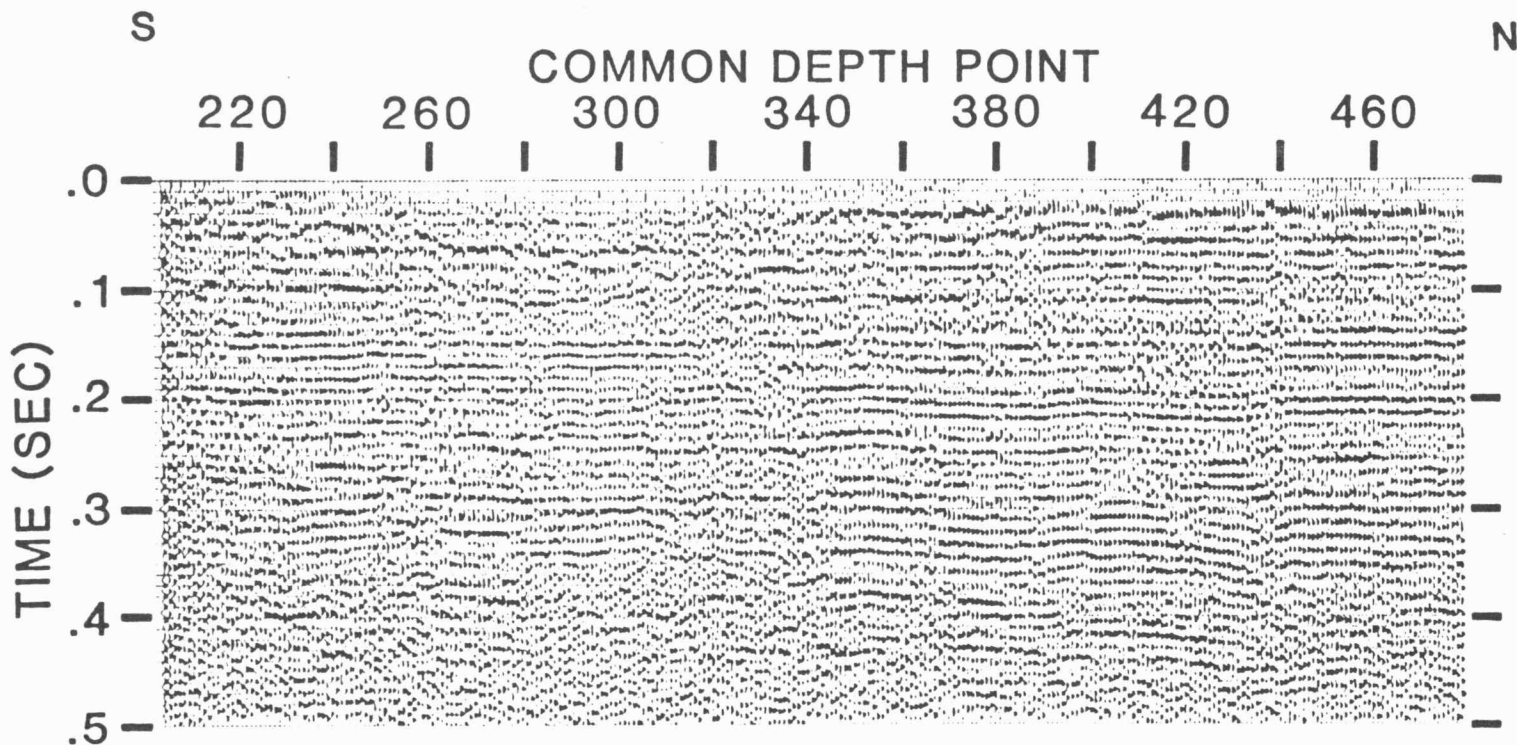


Figure 17.- Seisgun-MiniSosie combo-stack - line 2.

DIGITIZING AND RESAMPLING OF WELL LOGS

All well logs used in this study were digitized with a Tektronix 4052 Computer Graphic System and a 4956 Graphic Tablet using Program Diglog (see Appendix III). The program calculates a matrix to convert digitized tablet coordinates into the appropriate log values. It allows the user to continuously sample the log. The values are subsequently transferred to the Data General MV/8000. A time filter is used to maximize the density of the sample population.

Using Program Convert (Appendix IV), log values are determined at one foot depth increments using a trapezoidal rule integration. The integration algorithm functions as an anti-alias low pass filter and reduces the contribution of spurious noise due to pen wobble.

CONVERSION OF NEUTRON LOGS TO SONIC VELOCITY LOG

The creation of synthetic seismograms requires, at a minimum, subsurface velocity information in the form of a sonic velocity log. If, as in the study area, no velocity logs are available then it is sometimes possible to generate a pseudovelocity log. Rudman et al., (1975) shows that accurate synthetic velocity information could be empirically obtained from 16-inch short-normal resistivity logs using the scale function developed by Kim (1964). The scale function is given by the equation:

$$ITT = A + B * R_a^{-1/C},$$

where ITT is interval transit time (reciprocal of interval velocity), R_a is apparent resistivity, and A, B, and C are constants. The relationship evolves from the mutual dependence of both apparent resistivity and interval transit time upon porosity.

In Miami County, neutron count logs are commonly used to determine porosity. The relationship between interval transit time and porosity is given by the equation:

$$ITT = \frac{1}{V} = \frac{\emptyset}{V_f} + \frac{1-\emptyset}{V_m} \quad (\text{Sheriff, 1973}),$$

where V is acoustic velocity of the rock, V_f is acoustic velocity of the fluid, V_m is acoustic velocity of the matrix, and \emptyset is porosity. This relationship suggests that it may be possible to empirically derive synthetic sonic information from neutron porosity data.

The equation relating neutron response of a formation to porosity is given by the equation:

$$\log N_f = F - K * \phi_n,$$

where N_f is neutron response due to the formation, ϕ_n is neutron porosity, F is a complex constant relating to both formation transmission properties and tool design, and K is a complex constant relating to the transmission characteristics of hydrogen, rock per unit length, and source-detector spacing. An alternative method of determining porosity is given by the empirically derived equation:

$$\log \phi_n = G - L * N_a,$$

where ϕ_n is neutron porosity, N_a is neutron count as read from the log, and G and L are constants relating to tool design (Wood et al., 1974).

The conversion of neutron count to neutron porosity is accomplished using matrix algebra and the 40:1 method. The coefficients are, as stated above, dependent on tool design. Therefore, it was considered prudent to find a conversion algorithm relating neutron porosity, rather than neutron count, to interval transit time. Both neutron porosity and velocity logs are available for the ABC well (Figure 5).

The neutron porosity and velocity logs for the ABC well were digitized and log values determined on a foot by foot basis over an identical 800 foot interval. Using Program Poly (Appendix V), a fourth order polynomial least squares fit was calculated. The

neutron-sonic data pairs and the fourth order fit are shown in Figure 18.

The following relationship between neutron porosity and interval transit time was established:

$$\text{ITT} = 54.05777 + 1.35067 \phi_n - 0.00996757 \phi_n^2 + 0.0015926 \phi_n^3 - 0.0000264539 \phi_n^4.$$

The increase in the number of significant figures as a function of the power of ϕ_n is necessary in order to maintain the accuracy of the conversion algorithm. The correlation coefficient of the fit of this line to the data is 0.91.

A pseudovelocity log for the ABC well was generated from the neutron porosity data using the derived empirical relationship. Utilizing the Kansas On-line Automated Log Analysis System (KOALA), developed by Doveton and Cable (1980), plots were created of the neutron, velocity, and pseudovelocity logs, (Figure 19a). An overlay plot of the velocity and pseudovelocity logs is shown in Figure 19b. Differences in the magnitude and the timing of events in Figure 19b can be attributed to several factors. As previously stated, the velocity log measures the seismic velocity of the strata. The neutron log, however, measures the hydrogen nuclei density of the borehole formations. The presence of chemically bonded water in shale has the same effect on neutron porosity as free liquids. The result is that anomalously low acoustic velocities are determined in shale formations. In addition, the conversion algorithm functions as a low pass filter.

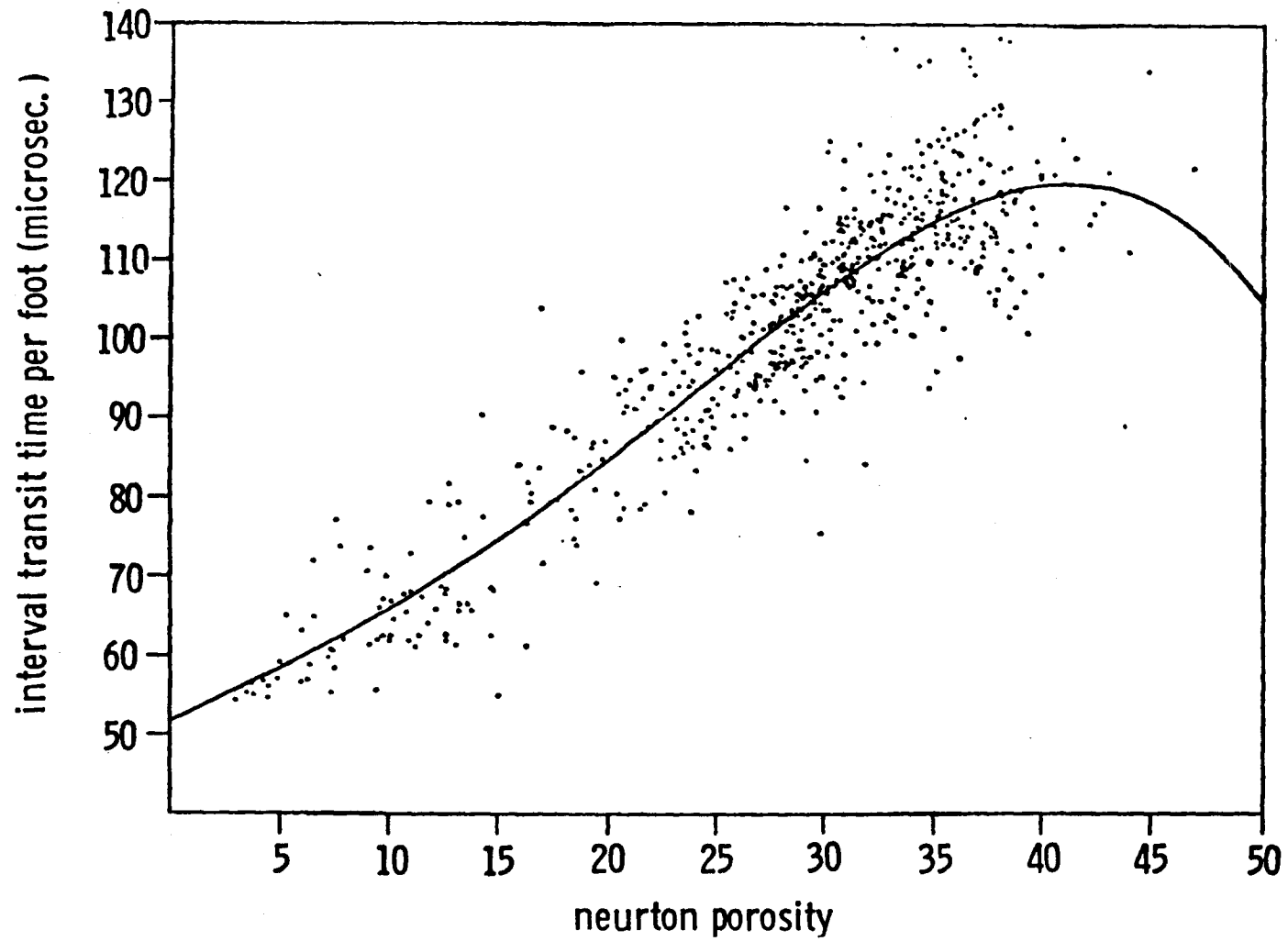


Figure 18.- Interval transit time versus neutron porosity and fourth order least squares fit for the ABC well.

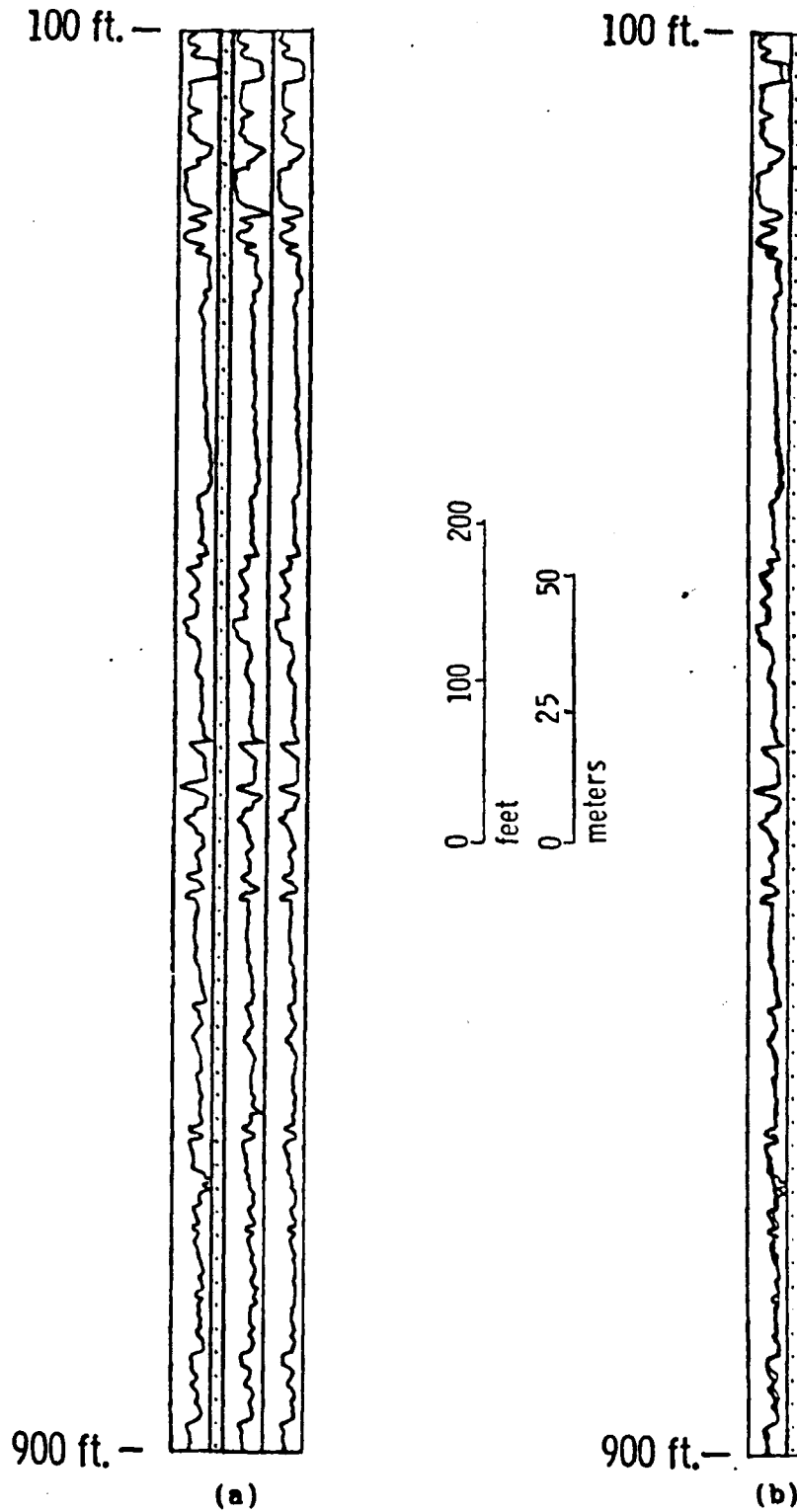


Figure 19.- ABC well logs: (a) velocity, neutron porosity, and psuedo-velocity (left to right), and (b) overlay of velocity and psuedo-velocity.

The conversion algorithm was tested to determine its accuracy when applied to another pair of well logs. The nearest location of a well for which neutron porosity and velocity logs were both recorded was in Lyons County. This was the Clinkenbeard #18 well, the location of which is shown in Figure 5 (Appendix I). Both logs were digitized and a pseudovelocity log was created from the neutron porosity log using the conversion algorithm from Miami County. Plots of the neutron, velocity and pseudovelocity logs are shown in Figure 20a. An overlay of the velocity and pseudovelocity well logs is shown in Figure 20b. The algorithm produced another close approximation of the true log.

A measure of the accuracy of the conversion algorithm is given by comparing the travel time to key horizons for both the velocity and pseudovelocity log (Rudman et al., 1975). The equation relating two-way travel time to interval transit time is given by the equation:

$$T(i) = ITT(i) * X,$$

where T is the two-way travel time to depth i in microseconds and X is the depth interval (in this case, one foot). The travel time to key horizons for the velocity and the pseudovelocity logs are given in Table 3 for the ABC and Clinkenbeard wells. It was concluded that the conversion formula, while accurate for this distant well, would be more accurate for wells closer to the ABC well.

As was previously stated, there were no neutron porosity well logs available for wells near the seismic lines. However, using a

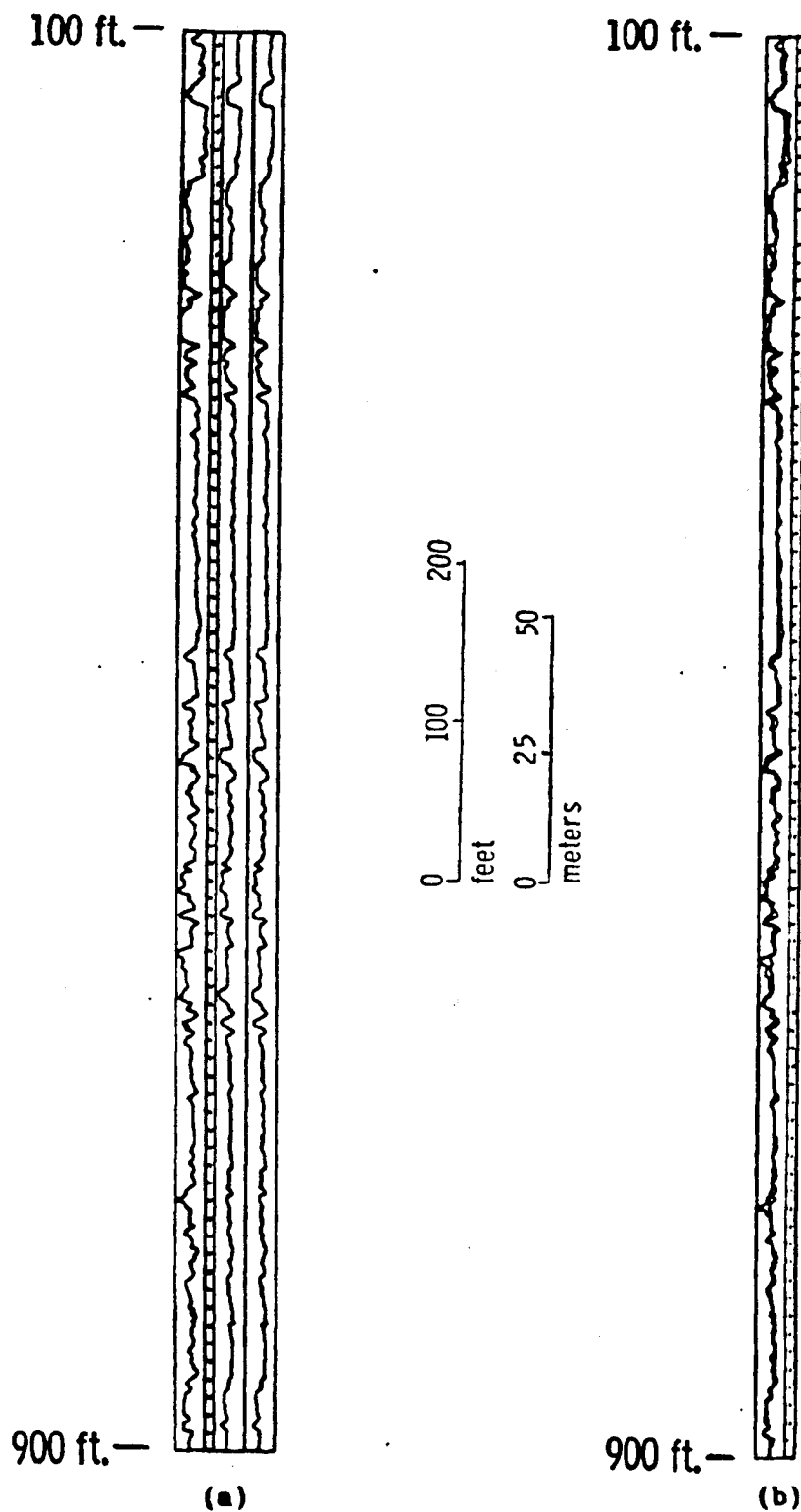


Figure 20.- Clinkenbeard well logs: (a) velocity, neutron porosity, and psuedovelocity (left to right), and (b) overlay of velocity and psuedovelocity.

Well	Top of (unit)	Traveltime (ms)		
		Sonic	Synthetic Sonic	% Change
ABC	Pleasanton Group	8.2	8.1	-1.4
	Marmaton Group	25.8	25.1	-2.5
	Cherokee Group	39.7	38.9	-1.9
	Tebo Coal Bed	59.5	59.3	-0.4
Clinkenbeard	Pleasanton Group	16.0	15.8	-1.0
	Marmaton Group	35.5	34.3	-3.5
	Cherokee Group	50.2	48.6	-3.2
	Tebo Coal Bed	64.6	62.9	-2.6

Table 3. Traveltimes to key horizons in the ABC and Clinkenbeard wells calculated from both sonic and synthetic sonic well logs.

modification of the 40:1 method, the neutron count from the S10A well, located near the seismic lines (Figure 5, Appendix I), was converted to a neutron porosity over the length of the well log. A pseudovelocity well log was then generated for this well using the neutron porosity-interval transit time conversion algorithm. For the first thirty feet, velocity information from the Wiseman 'A' 1-6 well (Figure 5, Appendix I) was used. For the unlogged strata below the S10A well, velocity information from the ABC well was used.

THE SYNTHETIC SEISMOGRAM

Synthetic seismograms were created to enhance the final interpretation of the seismic section by aiding in the correlation of stratal surfaces and unconformities with seismic reflection events and in the identification of surface multiples. In addition, they help to test the accuracy of the neutron porosity-interval transit time conversion algorithm. A review of the procedure used to generate a synthetic seismogram from well logs is instructive.

The technique of generating synthetic seismograms is widely addressed in the geophysical literature (Stone and Evans, 1980; Telford et al., 1976). As shown in Figure 21, information from a sonic log is converted from a depth versus interval transit time format to a two-way reflection time versus interval velocity format. If accurate density information is available, it also is converted to a reflection time format and an acoustic impedance log is formed from the product of interval velocity and density. A reflection coefficient series is generated from either reflection time log.

For vertically incident waves, the relationship between the reflection coefficient and acoustic impedance is:

$$R(i) = \frac{Z(i)-Z(i-1)}{Z(i)+Z(i-1)},$$

where R is the reflection coefficient at depth i and Z is the acoustic impedance (the product of density and interval velocity). If density is considered to be constant, the modified reflection

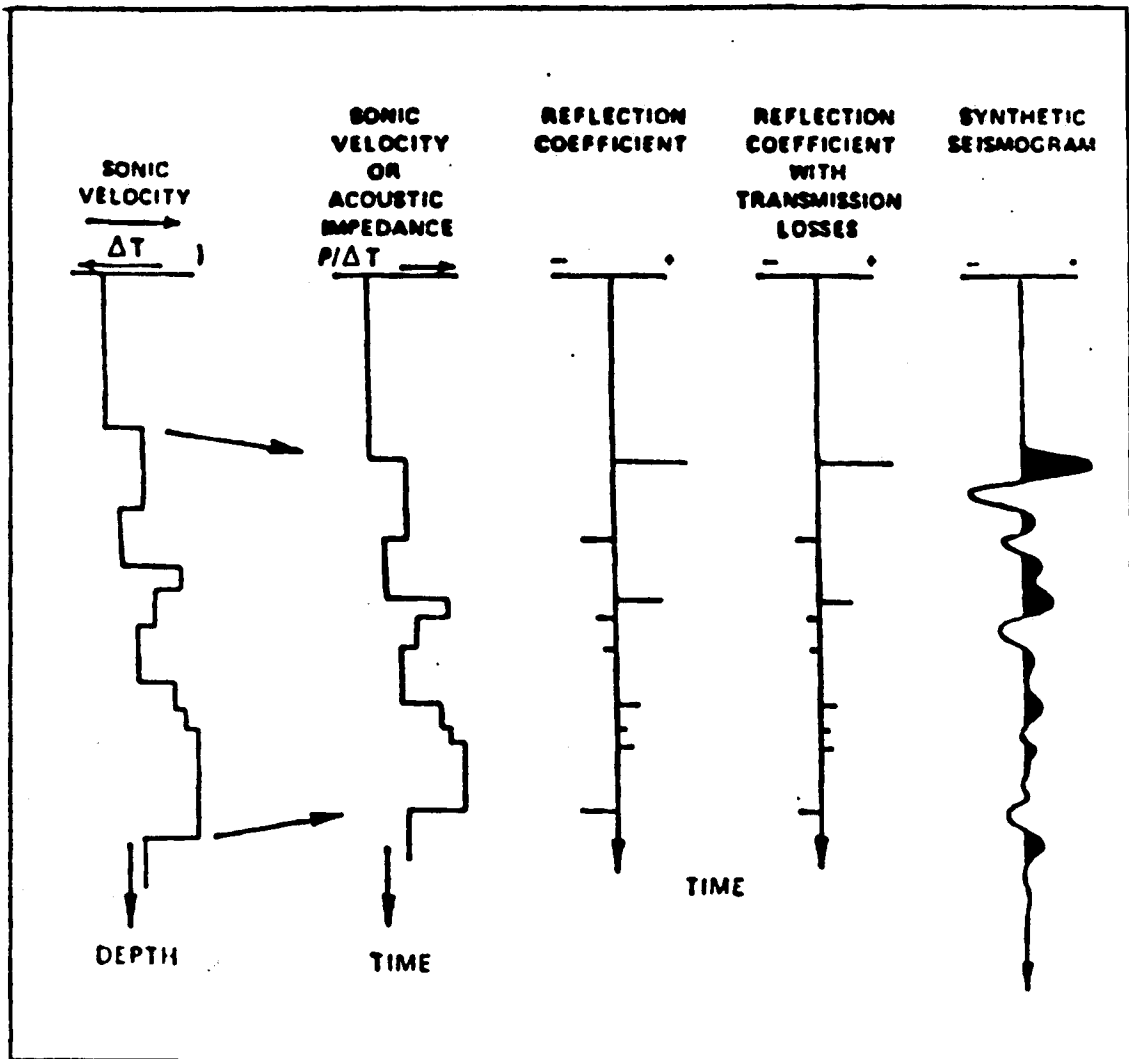


Figure 21.- Technique used to create a synthetic seismogram (from Stone and Evans, 1980, Figure 1).

coefficient is related to velocity by the equation:

$$R_m(i) = \frac{V(i)-V(i-1)}{V(i)+V(i-1)},$$

where V is the interval velocity at depth i .

After generating a reflection coefficient series, each reflection coefficient is further modified to account for two-way transmission losses. The modified reflection coefficient, R_t , which accounts for two-way transmission loss is calculated using the equation:

$$R_t(i) = R_m(i)[1 - R_m^2(i-1)][1 - R_m^2(i-2)] \dots [1 - R_m^2(1)],$$

where $R_m(i)$ is the modified reflection coefficient without two-way transmission loss at depth i . The synthetic seismogram is then created by convolving an estimated source wavelet with the modified reflection coefficient series.

In order to further test the neutron porosity-interval transit time conversion algorithm, synthetic seismograms were created for both the velocity log and the pseudovelocity log of the ABC well using the Snark module in KOALA (Doveton and Cable, 1980). This program does not include transmission losses when calculating reflection coefficients. In addition, it does not allow for changes in the shape of the Ricker wavelet with time due to absorption. The convolution of each log with a 50 Hz Ricker wavelet is shown in Figure 22. The synthetic seismograms produced with a 100 Hz Ricker wavelet is shown in Figure 23. In both cases, the timing and

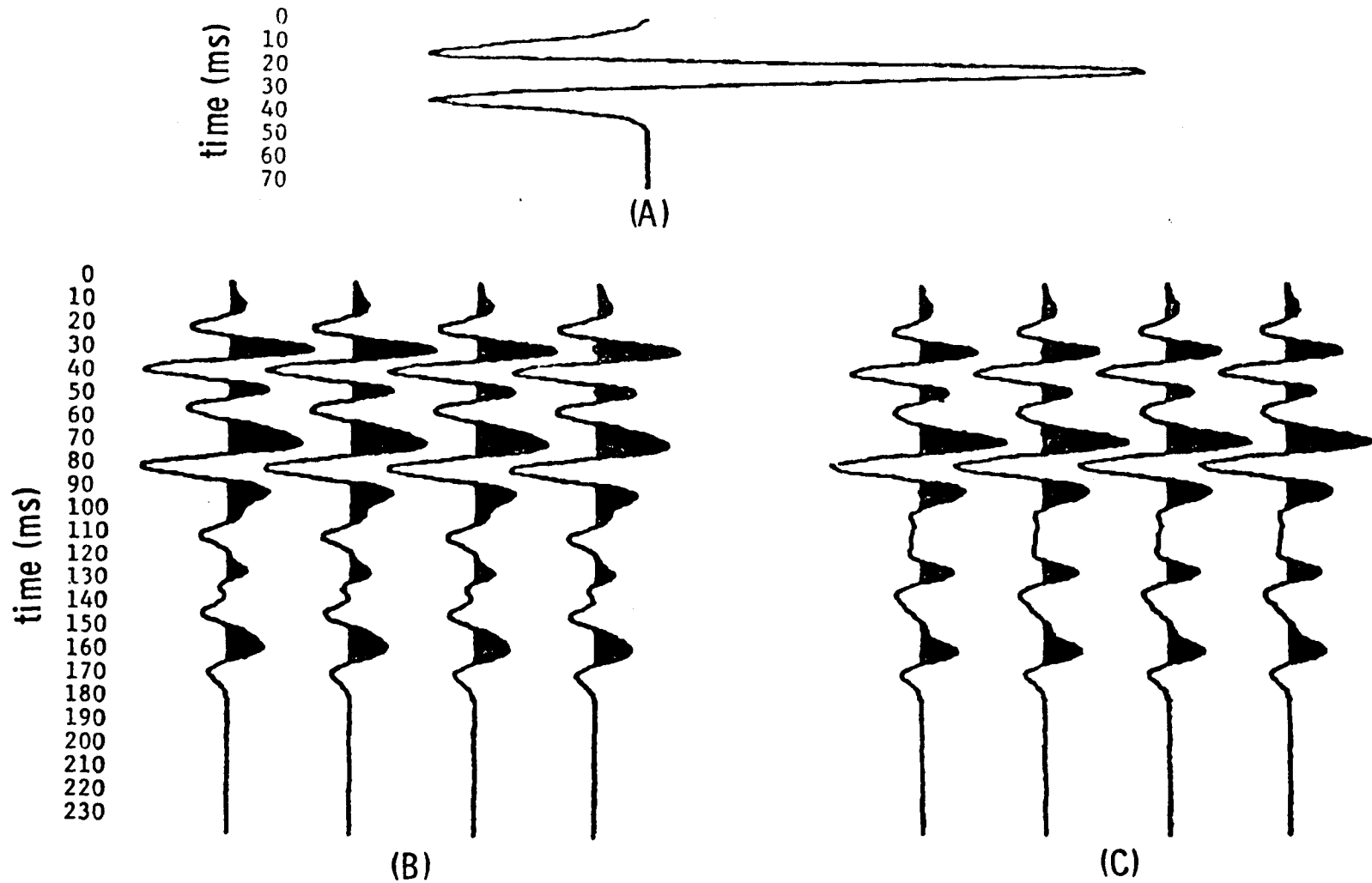


Figure 22.- (A) 50 Hz Ricker-like wavelet, (B) synthetic seismogram from ABC velocity log, and (C) synthetic seismogram from ABC pseudo-velocity log.

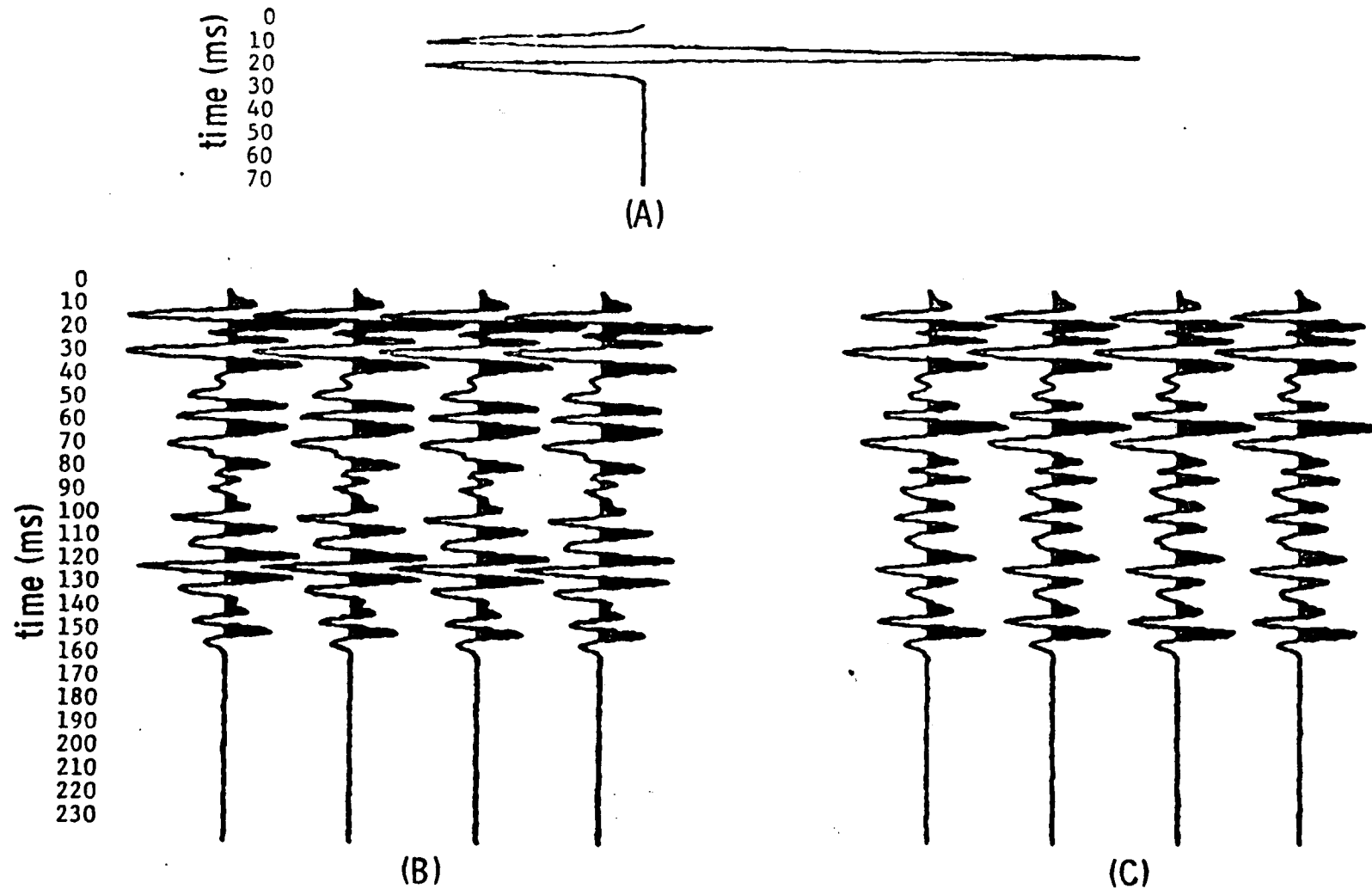


Figure 23.- (A) 100 Hz Ricker-like wavelet, (B) synthetic seismogram from ABC velocity log, and (C) synthetic seismogram from ABC pseudo-velocity log.

polarity of the seismic reflections is correct. The differences in reflection amplitude are mainly due to the smoothing effects of the neutron porosity-interval transit time conversion algorithm. Synthetic seismograms were also created for the Clinkenbeard well using a 50 Hz and a 100 Hz Ricker wavelet for both the velocity log and the pseudovelocity log (Figures 24 and 25). Analysis reveals that the magnitude and timing of the reflection events are essentially preserved.

Using Program Synseis (Appendix VI) reflection coefficient series were created from the S10A pseudovelocity log. This program allowed the creation of a reflection coefficient series that incorporated not only transmission losses, but also contributions due to the propagation of multiples. The multiple generating technique was based on work in signal analysis by Wuenschel (1960), Treital and Robinson (1966), and Robinson and Treitel (1980). A reflection coefficient of 0.25 was used for the free surface of the earth.

The primary reflection coefficient series is shown in Figure 26a. The wavelet (15-30-100-150 bandpass with a -90 degree phase shift) which is convolved with the different reflection coefficient series is shown in Figure 26b. Figure 26c is the synthetic seismogram due to primary reflections only with no transmission losses. It indicates that primary reflection should, ideally, occur as deep as 370 milliseconds (2311 feet, 705 meters) in the S10A well. If transmission losses are taken into account (Figure 26d), then primary energy is highly attenuated in the first 110 milliseconds (580 feet, 177 meters). The interval, between the surface and the Fort

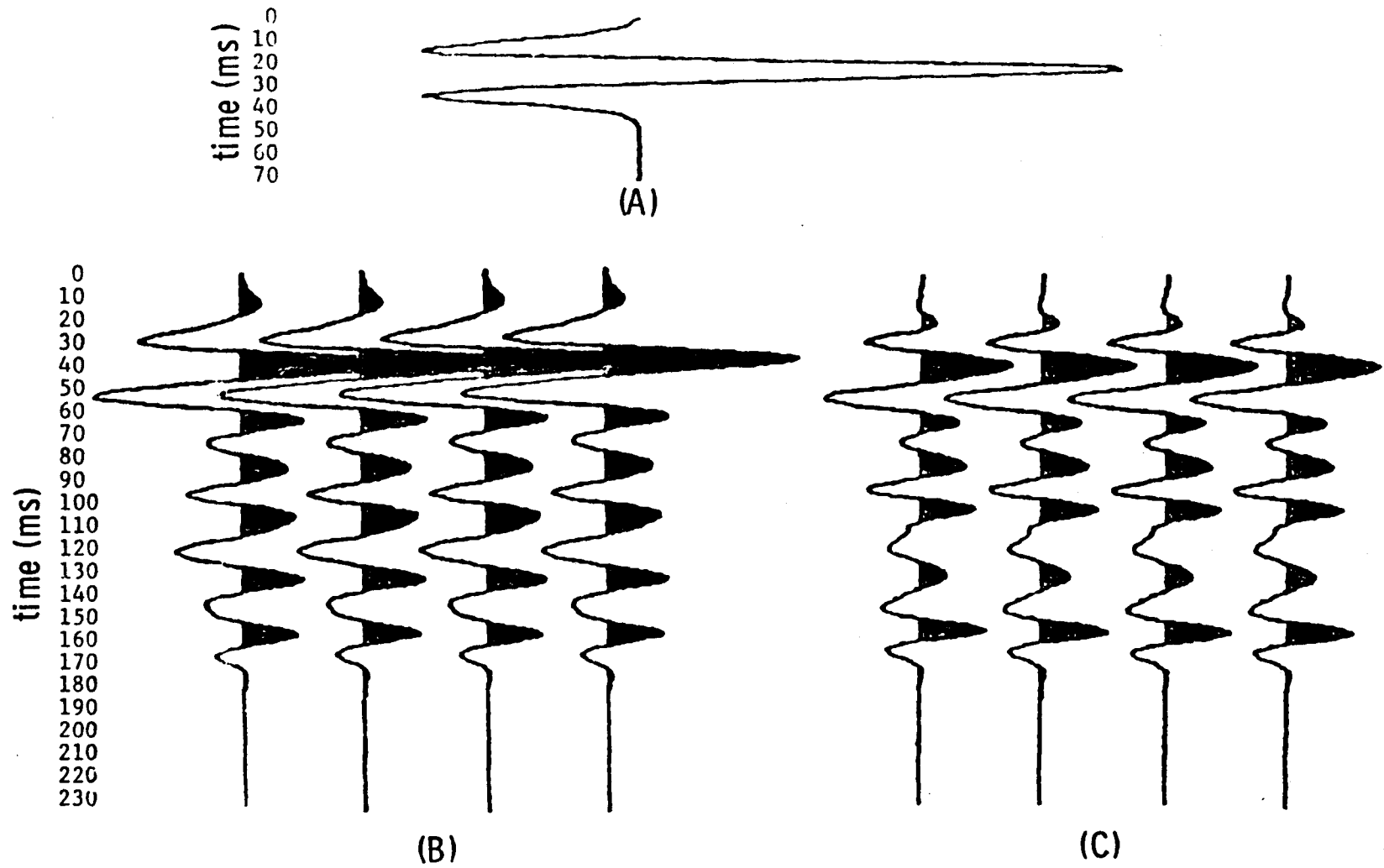


Figure 24.- (A) 50 Hz Ricker-like wavelet, (B) synthetic seismogram from Clinkenbeard velocity log, and (C) synthetic seismogram from Clinkenbeard pseudovelocity log.

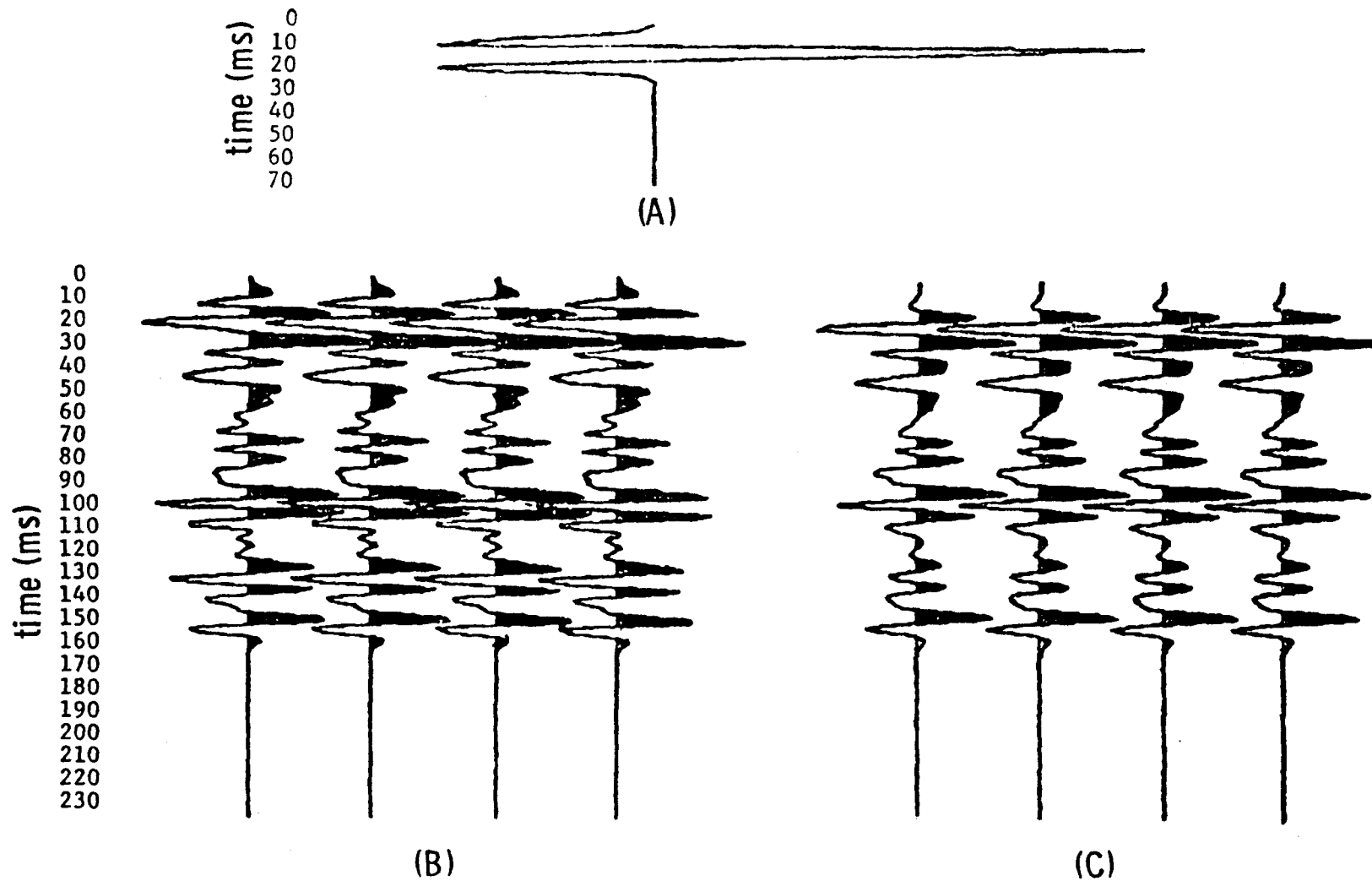


Figure 25.- (A) 100 Hz Ricker-like wavelet, (B) synthetic seismogram from Clinkenbeard velocity log, and (C) synthetic seismogram from Clinkenbeard pseudovelocity log.

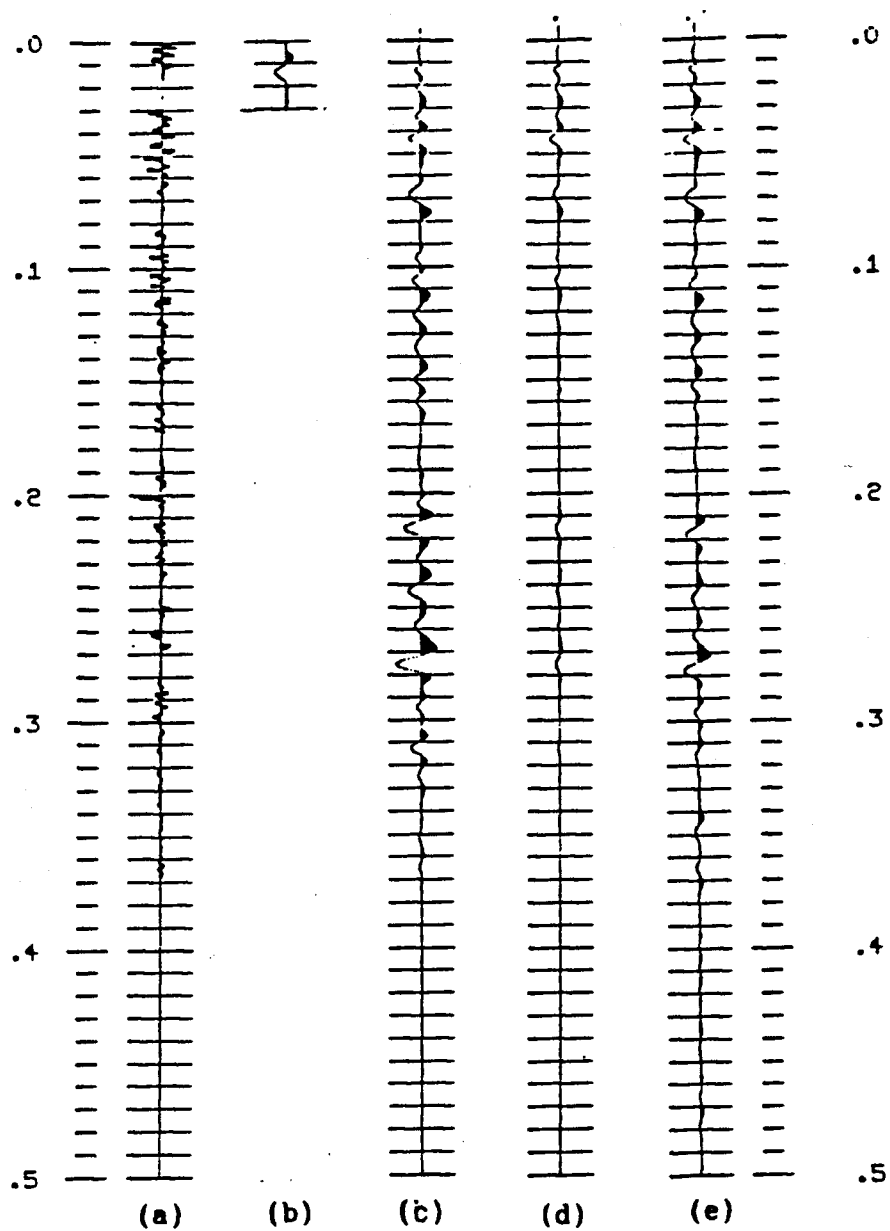


Figure 26.- S10A synthetic seismogram:

- a) reflection coefficient series;
- b) seismic wavelet (15-30-100-150, -90 degree phase shift);
- c) synthetic with primary energy only;
- d) synthetic with primary energy plus transmission losses;
- e) synthetic with primary and multiple energy (transmission losses included).

Scott (located at 110 milliseconds) consists of cyclothem. O'Doherty and Anstey (1971) state that in cyclic patterns of sedimentation, there is a significant decline in transmitted energy. Above the Fort Scott there are many reflection coefficients greater than 0.10 and several greater than 0.20. Consequently, there is a 12 dB decrease in transmitted energy at the base of the Fort Scott due transmission loss.

In Figure 26e, multiples were included in the creation of the synthetic seismogram. It is apparent that the inclusion of interbed multiples compensates to some degree for the loss of energy due to the effects of transmission. According to O'Doherty and Anstey (1971, p. 444), "the multiply-reflected signal in a series of thin plates bounded by interfaces of opposite polarity is always the same sign as the direct transmitted signal and tends to overtake it in amplitude." That is, the multiply-reflected signal can become the dominant reflected energy in a cyclothem environment.

The inclusion of multiple energy has two important effects upon a synthetic seismogram. First, the wavelet which has passed through a cyclic section is broader than the primary wavelet of Figure 26c. This is due to the contribution of the multiples which are delayed in time relative to the primary wavelet, and has a low pass filtering effect. The higher frequencies of the signal are more sensitive to changes in the signal (Shroenberger and Levin, 1974). Also, the arrival times of the peaks of the wavetrain with multiples lag behind those of the signal with primary reflections only. Again energy from multiples is delayed with respect to direct arrivals

(Shroenberger and Levin, 1978).

INTERPRETATION OF SEISMIC DATA

The initial step in interpreting the seismic data was to divide the seismic sections into seismic sequences. Seismic sequences are zones in which reflections are consonant. The zones are interpreted to be depositional sequences composed of generally conformable, genetically related strata. Each seismic sequence is bounded by a discontinuity associated with an unconformity (Mitchum et al., Part 6, 1977b). Figures 27 and 28 show the seismic sequences which have been identified for lines 1 and 2, respectively. Each has been separated into ten seismic sequences. As an aid for associating geologic strata with seismic reflectors, Figure 29 shows the correlation between the S10A synthetic seismogram and the seismic data.

Sequence A represents rocks of the Upper Cambrian from the Precambrian basement to the top of the Eminence Dolomite including the Lamotte Sandstone and the Bonneterre Dolomite. On line 1 the basement reflection occurs between 395 and 400 milliseconds (approximately 2300 feet, 701 meters). There is a discontinuity at the upper boundary of the sequence. The associated unconformity is apparent between CDP 263 and CDP 316 on line 1 where an additional reflection event is present. This reflection is truncated at either end by the unconformity. Assuming a velocity of 22,000 ft/sec (6706 m/sec), determined from the ABC velocity log, the vertical relief on top of the Eminence Dolomite due to this positive topographic feature is 90 feet (27 meters). The seismic record of the strata within this sequence is somewhat ambiguous. The lower boundary for

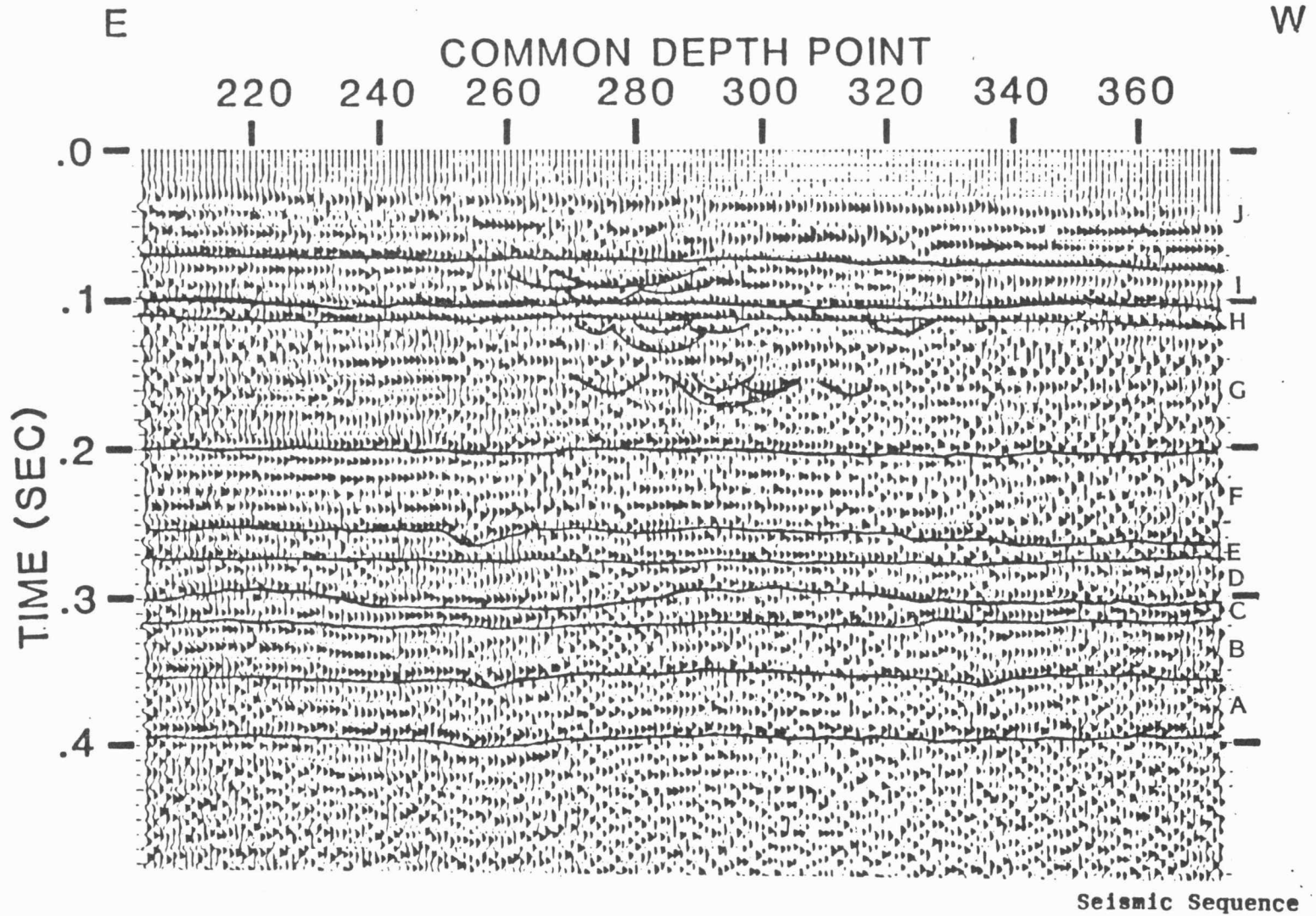


Figure 27.- Seismic interpretation of line 1.

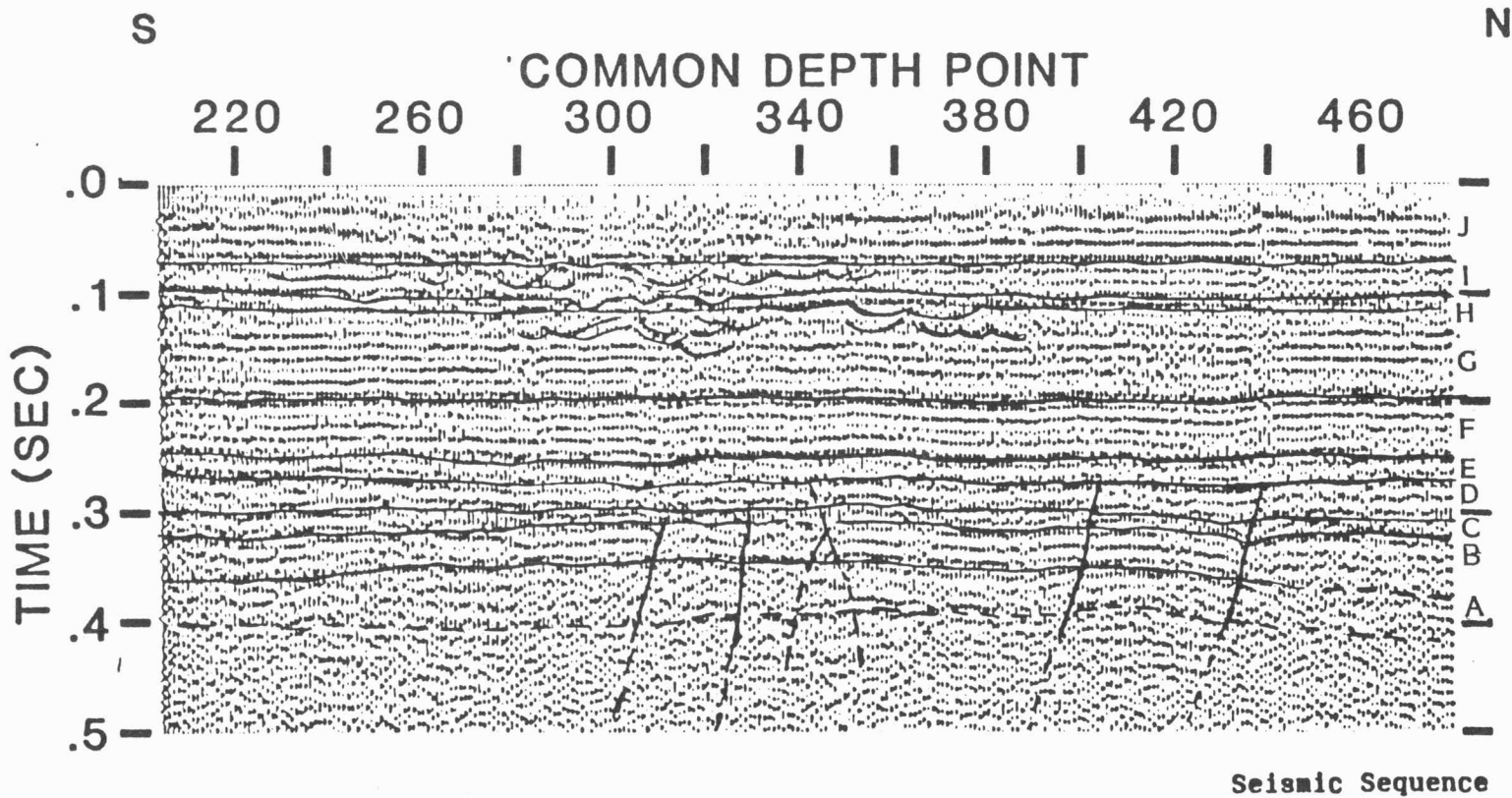


Figure 28.- Seismic interpretation of line 2.

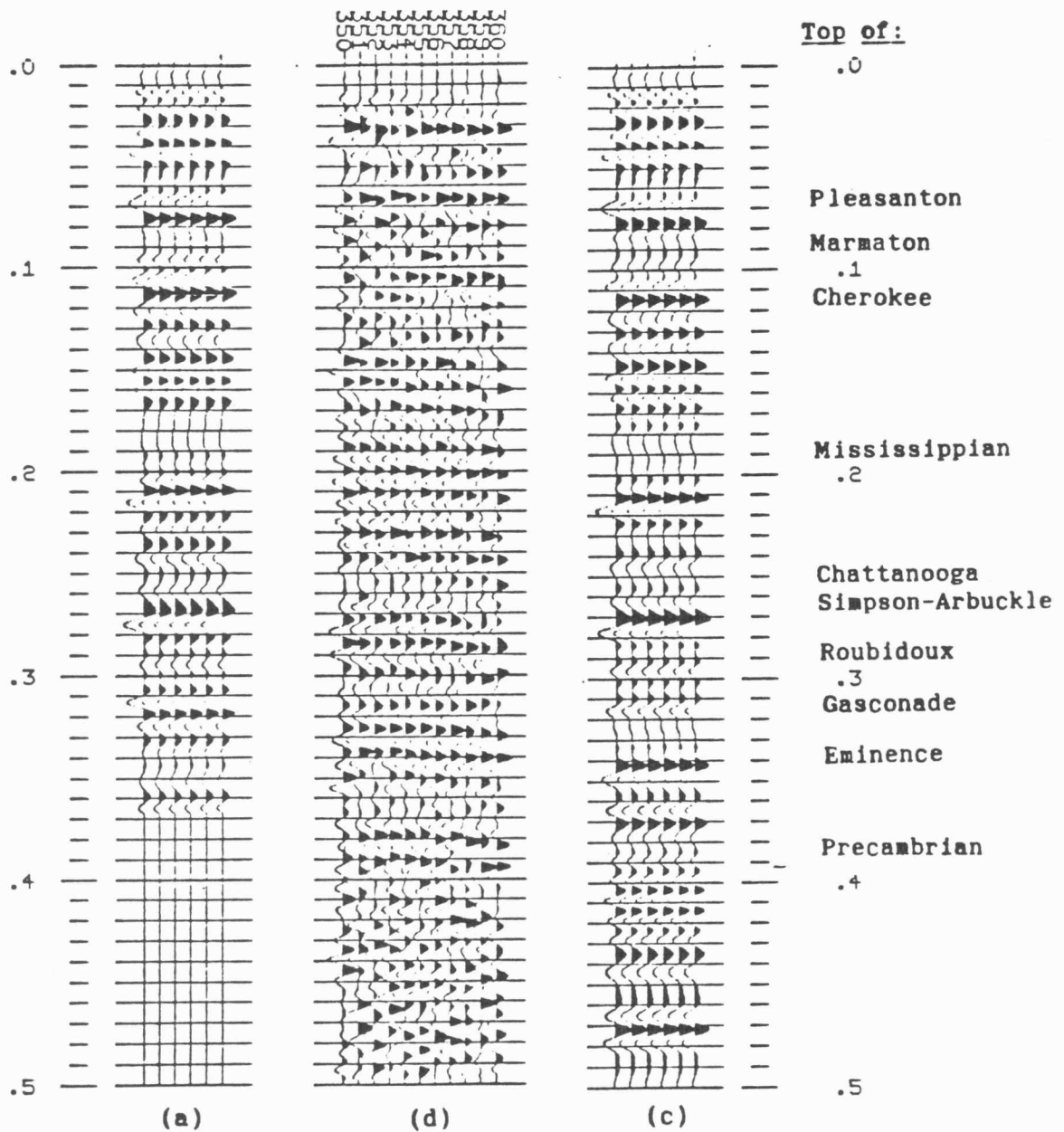


Figure 29.- Correlation between S10A synthetic seismograms and MiniSosie seismic data (from line 1):

- a) synthetic with primary energy only;
- b) seismic data
- c) synthetic with primary and multiple energy (transmission losses included).

line 2 has been inferred from line 1. Events below the Precambrian surface are multiples (see Figure 26e).

Sequence B represents rocks of the Van Buren Formation and the Gasconade Dolomite. At its base, the sequence exhibits a thinning over the Eminence topographic high on line 1. There is an apparent thickening of the sequence between CDP 218 and CDP 230 on line 2. This thickening may be due to a slight structural folding prior to the post-Gasconade peneplanation. Elsewhere on both seismic lines, reflection events of this sequence exhibit a distinct parallelism, as does sequence A. This is to be expected considering the shallow marine environment in which these strata were deposited.

Sequence C represents rocks of the Roubidoux Formation. According to Keroher and Jewell (1948), the Roubidoux unconformably overlies older strata. The unconformity at the top of sequence is apparent between CDP 250 and CDP 270 on line 2. In this region, there is a pinchout of the reflection event that is present at 304 milliseconds on CDP 204. On line 1 this reflection event is also present between CDP 215 and CDP 230 and between CDP 277 and CDP 323 but has been removed elsewhere by erosion. The apparent relief on top of the Roubidoux determined from the seismic data on line 1 is approximately 75 feet (23 meters), assuming a velocity of 15,400 ft/sec (4695 m/sec) (from the ABC velocity log).

Sequence D represents the Jefferson City and the Cotter Dolomites. The basal Jefferson City reflector exhibits a thinning on line 1 over the topographic highs of the pre-Jefferson City erosional surface and a thickening over the topographic lows. The

upper seismic discontinuity is evident on line 1 between CDP 235 and CDP 260. Between these locations there is an additional reflection event which has been truncated by the pre-St. Peter peneplanation.

Strata which are represented in sequence E are the thin St. Peter Sandstone, the "Hunton Group," and the Chattanooga Shale. The St. Peter is not visible on the seismic sections because of its thinness over the study area (less than 15 feet, 5 meters). Therefore, the seismic discontinuity at the base of this sequence is a composite due to both the unconformity at the base of the St. Peter and the unconformity at the base of the "Hunton Group." At the top of the sequence on line 1, between CDP 250 and CDP 265, there is evidence of a channel in the Chattanooga Shale cut by pre-Mississippian erosion.

Sequence F represents Mississippian limestones. On line 1 there is a thickening of the Mississippian strata over the stream cut in the Chattanooga Shale. The reflection events within this sequence exhibit parallelism.

Seismic sequence G represents rocks of the Cherokee Group which were deposited during Desmoinesian time. Reflection events exhibit high but variable amplitude, high continuity and parallelism. According to Sangree and Widmier (1977), the environmental facies interpretation is that of fluvial clastics interbedded with widespread marsh deposits. The variable nature of the reflections in this sequence and sequences H, I, and J can be partially attributed to the cyclic nature of the strata. As previously stated, these rocks tend to have rapid and repeated changes in seismic velocity.

Consequently, the reflections on the seismic record are actually composites of several superimposed reflections. The amplitude of a particular composite reflection is susceptible to changes in either the thickness or the lithology of any stratigraphic unit which contributes to the composite reflection.

In the middle and lower zones of seismic sequence G, seismic reflections indicate the presence of paleo-stream channels. These channels are located on line 2 at CDP's 281, 315, and 322 at the following times: 160, 150 and 170 milliseconds, respectively. The channels may be associated with a fall in sea level during a regressive cycle.

The "squirrel" sands are located at the top of the sequence below the Fort Scott Limestone. The Fort Scott produces the basal reflection of seismic sequence H. Over most of the area the gamma-ray well logs indicate that the "squirrel" sands are point bars deposited in a deltaic environment. The identification of "squirrel" sands deposited as point bars is difficult due to the long, apparently "ringy" seismic wavelets, the transitional lithology at the base of the sands, the effects of scaling during processing, and the limitations of available modelling programs. However, there does appear to be several channels located at the base of the Fort Scott. On line 1, these channels are located between CDP 270 and CDP 293. On line 2 there appears to be a channel located between CDP 290 and CDP 300. In each case there appears to be a dimming of the Fort Scott reflector. This may be

due to the change in seismic velocity between channel "squirrel" sandstones and the non-channel sandstones. The higher velocity of the channel sand may result in a lower reflection amplitude of the Fort Scott Limestone over a "squirrel" channel sand. Assuming a seismic velocity of 10,000 ft/sec (3049 m/sec) of the sand, the channels are approximately 50 feet (15 meters) thick. There are several wells which have recently been drilled along line 1 in which the gamma-ray well logs indicate the presence of a well developed "squirrel" channel sand that is over 40 feet (12 meters) thick. It may be that this channel intersects line 1 where there are apparent channels beneath the Fort Scott.

Sequence H represents the Marmaton Group. As previously stated there is an increase in the presence of limestone in the strata younger than the Cherokee Group. Consequently, the amplitude of the composite reflection is highly responsive to the relationship between the lithology and thickness of a member limestone and that of a neighboring shale or sandstone. In some instances, it is possible to "tune out" a reflection due to waveform superposition. An example is the reflection event on line 1 at CDP 203 at 88 milliseconds. This reflection has variable amplitude across the line and appears to "tune out" to the west.

Sequence I represents rocks of the Pleasanton Group. This sequence is characterized by reflections indicating the presence of numerous channels. Most of these channels are located between CDP 255 and CDP 300 on line 1 and between CDP 270 and CDP 360 on line 2.

Sequence J represents rocks of the Kansas City Group. Reflect-

tions within this sequence exhibit a lack of continuity which is probably due to muting of the raw field data or to lack of data at short source-geophone offsets.

CONCLUSIONS

The "squirrel" sands are located in the Pennsylvanian system. This section of the stratigraphic column is very complex seismically due to the rapid and cyclic variations in seismic velocity. It appears that it is possible to locate "squirrel" sands that have been deposited within channels using MiniSosie. The presence of these channels apparently results in a dimming of the Fort Scott composite reflection due to interference. In addition to the "squirrel" sands there appear to be additional channels within the Pleasanton and Cherokee Groups of the Pennsylvanian. The composite reflections which indicate the occurrence of channels are generally located within two zones, one on each seismic line, which may indicate that the channels are fault controlled.

In order to enhance the MiniSosie data deep in seismic sections, a combo-stack was created using both the Seisgun and the MiniSosie data sets. The combo-stacks aided in the identification of several unconformities in the pre-Mississippian seismic record. These unconformities have been previously recognized by geologists using well log data.

Structurally, the line 2 seismic data indicates that there is an apparent anticline in the pre-St. Peter strata. The top of this anticline has been beveled. The seismic data from line 2 indicates the presence of several faults on line 2 which may be associated with the folding. At least one of the faults may extend into the Pennsylvanian strata.

The data gathered for this study was one of the first high resolution data sets gathered by the Kansas Geological Survey. This and a subsequent study indicate that the 110 Hz low-cut pre-emphasis filter was an unfortunate choice. Subsequent high resolution studies have been recorded with a 55 Hz low-cut filter. This ensures a recording of data over at least two octaves which reduces the "ringiness" of the seismic wavelet is decreased, while severely attenuating the reflection amplitude of the first breaks and groundroll.

A comparison of Seisgun and MiniSosie data reveals that MiniSosie is the more productive surface source of seismic energy when searching for shallow seismic targets in eastern Kansas. This is primarily due to its superior attenuation of random noise. MiniSosie data might be further improved by increasing the vertical stack to 2000 impacts.

To enhance the stacked data, it may be feasible to use near trace stacks when searching for shallow targets such as the "squirrel" sands. Transformation of the stacked data to zero-phase would simplify interpretational problems associated with the long source wavelets. In addition, this would facilitate the use of "thin-bed" analysis.

Finally, the dominant frequency of the MiniSosie data was 90 Hz at shallow depths. Deeper in the seismic record the dominant frequency decreased to approximately 75 Hz. This is due to the attenuation of the higher frequencies by the earth as a result of absorption and the interference effects of multiples (Sheriff,

1975). The development of higher frequency, high energy sources will, improve the resolution of the seismic tool. This will enhance the ability to seismically resolve the presence of "squirrel" sands.

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APPENDIX I-LOCATION OF WELLS

WELL		TWN	RNG	SEC	LOCATION
ABC	NO. 1-A	17S	22E	22	2210 NSL 430 WEL
CLINKENBEARD	#18	24S	18E	3	414 NSL 471 WEL
PHLUG	#S-10-A	16S	21E	25	S/2 NW/4 769 SNL 216 EWL
WISEMAN	"A" 1-6	15S	21E	30	C W/2 NW/4

APPENDIX II-ACQUISITION PARAMETERS

Energy Source	MiniSosie	Seisgun		
Number of Sources	3 earth compactors	1 Seisgun		
Vertical Stack (shot)	1200	10		
Source Array	Linear	2x5 Linear		
Length	55 ft. (16.8m)	26.3 ft. (8.0m)		
Spacing	Continuous	6.6 ft. (2.0m)		
Receiver Array	1x10 Linear	1x10 Linear		
Length	29.5 ft. (9.0m)	29.5 ft. (9.0m)		
Spacing	3.3 ft. (1.0m)	3.3 ft. (1.0m)		
Filters-High	250/24 db/octave	250/24 db/octave		
Low	110/24 db/octave	110/24 db/octave		
60 hz Notch	Yes	Yes		
Sample Rate (per second)	1000	1000		
Record Length (seconds)	0.5	0.5		
Geophone Spread				
Trace	1	12	13	24
Shotpoint-Geophone Distance	+715 ft. (217.9m)	+110 ft. (33.5m)	-110 ft. (33.5m)	-715 ft. (217.9m)
Geophones-Make	Mark			
Model	L25D			
Frequency	30 Hertz			
Base	3 inch spike			

APPENDIX III - PROGRAM DIGLOG

 THIS PROGRAM CALCULATES A MATRIX TO CONVERT DIGITIZED TABLET
 COORDINATES INTO THE APPROPRIATE LOG VALUES. IT CONTINUOUSLY
 SAMPLES LOG DATA AND WRITES THE CONVERSION PARAMETERS AND THE
 DIGITIZED DATA TO AN OUTPUT FILE ON THE DATA GENERAL MV 8000.
 THE PROGRAM IS WRITTEN IN BASIC.

 THE CONVERSION FROM TABLET TO LOG COORDINATES IS ACCOMPLISHED BY
 SOLVING THE FOLLOWING MATRIX EQUATIONS:

$$\begin{array}{ccccccc}
 * & 1 & P1 & Q1 & * & * & A & * & * & X1 & * \\
 * & & & & * & * & & * & * & & * \\
 * & 1 & P2 & Q2 & * & X & * & B & * & = & * & X2 & * \\
 * & & & & * & & * & & * & & * & & * \\
 * & 1 & P3 & Q3 & * & & * & C & * & = & * & X3 & *
 \end{array}$$

AND

$$\begin{array}{ccccccc}
 * & 1 & P1 & Q1 & * & * & D & * & * & Y1 & * \\
 * & & & & * & * & & * & * & & * & & * \\
 * & 1 & P2 & Q2 & * & X & * & E & * & = & * & Y2 & * \\
 * & & & & * & & * & & * & & * & & * \\
 * & 1 & P3 & Q3 & * & & * & F & * & & * & Y3 & *
 \end{array}$$

FOR THE CONVERSION MATRICES

$$\begin{array}{cccc}
 * & A & * & * & D & * \\
 * & & * & * & & * \\
 * & B & * & AND & * & E & * \\
 * & & * & & * & & * \\
 * & C & * & & * & F & *
 \end{array}$$

THIS IS ACCOMPLISHED USING CRAMER'S RULE WHERE THE TABLET
 COORDINATES (P1,Q1), (P2,Q2), AND (P3,Q3) CORRESPOND TO THE LOG
 COORDINATES (X1,Y1), (X2,Y2), AND (X3,Y3), RESPECTIVELY.

20 REMARK *****
 40 REMARK THE USER SHOULD OPEN AN OUTPUT FILE AT DEVICE #40.
 50 REMARK THE DATA SHOULD BE WRITTEN TO THE OUTPUT FILE IN
 60 REMARK (F12.5,2X,F12.5) FORMAT TO INSURE COMPATIBILITY
 70 REMARK WITH PROGRAM CONVRT.
 80 REMARK *****
 90 REMARK P = X COORDINATE FROM TABLET
 100 REMARK Q = Y COORDINATE FROM TABLET
 110 REMARK C1 = MINIMUM DEPTH FOR NEW LOG VALUE CALCULATION
 120 REMARK C2 = MAXIMUM DEPTH FOR NEW LOG VALUE CALCULATION
 130 REMARK I1 = INTERVAL IN FEET OVER WHICH LOG VALUES ARE
 140 REMARK TO BE CALCULATED
 150 REMARK *****

```

160 DIM U(3000),V(3000)
170 PRINT "WHAT IS THE OUTPUT FILENAME? "
180 INPUT F$
190 REMARK
190 REMARK OPEN THE OUTPUT FILE
200 REMARK
210 PRINT "WHAT IS THE LOG MINIMUM? "
220 INPUT B1
230 PRINT "WHAT IS THE LOG MAXIMUM? "
240 INPUT B2
250 PRINT "WHAT IS THE MINIMUM DEPTH? "
260 INPUT C1
270 PRINT "WHAT IS THE MAXIMUM DEPTH? "
280 INPUT C2
290 PRINT "WHAT IS THE DIGITIZING INTERVAL? "
300 INPUT I1
310 PRINT "PLEASE DIGITIZE TH FOLLOWING POINTS. "
320 PRINT " LOG VALUE DEPTH"
330 PRINT B1,C1
340 INPUT @8:P,Q,B$
350 PRINT "G"
360 X1=C1
370 Y1=B1
380 P1=P
390 Q1=Q
400 PRINT B2,C1
410 INPUT @8:P,Q,B$
420 PRINT "G"
430 X2=C1
440 Y2=B2
450 P2=P
460 Q2=Q
470 PRINT B2,C2
480 INPUT @8:P,Q,B$
490 PRINT "G"
500 X3=C2
510 Y3=D2
520 P3=P
530 Q3=Q
540 REMARK
550 REMARK DETERMINE THE COEFFICIENTS OF THE CONVERSION MATRICES
560 REMARK
570 A1=P2*Q3+P3*Q1+P1*Q2-P2*Q1-P1*Q3-P3*Q2
580 A=(X1*P2*Q3+X2*P3*Q1+X3*P1*Q2-X1*P3*Q2-X2*P1*Q3-X3*P2*Q1)/A1
590 B=(X1*Q2+X2*Q3+X3*Q1-X1*Q3+X2*Q1-X3*Q2)/A1
600 C=(X1*P3+X2*P1+X3*P2-X1*P2+X2*P3-X3*P1)/A1
610 D=(Y1*P2*Q3+Y2*P3*Q1+Y3*P1*Q2-Y1*P3*Q2-Y2*P1*Q3-Y3*P2*Q1)/A1
620 E=(Y1*Q2+Y2*Q3+Y3*Q1-Y1*Q3-Y2*Q1-Y3*Q2)/A1
630 F=(Y1*P3+Y2*P1+Y3*P2-Y1*P2-Y2*P3-Y3*P1)/A1
640 REMARK
650 REMARK WRITE CONVERSION PARAMETERS TO OUTPUT FILE

```

```

660     REMARK
670     PRINT @40:C1
680     INPUT @40:GO
690     PRINT @40:C2
700     INPUT @40:GO
710     PRINT @40:I1
720     PRINT @40:GO
730     PRINT @40:A
740     PRINT @40:GO
750     PRINT @40:B
760     PRINT @40:GO
770     PRINT @40:C
780     PRINT @40:GO
790     PRINT @40:D
800     PRINT @40:GO
810     PRINT @40:E
820     PRINT @40:GO
830     PRINT @40:F
840     PRINT @40:GO
850     PAGE
860     PRINT "BEGIN DIGITIZING IN STREAM MODE"
870     PRINT "FOR OPTIMUM RESULTS SET SLIDE TO HALF-WAY POINT"
880     PRINT "TO EXIT PROGRAM"
890     PRINT "DIGITIZE A POINT ON THE RIGHT-HAND SIDE OF THE" 891
PRINT "TABLET"
900     REMARK
910     REMARK READ DIGITIZED POINTS FROM TABLET
920     REMARK
930     N9=0
940     Z=0
950     INPUT @8:P,Q,B$
960     N9=N9+1
970     IF N9<30 THEN 1010
980     N9=0
990     PRINT "G"
1000    PAGE
1010    Z=Z+1
1020    U(Z)=P
1030    V(Z)=Q
1040    IF Z=3000 THEN 1270
1050    IF X>S3*1.01 THEN 1300
1060    GO TO 950
1070    I=1
1080    IF I>Z THEN 1140
1090    PRINT @40:U(I),V(I)
1100    INPUT @40:GO
1110    I=I+1
1120    GO TO 1080
1140    PRINT "GGGGG"
1150    PRINT "DO YOU WANT TO CONTINUE DIGITIZING WITHIN THE"
1151    PRINT "DIGITIZED "

```

```
1160 PRINT "MINIMUM AND MAXIMUM DEPTH VALUES? "  
1170 INPUT K$  
1180 IF K$="NO" THEN  
1190 IF K$="N" THEN  
1200 PRINT "CONTINUE DIGITIZING"  
1210 GO TO 930  
1220 REMARK  
1230 REMARK ***** CLOSE THE OUTPUT FILE *****  
1240 REMARK  
1250 PRINT "THE OUTPUT FILE IS ",F$  
1260 END  
1270 PRINT "GGGGGGGGGGGGG"  
1280 PRINT "THE BUFFER IS FULL. DATA IS BEING TRANSFERRED."  
1290 GO TO 1070  
1300 PRINT "GGGGGGGGGGGGG"  
1310 PRINT "YOU HAVE INDICATED THAT YOU WANT TO EXIT THE PROGRAM"  
1320 GO TO 1070
```

APPENDIX IV - PROGRAM CONVRT

```

C*****
C
C THIS PROGRAM READS DIGITIZED TABLET COORDINATES FROM AN INPUT
C FILE. IT TRANSFORMS FROM TABLET TO LOG COORDINATES BY ROTATING,
C TRANSLATING, AND SCALING. IT THEN CALCULATES NEW LOG VALUES USING
C A TRAPEZOIDAL RULE INTEGRATION BASED ON A USER DEFINED LOG
C INTERVAL. FINALLY, IT WRITES DEPTH AND THE NEW LOG VALUES TO AN
C OUTPUT FILE.
C
C*****
C
C THE CONVERSION FROM TABLET TO LOG COORDINATES IS ACCOMPLISHED BY
C SOLVING FOR THE CONVERSION MATRIX COEFFICIENTS
C
C      * A *      * D *
C      * *      * *
C      * B *      AND * E *      IN THE DIGITIZING PROGRAM.
C      * *      * *
C      * C *      * F *
C
C*****
C P = X TABLET COORDINATE FROM INPUT FILE
C Q = Y TABLET COORDINATE FROM INPUT FILE
C D1 = MINIMUM DEPTH FOR NEW LOG VALUE CALCULATION
C D2 = MAXIMUM DEPTH FOR NEW LOG VALUE CALCULATION
C I1 = INTERVAL IN FEET OVER WHICH LOG VALUES ARE TO BE CALCULATED
C
C*****
C
C      ***** INITIATE CONSTANTS *****
C
C      CHARACTER*20 INPUT,OUTPUT
C      DIMENSION PARAM(9)
C      REAL I1
C      YSUM=0
C      X1=0
C      K=0
C      M=0
C      N=0
C
C
C      ***** OPEN DATA FILES *****
C
C      PRINT *,"WHAT IS THE NAME OF THE INPUT FILE?      "
C      READ (*,"(A20)")INPUT
C      PRINT *,"WHAT IS THE NAME OF THE OUTPUT FILE?    "
C      READ(*,"(A20)")OUTPUT
C      OPEN(1,FILE=INPUT,RECFM="DS")
C      OPEN(2,FILE=OUTPUT,RECFM="DS")
C

```

```

C      ***** READ PARAMETERS FROM INPUT FILES *****
C
      DO I=1,9
          READ(1,5)PARAM(I)
5         FORMAT(F12.5)
      END DO
      D1=PARAM(1)
      D2=PARAM(2)
      I1=PARAM(3)
      A=PARAM(4)
      B=PARAM(5)
      C=PARAM(6)
      D=PARAM(7)
      E=PARAM(8)
      F=PARAM(9)

C
C ** READ DATA FROM INPUT FILE AND CONVERT TO LOG COORDINATES **
C
10      D5=D1+(I1*K)-I1/2
        D6=D1+(I1*K)+I1/2
15      READ(1,20,END=900)P,Q
20      FORMAT(F12.5,2X,F12.5)
        X=A+B*P+C*Q
        Y=D+E*P+F*Q

C
C ** CALCULATE VALUES TO BE ASSIGNED BY TRAPEZOIDAL INTEGRATION **
C
        M=M+1
        IF ((M.GT.1).AND.(X.LE.X1)) GO TO 15
        IF ((M.EQ.1).OR.(X.LE.D5)) THEN
            Y1=Y
            X1=X
            GO TO 15
        END IF
        IF ((X.GT.D5).AND.(X1.LT.D5)) THEN
            CALL INTERP(X,X1,D5,Y,Y1,YSUM,YBEGIN,N)
            N=1
            GO TO 15
        END IF
        IF (X.GT.D6) THEN
            CALL INTERP(X,X1,D6,Y,Y1,YSUM,YBEGIN,N)
            GO TO 35
        END IF
        YSUM=YSUM+(Y+Y1)*(X-X1)/2
        X1=X
        Y1=Y
        GO TO 15
35      XSUM=D1+I1*K

C
C ** WRITE DATA TO OUTPUT FILE AND CLEAR BUFFER **
C

```

```

        WRITE(2,20)XSUM,YSUM
        IF (X.GT.(D2+I1/2)) STOP
        K=K+1
        YSUM=YBEGIN
        GO TO 10
900     STOP
        END
C*****
C
C ** SUBROUTINE TO CALCULATE CONTRIBUTION OF TRAPEZOID EDGES **
C
C*****
C
        SUBROUTINE INTERP(X,X1,DX,Y,Y1,YSUM,YBEGIN,N)
C
        SLOPE=(Y-Y1)/(X-X1)
        YINT=(DX-X1)*SLOPE+Y1
        IF (N.EQ.0) THEN
            YSUM=YSUM+(Y+YINT)*(X-DX)/2
        ELSE
            YSUM=YSUM+(YINT+Y1)*(DX-X1)/2
            YBEGIN=(Y+YINT)*(X-DX)/2
        END IF
        X1=X
        Y1=Y
        RETURN
        END

```

APPENDIX V - PROGRAM POLYD

(adapted from Davis, 1973)

```
C*****
C
C THIS PROGRAM FITS A NTH ORDER CURVILINEAR POLYNOMIAL REGRESSION.
C
C*****
C     ARRAY A CONTAINS X AND Y DATA
C     ARRAY B CONTAINS THE TERMS OF THE COEFFICIENT MATRIX DEFINED
C     IN EQUATION 5.28.
C     ARRAY C ORIGINALLY CONTAINS THE VECTOR OF THE RIGHT HAND
C     SIDE
C     OF THE NORMAL EQUATIONS AS DEFINED BY 5.28. AFTER SOLVING
C     THE SET OF NORMAL EQUATIONS, ARRAY C CONTAINS THE
C     COEFFICIENTS
C     OF THE REGRESSION EQUATION.
C     ARRAY D CONTAINS X,Y, Y-CALCULATED, AND DEVIATION FOR ALL
C     POINTS
C
C     MAXIMUM NUMBER OF OBSERVATIONS IS 1000
C     THE MAXIMUM ORDER OF THE POLYNOMIAL IS 19.
C
C     THE OUTPUT FILE "POLYOUT" CONTAINS THE COEFFICIENTS OF THE
C     POLYNOMIAL
C     EQUATION, THE DATA STORED IN ARRAY D, AND THE STATISTICS OF
C     THE EQUATION.
C     THE OUTPUT FILE "LOGOUT" CONTAINS THE DEPTH AND Y-CALCULATED
C     VALUES.
C
C*****
C
C     ***** INITIALIZE ARRAYS AND CONSTANTS *****
C
C     DIMENSION A(1000,2),B(20,20),C(20),D(1000,4),E(1001,2),XP(20)
C     CHARACTER*20 INPUT1,INPUT2
C
C     PRINT *, "ENTER THE ORDER OF THE POLYNOMIAL? "
C     READ *,IORD
C     IF (IORD.GT.19) GO TO 1
C     IORD1 = IORD+1
C
C     ***** OPEN DATA FILES *****
C
C     PRINT *,"WHAT IS THE NAME OF THE INDEPENDENT VARIABLE INPUT
& FILE? "
C     READ (*,"(A20)")INPUT1
C     PRINT *,"WHAT IS THE NAME OF THE DEPENDENT VARIABLE INPUT
& FILE? "
C     READ (*,"(A20)")INPUT2
C     OPEN(1,FILE=INPUT1,RECFM="DS")
```

```

OPEN(2,FILE=INPUT2,RECFM="DS")
OPEN(3,FILE="POLYOUT",RECFM="DS")
OPEN(4,FILE="LOGOUT",RECFM="DS")
C
C ***** READ DATA FROM INPUT FILES *****
C
CALL READM(A,N,M,1000,2,DEPTH)
C
C ***** CALCULATE SUMS FOR LEAST SQUARES SOLUTION *****
C
DO 100 I=1,IORD1
C(I)=0.0
DO 101 J=1,IORD1
B(I,J)=0.0
101 CONTINUE
100 CONTINUE
DO 102 I=1,N
XP(1)=1.0
DO 103 J=2,IORD1
XP(J)=XP(J-1)*A(I,1)
103 CONTINUE
DO 104 J=1,IORD1
DO 105 K=1,IORD1
B(J,K)=B(J,K)+XP(J)*XP(K)
105 CONTINUE
C(J)=C(J)+XP(J)*A(I,2)
104 CONTINUE
102 CONTINUE
C
C ** CALCULATE THE COEFFICIENTS OF THE REGRESSION EQUATION **
C
CALL SLE(B,C,IORD1,20,1.0E-06)
C
C ***** CALCULATE PREDICTED VALUES *****
C
DO 106 I=1,N
D(I,1)=A(I,1)
D(I,2)=A(I,2)
XXP=1.0
YYP=0.0
DO 107 J=1,IORD1
YYP=YYP+XXP*C(J)
XXP=XXP*D(I,1)
107 CONTINUE
D(I,3)=YYP
D(I,4)=D(I,2)-YYP
106 CONTINUE
C
C ***** CALCULATE ERROR MEASUREMENTS *****
C
SY=0.0

```

```

SY2=0.0
SYC=0.0
SYC2=0.0
DO 108 I=1,N
SY=SY+D(I,2)
SY2=SY2+D(I,2)*D(I,2)
SYC=SYC+D(I,3)
SYC2=SYC2+D(I,3)*D(I,3)
108 CONTINUE
SST=SY2-SY*SY/FLOAT(N)
SSR=SYC2-SYC*SYC/FLOAT(N)
SSD=SST-SSR
R2=SSR/SST
R=SQRT(R2)

C
C ***** WRITE DATA TO OUTPUT FILES *****
C

WRITE (3,1000)
DO I=1,IORD1
    WRITE(3,1001)I,C(I)
END DO
WRITE (3,1002)
DO I=1,N
    WRITE(3,1003)DEPTH,(D(I,K),K=1,4)
    WRITE(4,1004)DEPTH,D(I,3)
    DEPTH=DEPTH+1
END DO
WRITE(3,1995) IORD
WRITE(3,2000) N
WRITE(3,2001) SST
WRITE(3,2002) SSR
WRITE(3,2003) SSD
WRITE(3,2004) R2
WRITE(3,2005) R
1000 FORMAT(" THE PARAMETERS OF THE REGRESSION EQUATION")
1001 FORMAT(I2,F15.10)
1002 FORMAT("//," COL 1 = DEPTH",/, " COL 2 = X VARIABLE",/,
1 " COL 3 = Y VARIABLE",/,
2 " COL 4 = Y VALUE BASED ON REGRESSION EQUATION",/,
3 " COL 5 = COL 3 - COL 4")
1003 FORMAT(F6.0,4(2X,F12.5))
1004 FORMAT(F12.5,2X,F12.5)
1995 FORMAT("//," ORDER OF EQUATION = ",I5)
2000 FORMAT(" NUMBER OF SAMPLES = ",I5)
2001 FORMAT(" TOTAL SUMS OF SQUARES = ",F15.4)
2002 FORMAT(" SUMS OF SQUARES DUE TO REGRESSION = ",F15.4)
2003 FORMAT(" SUMS OF SQUARES DUE TO DEVIATION = ",F15.4)
2004 FORMAT(" GOODNESS OF FIT = ",F15.6)
2005 FORMAT(" CORRELATION COEFFICIENT = ",F15.6)
STOP
END

```

```

C*****
C
C      ***** SUBROUTINE TO READ INPUT DATA *****
C
C*****
C
C      SUBROUTINE READM (A, N, M, N1, M1,DEPTH)
C
C      DIMENSION A(N1,M1)
C      M=2
C
C      ***** READ DATA FROM INPUT FILES *****
C
C      DO I = 1,1000
10          READ (1,1001,END=900) DUM,X
              READ (2,1001,END=900) DUM,Y
              A(I,1)=X
              A(I,2)=Y
              IF (I.EQ.1) DEPTH=DUM
C
C      END DO
900         N=N-I-1
              RETURN
1001        FORMAT (F12.5,2X,F12.5)
              END
C*****
C
C      ** SUBROUTINE FOR SOLUTION OF N SIMULTANEOUS EQUATIONS **
C
C      MATRIX A IS N BY N. MATRIX B IS 1 BY N AND CONTAINS THE
C      SOLUTION.
C*****
C      SUBROUTINE SLE (A, B, N, N1, ZERO)
C
C      DIMENSION A(N1,N1)
C      DIMENSION B(N1)
C      DO I = 1,N
C          DIV = A(I,I)
C          IF (ABS(DIV) - ZERO .LE. 0) THEN
C              STOP
C          ELSE
C              DO J = 1,N
C                  A(I,J) = A(I,J) / DIV
C              END DO
C              B(I) = B(I) / DIV
C              DO J = 1,N
C                  IF (I - J .NE. 0) THEN
C                      RATIO = A(J,I)
C                      DO K = 1,N
C                          A(J,K) = A(J,K) - RATIO * A(I,K)
C                      END DO
C                      B(J) = B(J) - RATIO * B(I)

```

```
END IF
END DO
END IF
END DO
RETURN
END
```

APPENDIX VI - PROGRAM SYNSEIS

```
C*****
C THIS IS THE MAIN PROGRAM FOR THE GENERATION OF FILES FOR SYNTHETIC
C SEISMOGRAMS USING EITHER SPEX. THE INPUT FILE MUST HAVE VALUES
C AT ONE FOOT INCREMENTS.
```

```
C*****
      DIMENSION RF(1000),TR1(1000),TR2(1000),RIMP(1000),D(1000)
      DIMENSION A(2,2,2000),A1(2,2,2000),A2(2,2,2000),B(1000,2,2)
      DIMENSION AA(2000),BB(2000),C(2000),C1(1000)
      CHARACTER*1 ANS1,ANS2,ANS3,AN
      COMMON /MAT/A,A1,A2,B,AA,BB,C,C1
      COMMON /ANS/ANS1,ANS2,ANS3,AN
      COMMON /REF/RF,TR1,TR2,RIMP
      COMMON /MULT/JMULT,JNUM
      L=0
      I=0
      WRITE(*,*)"*****"
& *****"
      WRITE(*,*)"          WARNING:"
      WRITE(*,*)"YOUR INPUT FILE MUST HAVE VALUES DIGITIZED AT ONE
& FOOT INCREMENTS"
      WRITE(*,*)"*****"
& *****"
      CALL INIT
      CALL MATINIT
      CALL TWOTIME(L,D)
      CALL CALCULATE(L,D)
      CALL MATLOAD(RF,A,B,TR1,L)
      CALL MULTIPLE(A,A1,A2,B,L)
      CALL POLYDIV(A,AA,BB,C,C1,L)
      CALL TAPEGEN(RF,RIMP,C1)
      CALL CLOSING
      STOP
      END
```

```
C*****
C THIS SUBROUTINE INITIALIZES THE SYNSEIS PROGRAM.
C*****
```

```
      SUBROUTINE INIT
      CHARACTER*1 AN,ANS1,ANS2,ANS3
      CHARACTER*20 OUTPUT1,OUTPUT2,OUTPUT3
      COMMON /OUTPUT/OUTPUT1,OUTPUT2,OUTPUT3
      COMMON /ANS/ANS1,ANS2,ANS3,AN
      COMMON /MULT/JMULT,JNUM,ITRACE
```

```
C
C OPEN SPEX FILES
```

```
      WRITE(*,*)"*****"
      WRITE(*,*)" FOR SYNTHETICS USING SPEX"
      WRITE(*,*)"*****"
      WRITE(*,*)"DO YOU WANT A FILE WITH REFLECTION COEFFICENTS
```

```

& ONLY? "
  READ (*,"(A)")ANS1
  IF (ANS1.EQ."Y") THEN
    WRITE(*,*)"WHAT DO YOU WISH TO CALL THIS FILE? "
    READ(*,"(A20)")OUTPUT1
    OPEN(1,MODE="BINARY",RECFM="DYNAMIC",FILE=OUTPUT1,
& FORM="UNFORMATTED")
  END IF
  WRITE(*,*)"DO YOU WANT A FILE WITH TRANSMISSION LOSSES
& INCLUDED? "
  READ(*,"(A)")ANS2
  IF (ANS2.EQ."Y") THEN
    WRITE(*,*)"WHAT DO YOU WISH TO CALL THIS FILE? "
    READ(*,"(A20)")OUTPUT2
    OPEN(2,MODE="BINARY",RECFM="DYNAMIC",FILE=OUTPUT2,
& FORM="UNFORMATTED")
  END IF
  WRITE(*,*)"DO YOU WANT A FILE WITH TRANSMISSION LOSSES AND
& MULTIPLES INCLUDED? "
  READ(*,"(A)")ANS3
  IF (ANS3.EQ."Y") THEN
    WRITE(*,*)"WHAT DO YOU WISH TO CALL THIS FILE? "
    READ(*,"(A20)")OUTPUT3
    OPEN(3,MODE="BINARY",RECFM="DYNAMIC",FILE=OUTPUT3,
& FORM="UNFORMATTED")
  END IF
  WRITE(*,*)"WHAT IS THE SAMPLE RATE FOR THIS DATA IN
& MICROSECONDS? "
  READ *,JMULT
  WRITE(*,*)"HOW MANY SAMPLES PER TRACE? "
  READ *,JNUM
  WRITE(*,*)"DO YOU WANT A SURFACE REFLECION COEFFICIENT? "
  READ(*,"(A1)")AN
  WRITE(*,*)"HOW MANY TRACES DO YOU WANT TO GENERATE
& (LIMIT=10)? "
  READ *,ITRACE
  RETURN
  END

```

```

C*****
C THIS IS SUBROUTINE LOADS ZEROES INTO ALL THE MATRICES WHICH WILL
C BE USED TO CALCULATE MULTIPLES.
C*****

```

```

SUBROUTINE MATINIT
  DIMENSION A(2,2,2000),A1(2,2,2000),A2(2,2,2000),B(1000,2,2)
  DIMENSION AA(2000),BB(2000),C(2000),C1(1000)
  DIMENSION RF(1000),TR1(1000),TR2(1000),RIMP(1000)
  COMMON /REF/RF,TR1,TR2,RIMP
  COMMON /MAT/A,A1,A2,B,AA,BB,C,C1
  COMMON /ANS/ANS1,ANS2,ANS3
  CHARACTER*1 ANS1,ANS2,ANS3
  IF (ANS3.NE."Y") RETURN

```

```

DO K=1,2000
AA(K)=0.0
BB(K)=0.0
C1(K)=0.0
C(K)=0.0
END DO
DO I=1,2
DO J=1,2
DO K=1,1000
A(I,J,K)=0.0
A1(I,J,K)=0.0
A2(I,J,K)=0.0
END DO
END DO
END DO
DO I=1,500
RF(I)=0.0
TR1(I)=0.0
TR2(I)=0.0
RIMP(I)=0.0
DO J=1,2
DO K=1,2
B(I,J,K)=0.0
END DO
END DO
END DO
RETURN
END

```

```

C*****
C THIS SUBROUTINE READS INPUT DATA FROM A SONIC LOG DIGITIZED
C AT ONE FOOT INTERVALS, COMPUTES VELOCITIES, AND TWO WAY TRAVEL
C TIMES.

```

```

C*****
SUBROUTINE TWOTIME(L,D)
CHARACTER*20 INPUT
DIMENSION V(1000),DP(5000),T(1000),TT(5000),DT(5000),D(1000)
COMMON /TWOTIM/V,TT
DFIRST=0.0
WRITE (*,*) "WHAT IS THE INPUT FILE NAME? "
READ (*,2) INPUT
2 FORMAT(A20)
OPEN(9,FILE=INPUT,RECFM="DS")
L=0
VELSUM=0
VEL=0
Z=1
I=0
4 I=I+1
VELSUM=VELSUM+VEL
5 READ(9,5,END=7)DP(I),DT(I)
FORMAT(F12.5,2X,F12.5)

```

```

        IF (I.EQ.1) THEN
            TT(I)=DT(I)/500.0
            VEL=1000000/DT(I)
            DD=DP(I)-1
            DFIRST=DD
            GO TO 20
        END IF
        J=I-1
        TT(I)=TT(J)+DT(I)/500.0
        VEL =1000000/DT(I)
6      IF (TT(I).GE.Z)THEN
        CALL INTERP(TT(I-1),TT(I),DI,Z,DP(I-1),VEL,VEL1)
        L=L+1
        VELSUM=VELSUM+VEL
        V(L)=VELSUM/(DI-DD)
        T(L)=Z
        IF (L.EQ.1) THEN
            D(L)=DFIRST
        ELSE
            D(L)=DD
        END IF
        DD=DI
        Z=Z+1.0
        VEL=VEL1
        VELSUM=0.0
        END IF
20     GO TO 4
7      RETURN
      END
      SUBROUTINE INTERP(TT1,TT2,DI,Z,DT,VEL,VEL1)
      S=((Z-TT1)/(TT2-TT1))
      DI=S+DT
      VEL2=VEL
      VEL=S*VEL2
      VEL1=(1-S)*VEL2
      RETURN
      END
C*****
C THIS PROGRAM CALCULATES THE REFLECTION, ONE-WAY TRANSMISSION,
C TWO-WAY TRANSMISSION COEFFICIENTS, AND REFLECTION
C COEFFICIENT WITH TWO-WAY TRANSMISSION LOSSES.
C
C FILE "OUTPUT" IS CREATED AND THE FOLLOWING DATA IS STORED:
C TWO-WAY TIME, DEPTH, VELOCITY OF THE FIRST LAYER, VELOCITY
C OF THE SECOND LAYER, REFLECTION COEFFICIENT, AND REFLECTION
C COEFFICIENT WITH TWO-WAY TRANSMISSION LOSSES.
C*****
C      D = DEPTH
C      RF = REFLECTION COEFFICIENT
C      TR1= ONE-WAY TRANSMISSION ARRAY
C      TR2= TWO-WAY TRANSMISSION ARRAY

```

```

C      RIMP= REFLECTION WITH TWO-WAY TRANSMISSION LOSS ARRAY
C*****
      SUBROUTINE CALCULATE(L,D)
      CHARACTER*1 AN,ANS1,ANS2,ANS3
      DIMENSION RF(1000),TR1(1000),TR2(1000),RIMP(1000)
      DIMENSION V(1000),D(1000)
      COMMON /TWOTIM/V,TT
      COMMON /REF/RF,TR1,TR2,RIMP
      COMMON /ANS/ANS1,ANS2,ANS3,AN
      OPEN (15,FILE="OUTPUT",RECFM="DS")
      IF (AN.EQ."N") THEN
          RF(1)=0.0
          TR1(1)=1.0
          RIMP(1)=0.0
          GO TO 5
      END IF
      RF(1)=0.25
      RIMP(1)=0.25
      TR1(1)=1.25
5     TR2(1)=(1-(RF(1)**2))
      TRTOT=1
      WRITE(15,1)
1     FORMAT ("V1 = VELOCITY OF FIRST LAYER",/,
2     "V2 = VELOCITY OF SECOND LAYER",/,
3     "RF = REFLECTION COEFFICIENTS---PRIMARIES ONLY",/,
      "IMP = REFLECTION COEFFICIENTS---WITH TRANSMISSION LOSSES")
      WRITE (15,*)
      WRITE(15,2)
2     FORMAT(3X,"TIME",2X,"DEPTH",4X,"V1",7X,"V2",
      & 8X,"RF",6X,"IMP")
      DO M=2,L
          RF(M)=(V(M)-V(M-1))/(V(M)+V(M-1))
          TR1(M)=2*V(M)/(V(M)+V(M-1))
          TR2(M)=(1-(RF(M)**2))
          TRTOT=TRTOT*TR2(M-1)
          RIMP(M)=RF(M)*TRTOT
      END DO
      DO M=1,L
          WRITE(15,30)M-1,D(M),V(M-1),V(M),RF(M),RIMP(M)
30     FORMAT(1X,I4,2X,F6.0,3X,F6.0,3X,F6.0,1X,2(2X,F6.3))
      END DO
      RETURN
      END
C*****
C THIS SUBROUTINE LOADS THE COMMUNICATION MATRICES FOR MULTIPLE.
C CALCULATION.
C*****
      SUBROUTINE MATLOAD(RF,A,B,TR1,M)
      CHARACTER*1 ANS1,ANS2,ANS3,AN
      DIMENSION A(2,2,2*M-1),B(M,2,2)
      DIMENSION RF(M),TR1(M)

```

```

COMMON /ANS/ANS1,ANS2,ANS3,AN
IF (ANS3.NE."Y") RETURN
DO I=1,M
  IF (I.EQ.1) THEN
    A(1,2,M)=RF(I)*TR1(I)
    A(1,1,M)=1*TR1(I)
    A(2,2,M)=1*TR1(I)
    A(2,1,M)=RF(I)*TR1(I)
  ELSE
    B(I,1,1)=1*TR1(I)
    B(I,1,2)=RF(I)*TR1(I)
    B(I,2,1)=RF(I)*TR1(I)
    B(I,2,2)=1*TR1(I)
  END IF
END DO
RETURN
END

```

```

C*****
C THIS SUBROUTINE CALCULATES THE FINAL COMMUNICATION MATRIX.
C EACH INDIVIDUAL COMMUNICATION MATRIX IS MULTIPLIES BY EACH
C SUCCEEDING COMMUNICATION MATRIX UNTIL ALL HAVE BEEN
C INCORPORATED IN A FINAL COMMUNICATION MATRIX.
C*****
C FOR MORE INFORMATION CONSULT:
C   ROBINSON AND TRIETEL CH. 13
C   KENASAWICH CH 16
C*****

```

```

SUBROUTINE MULTIPLE(A,A1,A2,B,M)
COMMON /ANS/ ANS1,ANS2,ANS3,AN
CHARACTER*1 ANS1,ANS2,ANS3,AN
DIMENSION A(2,2,2*M-1),A1(2,2,2*M-1),A2(2,2,2*M-1),B(M,2,2)
IF (ANS3.NE."Y") RETURN
DO K=2,M
DO I=2,2*M-1
  A1(1,1,I-1)=A(1,1,I)*B(K,1,1)
  A2(1,1,I)=A(1,2,I-1)*B(K,2,1)
  A1(1,2,I-1)=A(1,1,I)*B(K,1,2)
  A2(1,2,I)=A(1,2,I-1)*B(K,2,2)
  A1(2,1,I-1)=A(2,1,I)*B(K,1,1)
  A2(2,1,I)=A(2,2,I-1)*B(K,2,1)
  A1(2,2,I-1)=A(2,1,I)*B(K,1,2)
  A2(2,2,I)=A(2,2,I-1)*B(K,2,2)
END DO
DO I=1,2*M-1
  A(1,1,I)=A1(1,1,I)+A2(1,1,I)
  A(1,2,I)=A1(1,2,I)+A2(1,2,I)
  A(2,1,I)=A1(2,1,I)+A2(2,1,I)
  A(2,2,I)=A1(2,2,I)+A2(2,2,I)
END DO
END DO
RETURN

```

```

      END
C*****
C THIS PROGRAM PERFORMS POLYNOMIAL DIVISION AND LOADS THE
C MULTIPLE ARRAY.
C*****
C C1 = REFLECTION COEFFICIENT WITH TWO-WAY TRANSMISSION LOSSES
C   AND MULTIPLES INCLUDED.
C*****
      SUBROUTINE POLYDIV(A,AA,BB,C,C1,M)
      CHARACTER*1 ANS1,ANS2,ANS3,AN
      COMMON /ANS/ANS1,ANS2,ANS3,AN
      DIMENSION A(2,2,2*M-1),AA(2*M-1),BB(2*M-1),C(2000),C1(1000)
      IF (ANS3.NE."Y") RETURN
      DO I=1,2*M-1
         AA(I)=A(1,1,I)
         BB(I)=A(2,1,I)
      END DO
      DO I=1,2*M-1
         IF (AA(I).NE.0.0) THEN
            K=I
            GO TO 1
         END IF
      END DO
1     DO I=1,2000
         C(I)=BB(I)/AA(K)
         N=1
         DO J=I,2000
            BB(J)=BB(J)-AA(N)*C(I)
            N=N+1
         END DO
      END DO
      J=1
      DO I=1,2000,2
         C1(J)=C(I)
         J=J+1
      END DO
      RETURN
      END
C*****
C THIS SUBROUTINE CREATES THE SPEX OUTPUT FILES.
C THE TRACES CONSIST OF THE REFLECTION COEFFICIENTS, REFLECTION
C COEFFICIENTS WITH TWO-WAY TRANSMISSION LOSSES, AND REFLECTION
C COEFFICIENTS WITH TWO-WAY TRANSMISSION LOSSES AND MULTIPLES.
C*****
      SUBROUTINE TAPEGEN(RF,RIMP,C1)
      CHARACTER*1 ANS1,ANS2,ANS3,AN
      DIMENSION RF(JNUM),RIMP(JNUM),C1(JNUM)
      INTEGER*2 J,K,REEL1(1600),REEL2(200),TRHOUT(120)
      COMMON /MULT/JMULT,JNUM,ITRACE
      COMMON /ANS/ANS1,ANS2,ANS3,AN
      IF ((ANS1.NE."Y").AND.(ANS2.NE."Y").AND.(ANS3.NE."Y"))

```

```

& RETURN
REEL2(7)=ITRACE
REEL2(9)=JMUL
REEL2(10)=JMUL
REEL2(11)=JNUM
REEL2(12)=JNUM
REEL2(13)=1
REEL2(15)=1
J=1600
K=200
IF (ANS1.EQ."Y") WRITE(1)J,REEL1,K,REEL2
IF (ANS2.EQ."Y") WRITE(2)J,REEL1,K,REEL2
IF (ANS3.EQ."Y") WRITE(3)J,REEL1,K,REEL2
J=2*JNUM+120
DO I=1,ITRACE
TRHOUT(2)=I
TRHOUT(4)=I
TRHOUT(6)=1
TRHOUT(8)=I
TRHOUT(12)=1
TRHOUT(14)=1
TRHOUT(15)=1
TRHOUT(18)=1
TRHOUT(58)=JNUM
TRHOUT(59)=JMUL
IF (I.EQ.ITRACE)TRHOUT(88)=1
TRHOUT(92)=1
IF (ANS1.EQ."Y") WRITE(1)J,TRHOUT,RF
IF (ANS2.EQ."Y") WRITE(2)J,TRHOUT,RIMP
IF (ANS3.EQ."Y") WRITE(3)J,TRHOUT,C1
END DO
RETURN
END

```

```

C*****
C THIS SUBROUTINE PRINTS WHICH FILES HAVE BEEN OPENED AND CLOSES
C ALL FILES.
C*****

```

```

SUBROUTINE CLOSING
CHARACTER*1 ANS1,ANS2,ANS3,AN
CHARACTER*20 OUTPUT1,OUTPUT2,OUTPUT3
COMMON /ANS/ANS1,ANS2,ANS3,AN
COMMON /OUTPUT/OUTPUT1,OUTPUT2,OUTPUT3
WRITE(*,*)"*****"
& *****"
& WRITE(*,*)"THE FOLLOWING FILES HAVE BEEN CREATED FOR USE
& WITH SPEX"
& WRITE(*,*)
& IF (ANS1.EQ."Y") WRITE(*,*)OUTPUT1," REFLECTION
& COEFFICIENTS ONLY"
& IF (ANS2.EQ."Y")WRITE(*,*)OUTPUT2," TRANSMISSION
& LOSSES INCLUDED"

```

```
IF (ANS3.EQ."Y")WRITE(*,*)OUTPUT3," TRANSMISSION
& LOSSES AND MULTIPES INCLUDED"
WRITE(*,*)" OUTPUT --- AN OUTPUT FILE OF DEPTHS, VELOCITIES,
& AND TWO-WAY TRAVELTIMES"
WRITE(*,*)
WRITE(*,*)"*****"
& *****"
CLOSE (1)
CLOSE (2)
CLOSE (3)
RETURN
END
```