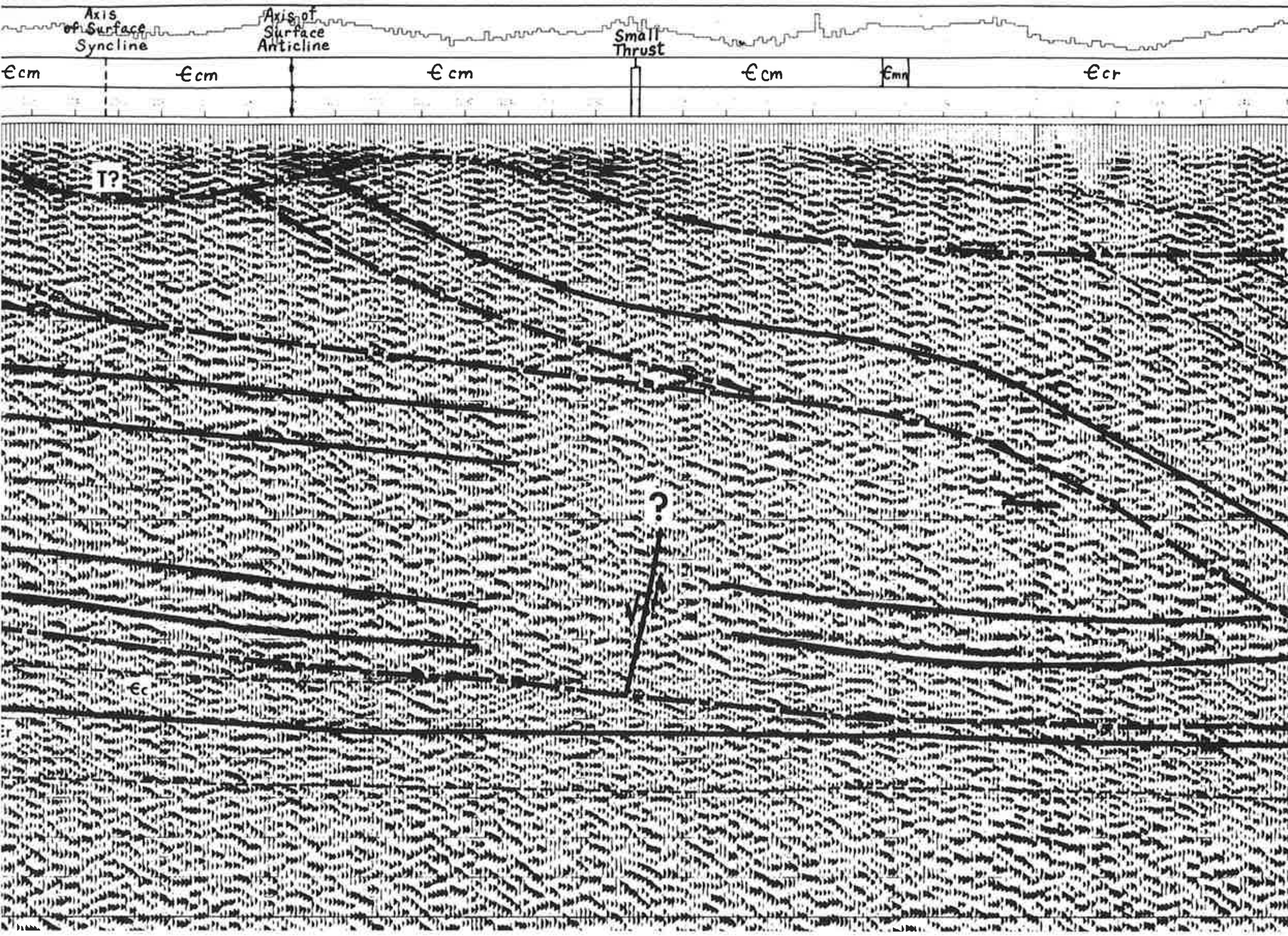

Seismic Investigations in Eastern Tennessee

Tennessee Divison Of Geology

Bulletin 78
1978

State of Tennessee
DEPARTMENT OF CONSERVATION
Division of Geology
Nashville, Tennessee

SEISMIC INVESTIGATIONS IN EASTERN TENNESSEE

by

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Geophysical Service Inc.
Dallas, Texas

Bulletin 78
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Research performed under U.S. Department of Energy Contract No. E-76-C-05-5196.

PREFACE

This report presents the results of seismic investigations made by Geophysical Service Inc. as part of an ongoing study which is designed to evaluate the hydrocarbon potential of the Devonian-Mississippian shales in eastern Tennessee. The research was performed under the U. S. Department of Energy contract No. EY-76-C-05-5196 with the Tennessee Division of Geology. It is the purpose of this program to provide basic geologic information which can be used to select potential reservoirs, as well as specific drilling targets, in the structurally complex Appalachian Valley and Ridge province.

Anthony T. Statler
Robert C. Milici

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DIVISION OF GEOLOGY

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ABSTRACT

A regional seismic program consisting of two common depth point Vibroseis* lines was collected in Eastern Tennessee as a part of the Eastern Gas Shales Project supported by the Department of Energy. These lines were located to provide basic knowledge of the subsurface geology of the region, and define the possible subcrop limits of Devonian shales associated with several major thrust features in the area.

The data have been interpreted in depth using velocity models derived from control provided by well data in undisturbed areas to the west. Surface geologic data have been integrated into the interpreted sections and have been incorporated on the base maps.

Recommendations concerning future geophysical effort in this area are included in the report.

* Trademark of Continental Oil Company.

INTRODUCTION

During 1977 a regional seismic investigation of eastern Tennessee was conducted by Geophysical Service Inc. This project was sponsored by the Tennessee Department of Conservation, Division of Geology. The objectives of the program were to provide a general regional seismic framework for the area and more specifically to attempt to define the amount of MISS-DEVONIAN shale section associated with exposures near Clinch Mountain.

PROGRAM

The program consisted of two regional VIBROSEIS* common depth point reflection lines (figure 1) and three local refraction studies indicated by numerals 1 to 3 on figure 1.

Lines TC-1 and TC-2 were new data collected during February and March, 1977 while K-1 South was an existing data set purchased from Geophysical Service Inc.

Refraction Studies:

Figure 2 shows the field layout used to gather the three refraction analyses. Energy was provided by a single VIBROSEIS unit taking ten sweeps at each designated source location. The field recording unit was a Texas Instruments 48-channel DFS** IV with a CFS-1 field computer. Summing of the individual sweeps and subsequent sweep removal was accomplished in the field. The geophones of each receiver group were bunched to maximize response to energy traveling horizontally.

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* Trademark of Continental Oil Company.
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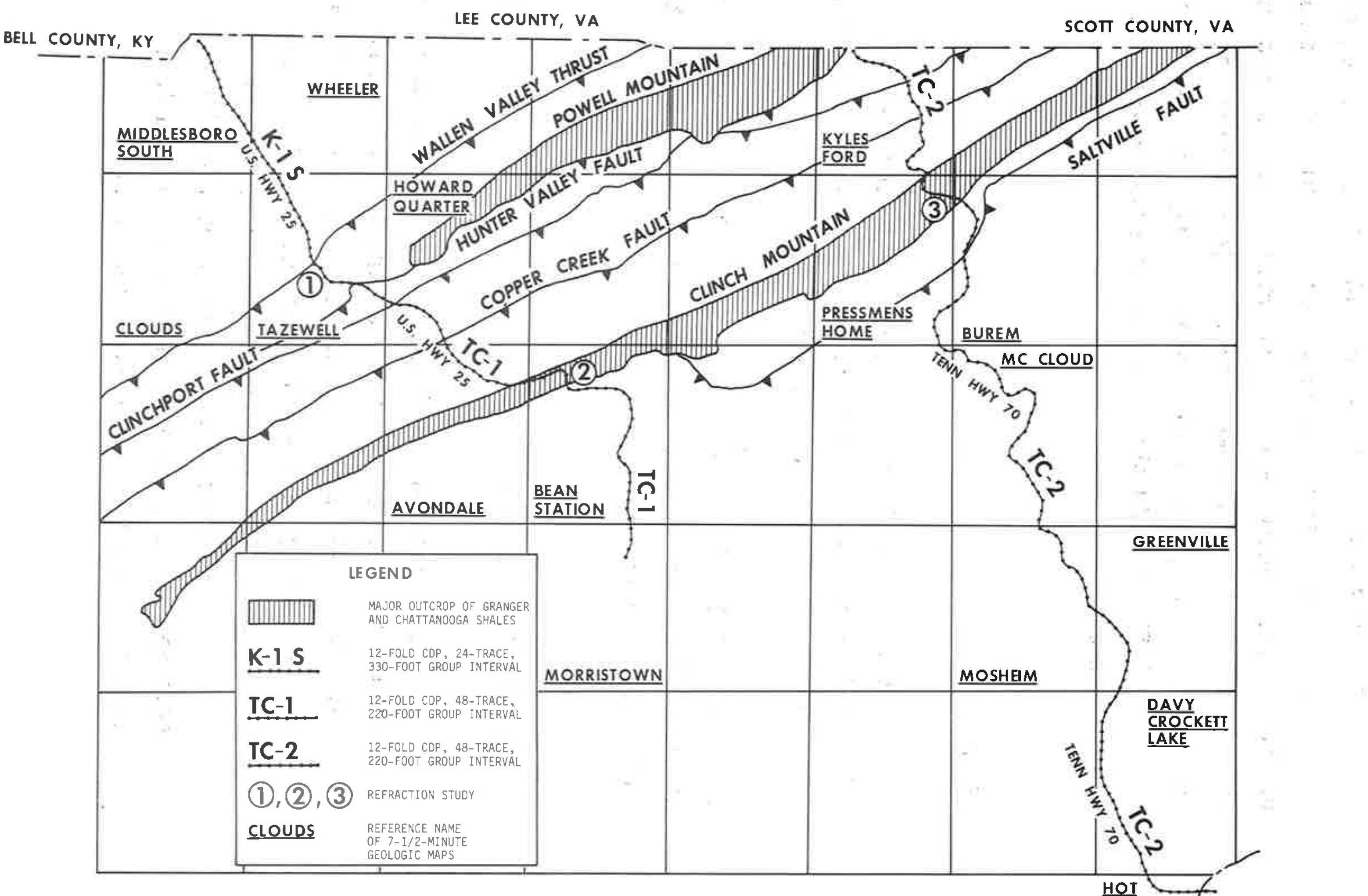
FIGURE 1

TENNESSEE DEPARTMENT OF CONSERVATION
DIVISION OF GEOLOGY

EASTERN TENNESSEE SEISMIC PROGRAM



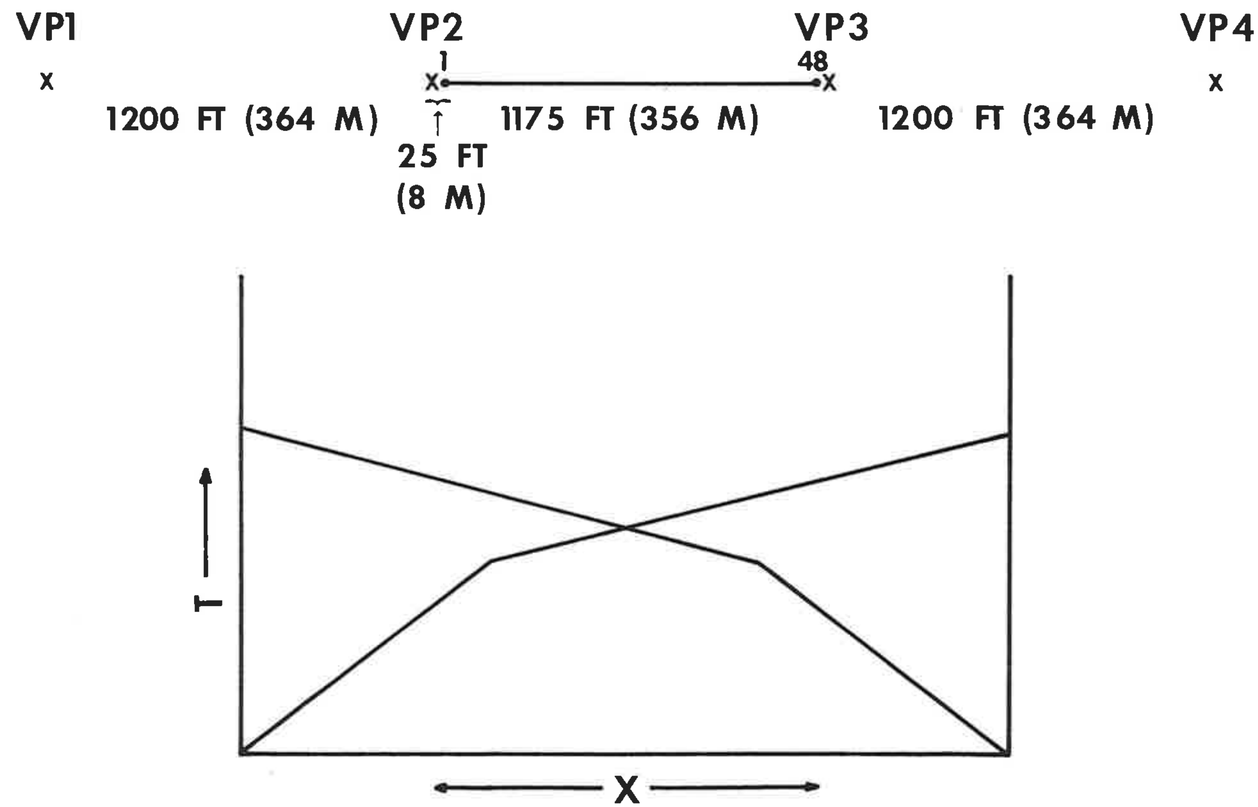
INDEX MAP REFERENCE

GEOLOGIC MAP OF TENNESSEE, 1966

SCALE 1:250000

FIGURE 2

REFRACTION ANALYSIS LAYOUT



The resulting record sections (figures 3A, 3B and 3C) were displayed in the central processing center. Small scale variable area presentations of the sort shown in the figures were used to make a qualitative analysis of refraction velocities and noise conditions. Very large scale wiggle trace sections were prepared to allow more accurate timing and plotting of the refracted events.

Reversed spreads were employed to provide information concerning the dip of the beds. If no dip exists across the zone of investigations, the arrival time patterns from opposite sides should exhibit identical velocities. Study No. 3 (figure 4C) is an excellent example of a no dip situation. All refraction studies were planned to be strike oriented, however, field expediency in placing the studies resulted in some structure being encountered in the case of studies 1 and 2 (figures 4A and 4B).

Very short range groups on all of the refraction studies were very difficult to interpret due to high energy noise created in proximity to the vibrator units. As a result the velocity of the shallowest zone had to be extrapolated from "fuzzy second breaks" on longer offset traces. Occasionally, as indicated on the final time distance plots (figures 4A, 4B and 4C), enough information could be extracted from a near offset trace to establish reliability of the estimated shallow velocity.

The primary reason for conducting these studies was to establish a velocity range for the shales and develop an estimate of the near-surface weathering problems in the area. The basic data were picked and plotted several times by the author and a co-worker. The plots shown in figures 4A-4C are the result of "boiling down" these ideas.

FIGURE 3A

TENNESSEE DEPARTMENT OF CONSERVATION

REFRACTION LINE 1

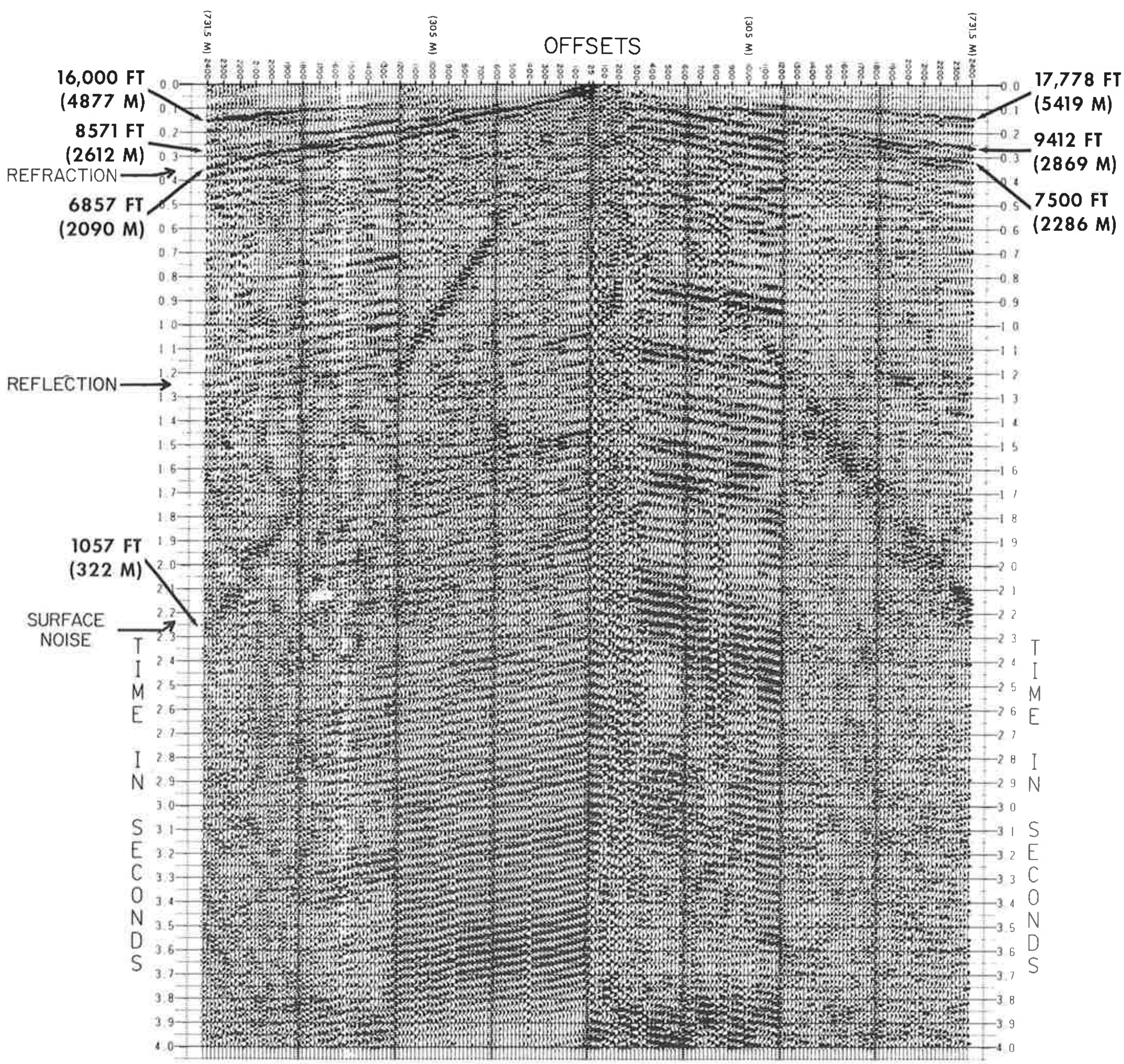


FIGURE 3B

TENNESSEE DEPARTMENT OF CONSERVATION

REFRACTION LINE 2

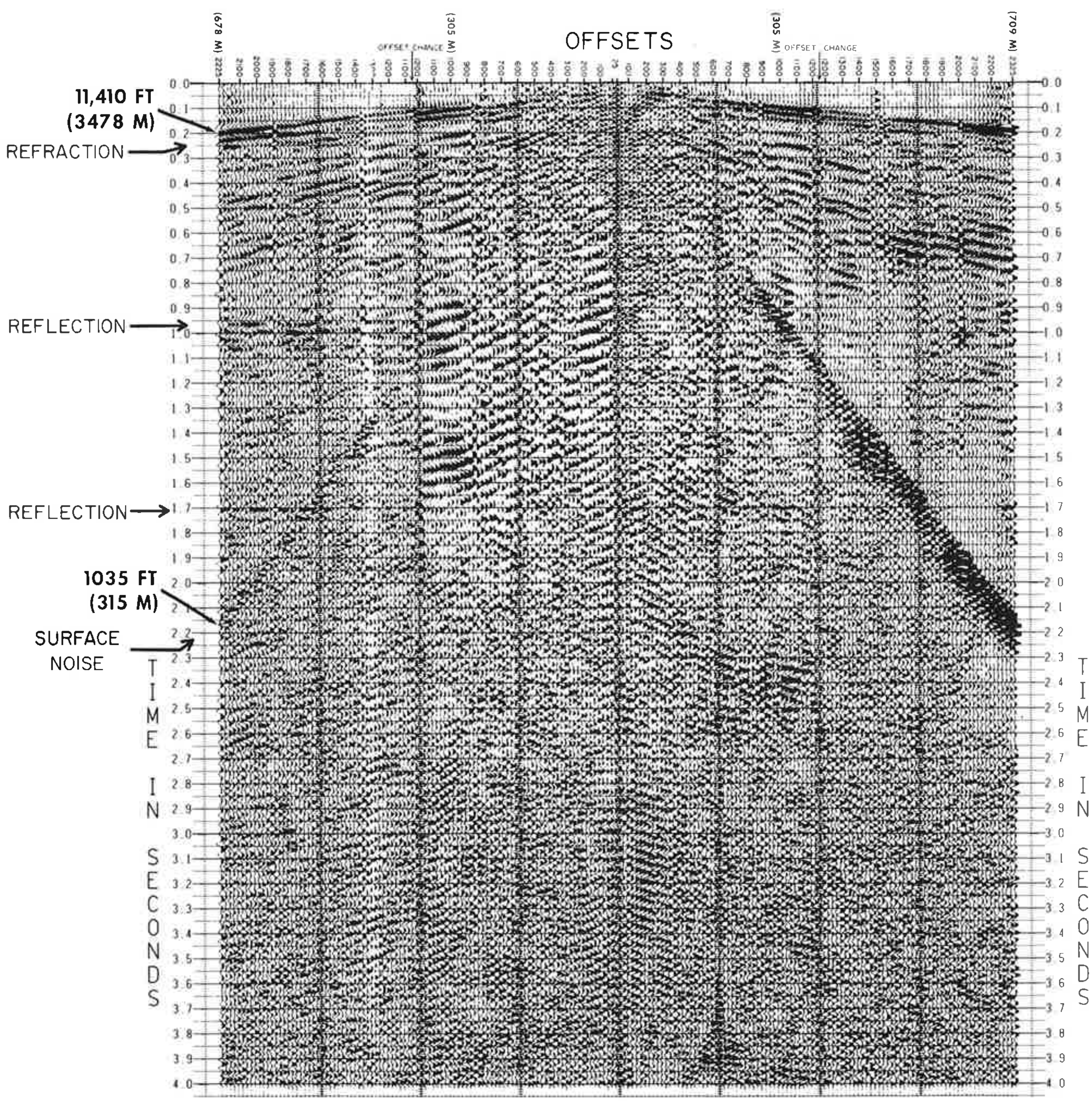


FIGURE 3C

TENNESSEE DEPARTMENT OF CONSERVATION
REFRACTION LINE 3

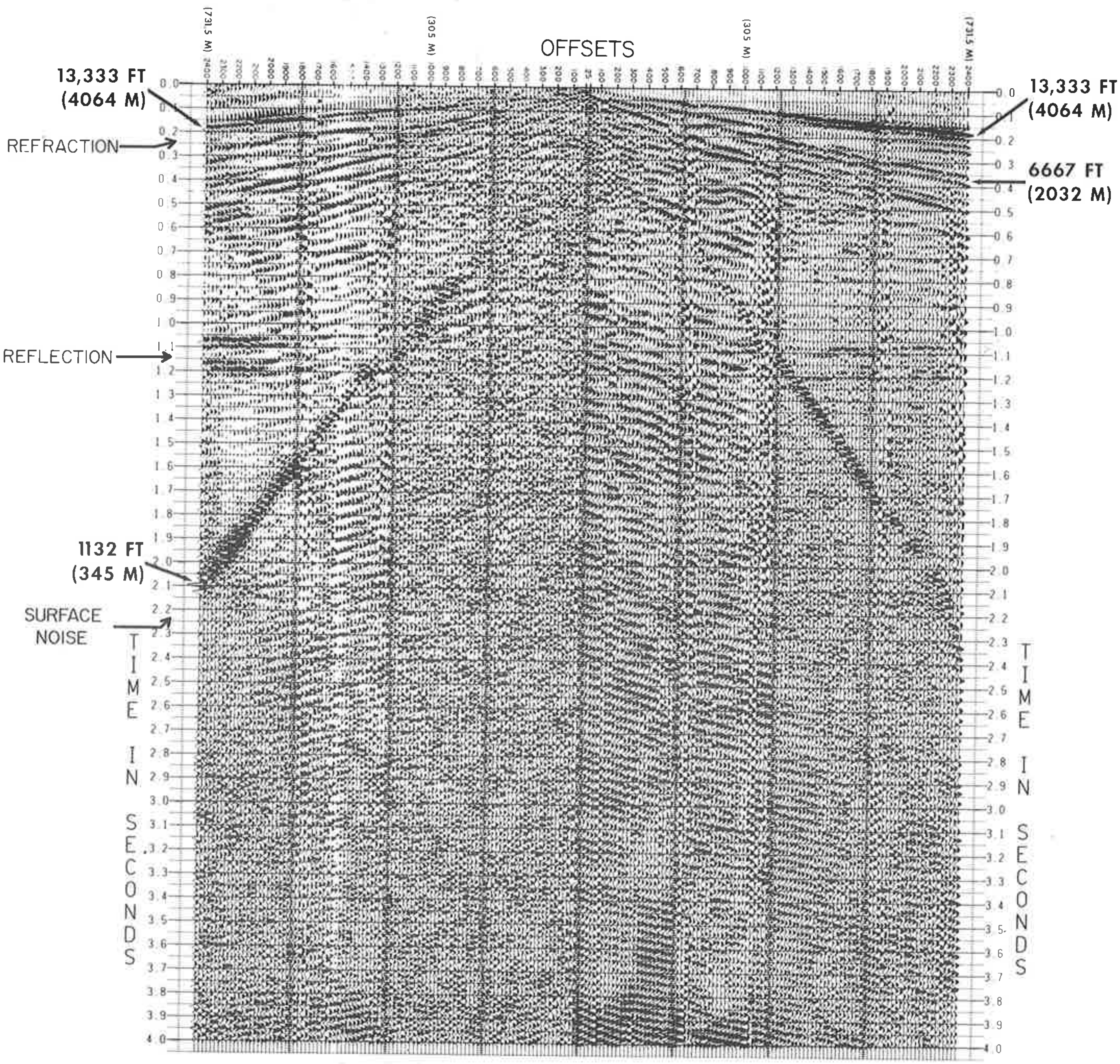


FIGURE 4A

REFRACTION STUDY NO. 1

TENNESSEE DEPARTMENT OF CONSERVATION
STATION SPACING 25 FEET (7.62 METERS)

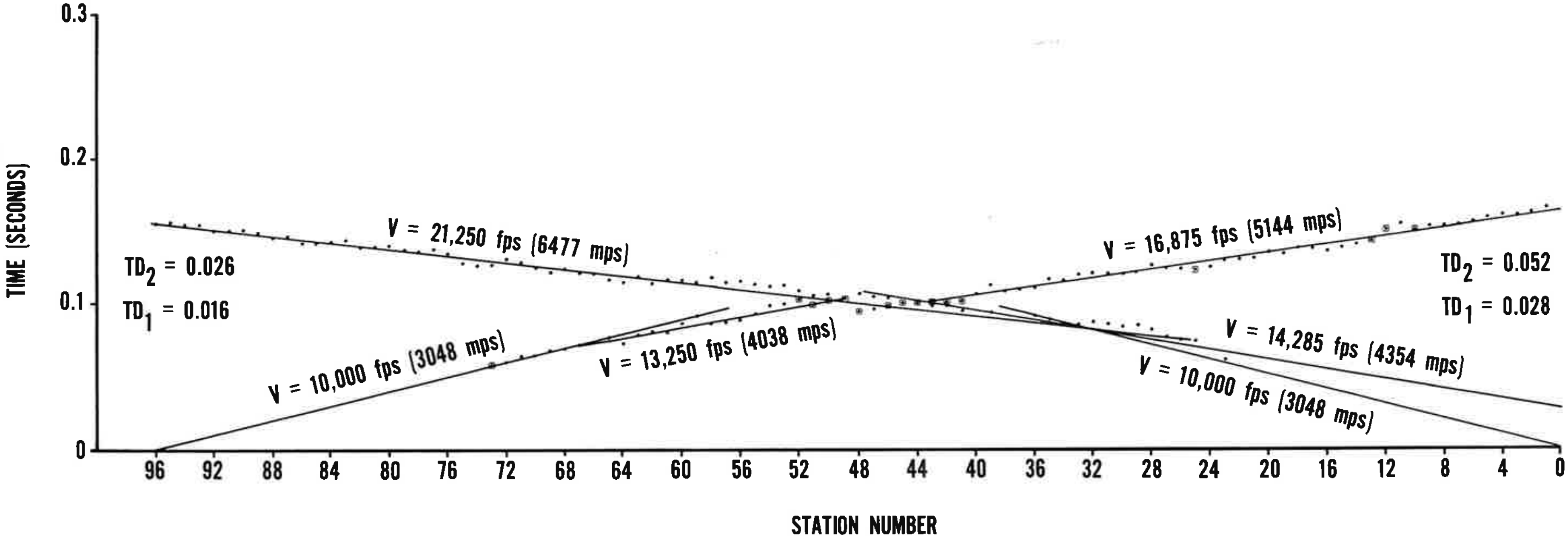


FIGURE 4B

REFRACTION STUDY NO. 2

TENNESSEE DEPARTMENT OF CONSERVATION
STATION SPACING 25 FEET (7.62 METERS)

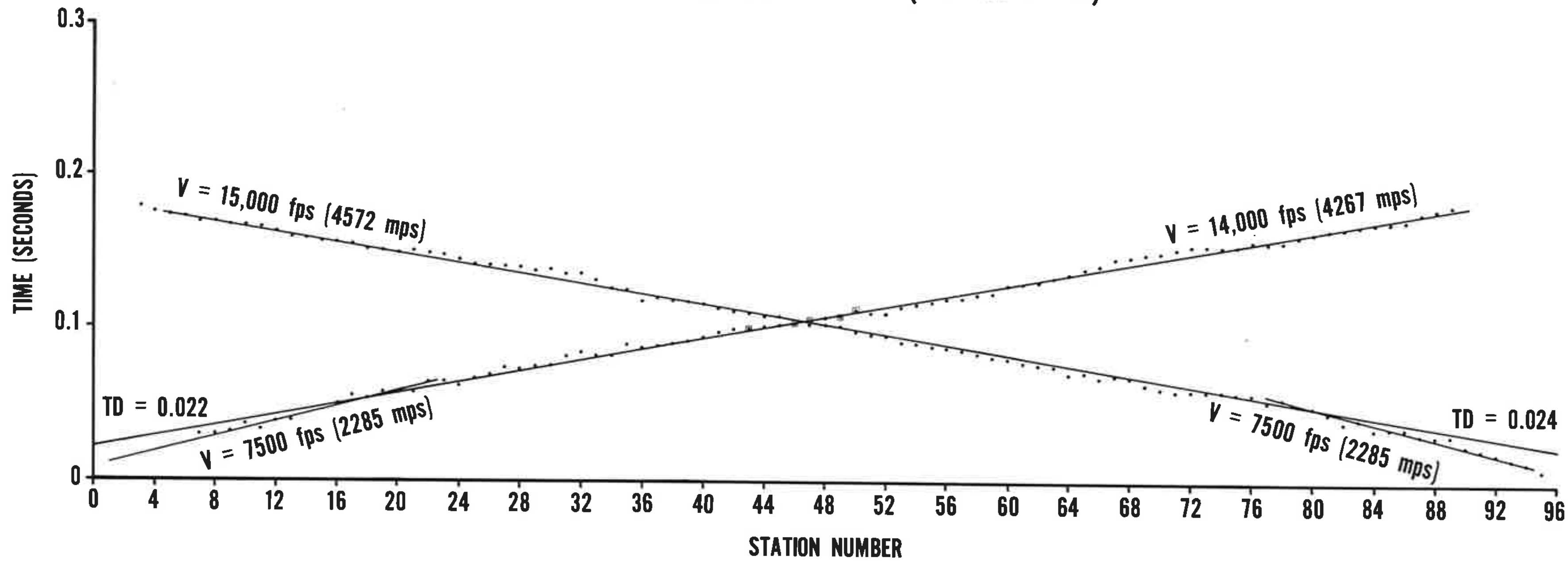
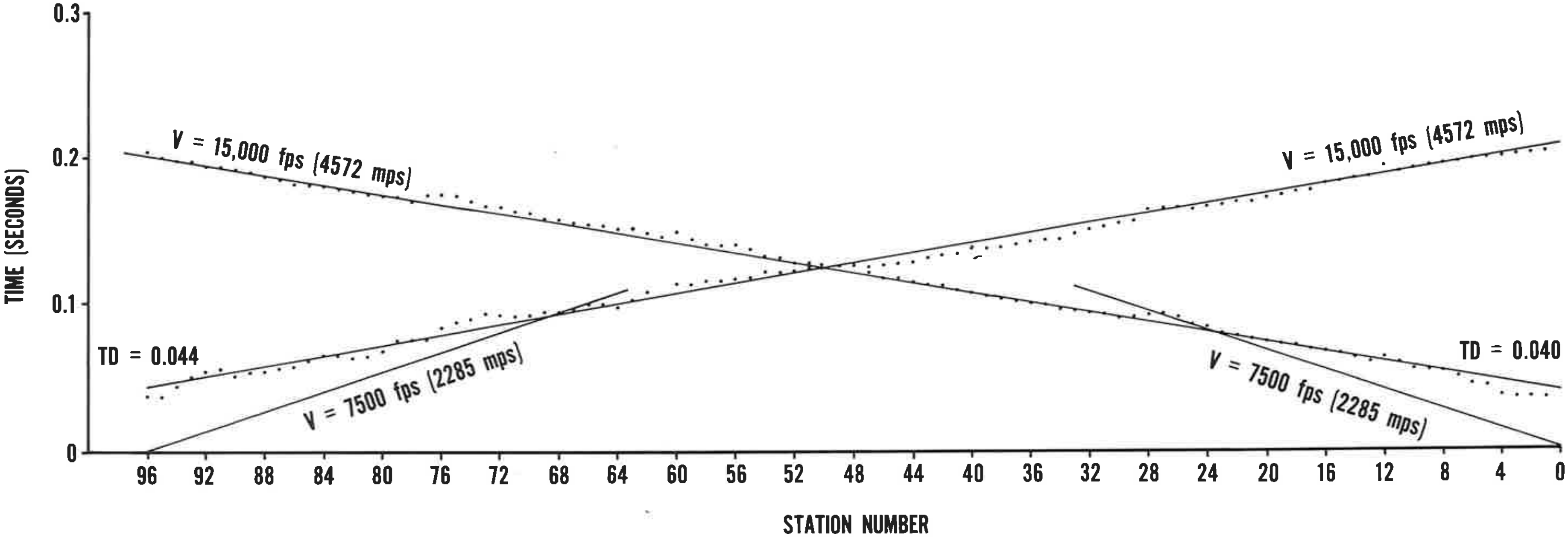


FIGURE 4C

REFRACTION STUDY NO. 3

TENNESSEE DEPARTMENT OF CONSERVATION
STATION SPACING 25 FEET (7.62 METERS)



Dip can be estimated for the two layer case according to the following equation:

$$D = \sin^{-1}\left(V_1/V_{2U}\right) - \sin^{-1}\left(V_1/V_{2D}\right)$$

D = dip angle

V_1 = first layer velocity

V_{2U} = up dip apparent second layer velocity (higher of two)

V_{2D} = down dip second layer velocity (lower of two)

The velocity of the second layer then becomes:

$$V_2 = \frac{V_1}{\mathrm{SIN}\left(\dfrac{\sin^{-1}\dfrac{V_1}{V_{2U}} + \sin^{-1}\dfrac{V_1}{V_{2D}}}{2}\right)}$$

Table I shows estimations made from all three refraction analyses using a simple averaging of the up and down dip spreads to eliminate dip. In the case of study no. 2, one could estimate dip at 2.4 degrees and V_2 at 14,480 ft/sec. Note that the difference produced by this small dip is inconsequential.

The column labeled "MIN. M-D SHALE" under thickness is an estimate of the minimum thickness of the V_2 layer which represents either Granger or Chattanooga shale at study locations 2 and 3. No shale was present at location 1 younger than Ordovician.

TABLE NO. 1

REFRACTION STUDY RESULTS

STUDY NO.	V_{LEFT}	V_{RIGHT}	V_{AVG}	X_{CL}	X_{CR}	X_{CAVG}	THICKNESS		COMMENTS
							ESTIMATED WEATHERING	MIN. M-D SHALE	
1 V_0	10,000	10,000	10,000	NA	NA	NA	144	NA	
V_1	13,250	14,285	13,767	650	800	725	NA	NA	Dipping
V_2	16,875	21,250	19,067	No Est.	825	No Est.	No Est.	No Est.	Faulted
2 V_0	7,500	7,500	7,500	NA	NA	NA	120	NA	
V_1	14,000	15,000	14,500	475	375	425	NA	443	Slight dip. Offset variance in long halves.
3 V_0	7,500	7,500	7,500	NA	NA	NA	184	NA	
V_1	15,000	15,000	15,000	700	575	637.5	NA	417	Possible slight dip. Delay time variance.

THICKNESS ESTIMATES BASED ON AVERAGED VELOCITY VALUES (V_{AVG}) AND CRITICAL DISTANCE (X_{CAVG})

Seismic Reflection Program - Data Collection:

Line K-1 S was collected in 1973 as part of a regional non-exclusive program conducted by Geophysical Service Inc. The line was reprocessed to enhance the shallow record for the Tennessee Department of Conservation to supplement line TC-1. The collection technique used was VIBROSEIS with a 24-channel DFS III system configured as a symmetrical, gapped, split spread (figure 5). As shown in figure 5, the source and receiver units moved along the seismic line in such a manner as to produce normal 12-fold common depth point redundancy with an interval of 165 feet between traces.

Within any one depth point there is a range of shot-to-detector distances possible of 990 to 4290 feet. This is only achieved when the line is straight. As will be shown later in this discussion (figure 17) crooked surface traverses lead to scattering of the subsurface depth which eventually restricts the fold and offset combinations being stacked. Maximum offsets are always shortened.

Lines TC-1 and TC-2 were collected using a modified scheme proposed by Tegland, 1976 (figure 6). This technique involved the DFS IV, 48-channel recording system equipped with CFS-1 computer which was used in the refraction data collection. The assymetric, gapped, split spread produced 12-fold common depth point redundancy on a 220 foot interval with shot-to-detector offset ranges from 660 feet to 8140 feet under normal, straight line conditions. Offset redundancy within a depth point only occurs on one-fourth of the contributors with this technique. Whereas, one-half are involved with the symmetrial spread.

The new technique was aimed at the following objectives:

1. Provide more closely spaced traces to better define steep dip.

FIGURE 5

SYMMETRIC SPLIT-SPREAD GEOMETRY USED IN COLLECTING LINE K-1S

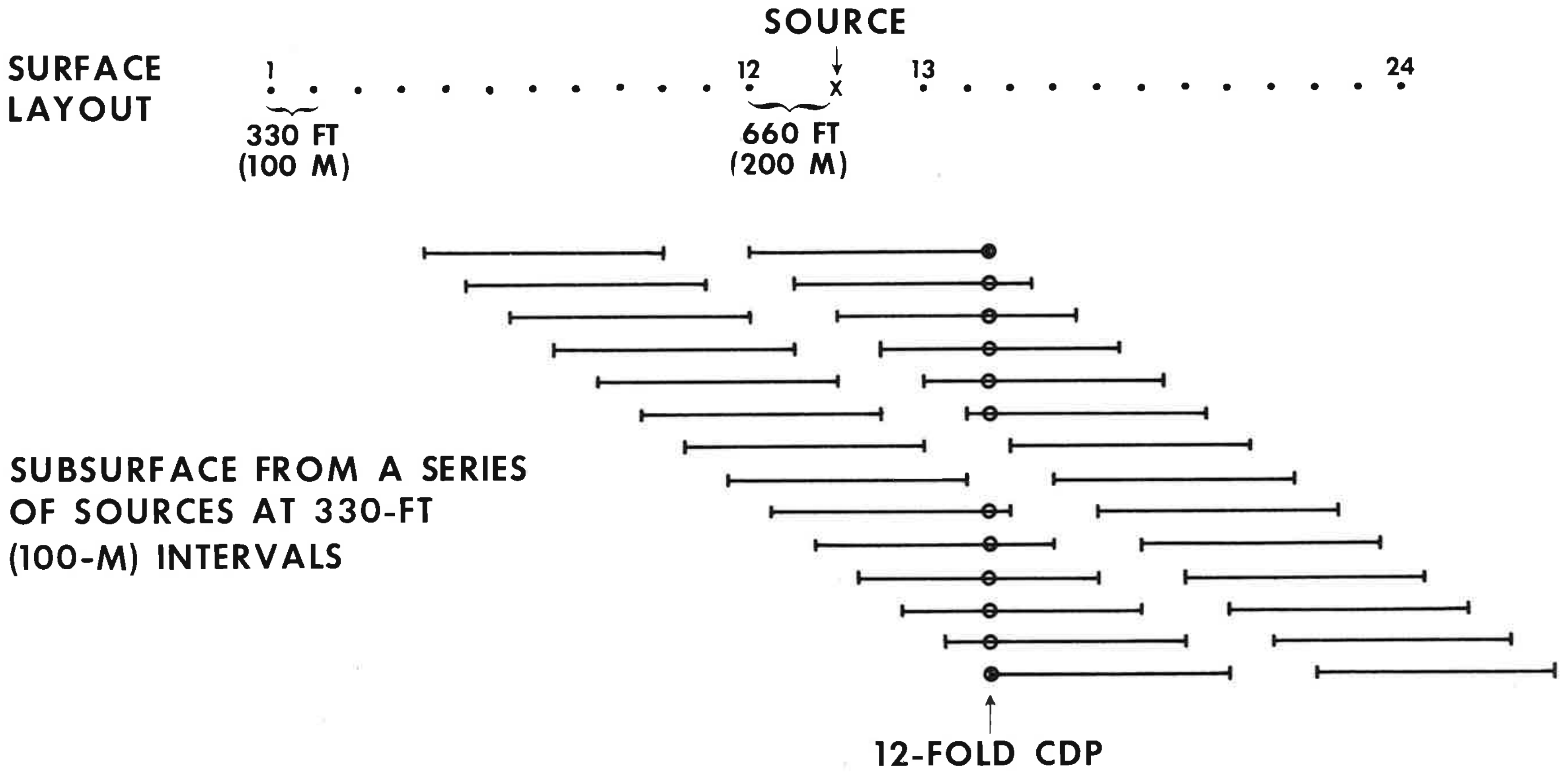
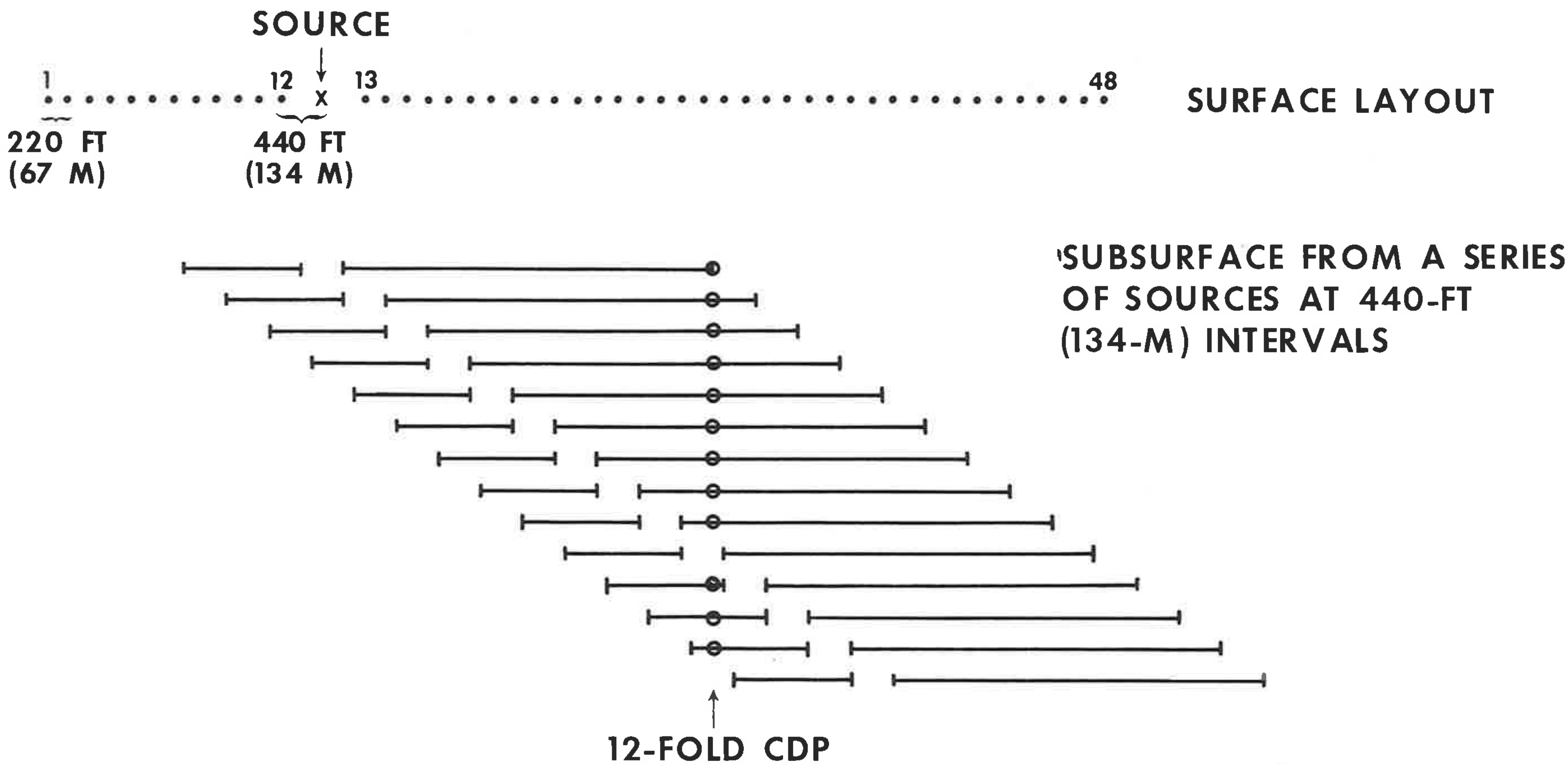


FIGURE 6

ASYMMETRIC SPLIT-SPREAD GEOMETRY USED IN COLLECTING LINES TC-1 AND TC-2



2. Provide an extended offset range to allow improved sampling, both shallow and deep, creating more flexibility in stacking and velocity analysis.

These aims were generally met although the shallowest part of the section proved to be somewhat disappointing in several segments of the program.

The source element in the new work consisted of two vibrator units spaced 40 feet apart and advancing in unison 17 feet to each sweep. Fifteen sweeps per VIBROSEIS pattern were taken. Figure 7 shows the response of this source system. A minor assumption was made when combining individual vibrator stations to yield the resultant array shown in this figure. The distance involved was 6 feet and it was felt that a more exact response calculation would not materially alter the picture.

The seismometers in each receiver array were spaced at 9.5 feet. Twenty-four individual geophones were employed in each group. Figure 8 shows the response of the seismometer array. In practice one experiences a combined effect of the source and receiver arrays as shown in figure 9 only when the line is straight. Bends in the line always reduce the overall dimensions of the array. This has the effect of changing the horizontal (wave number) scale on the plot. For example: A pair of bends which place all of the receivers on a line perpendicular to all the source elements would produce an effective receiver array of length zero. The wave number of a particular seismic event is the reciprocal of the wave length and is given by the following equation:

FIGURE 7

SOURCE ARRAY CHARACTERISTICS

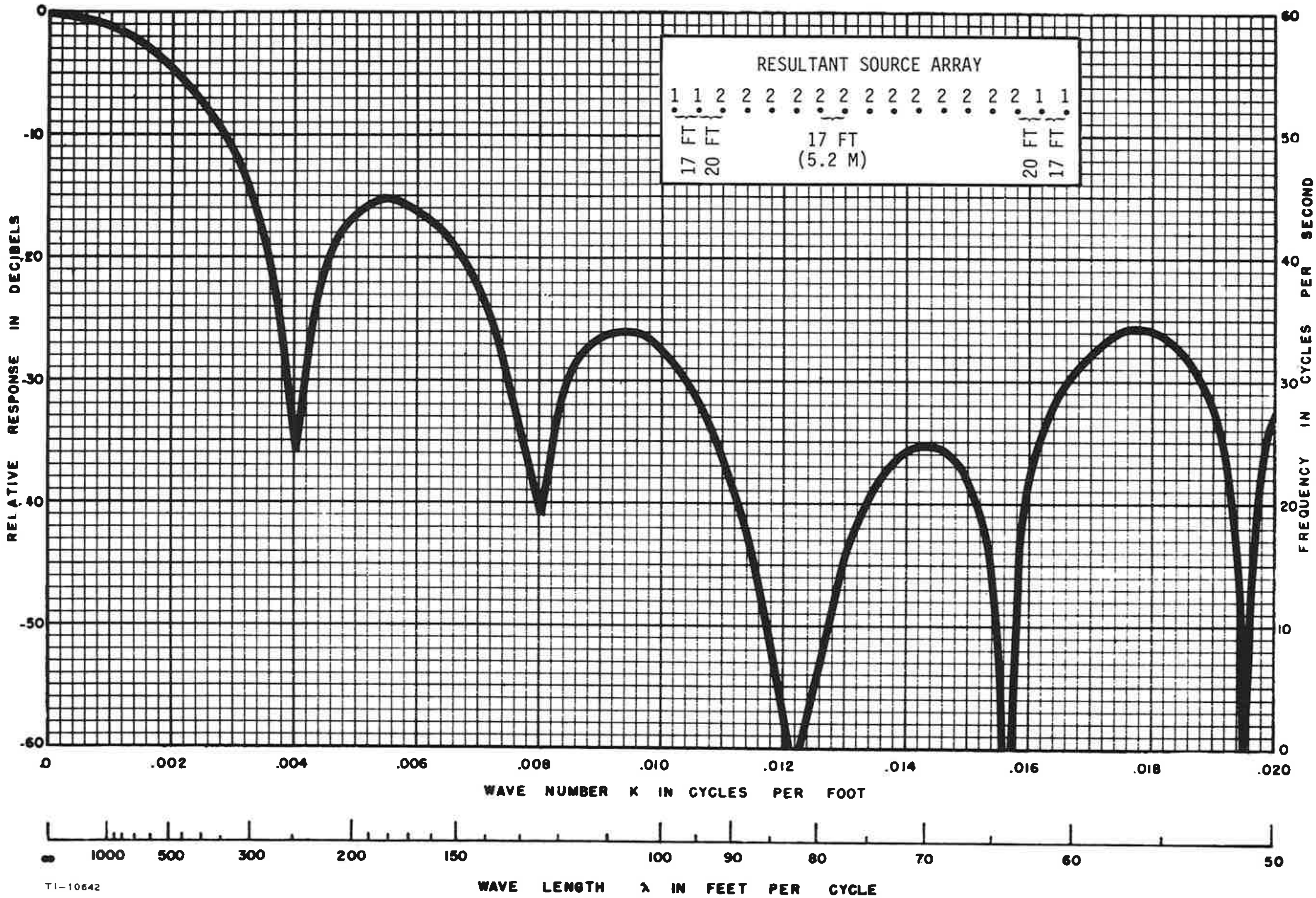


FIGURE 8

RECEIVER ARRAY CHARACTERISTICS

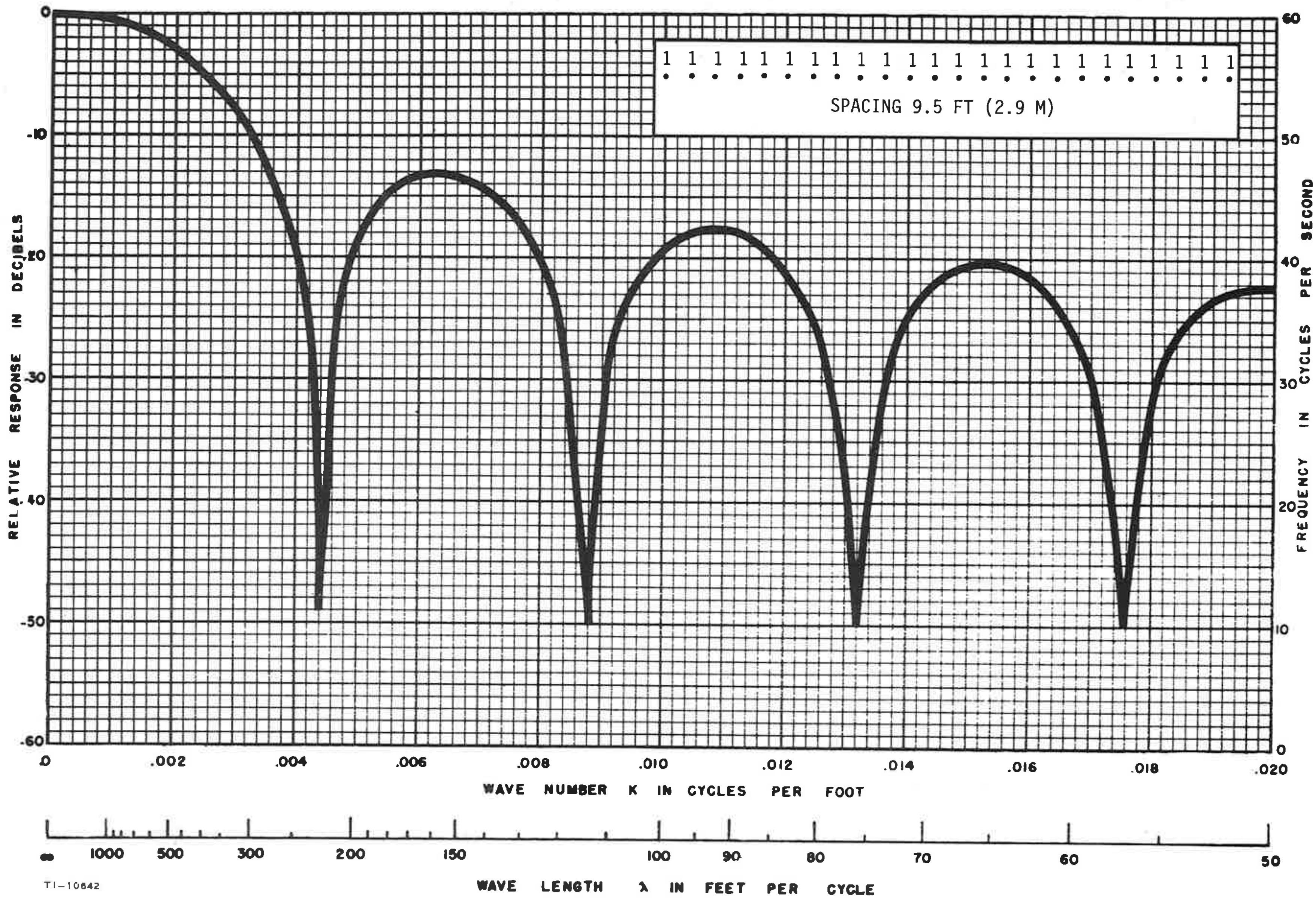
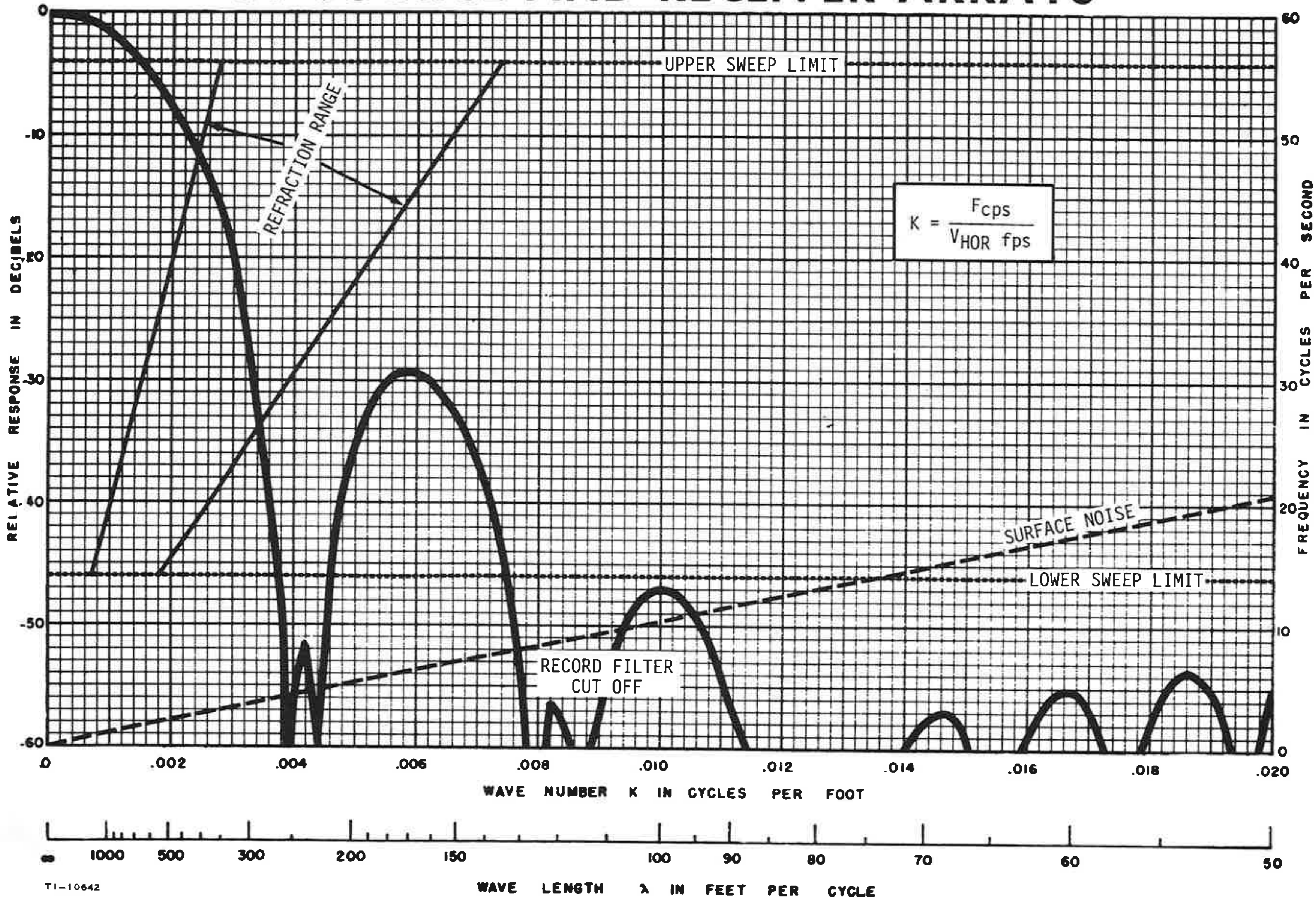


FIGURE 9

COMBINED RESPONSE OF SOURCE AND RECEIVER ARRAYS



$$K = F\left(\frac{dt}{dx}\right)$$

where F = frequency in Hz (cycles/sec)

dt = time difference between two observation points

dx = distance between observation points

$\frac{dx}{dt}$ = apparent wave velocity

Shown in figure 9 are velocity/frequency profiles of various "noise" events as identified on the refraction studies, which by the nature of their collection technique doubled as noise analyses. Good attenuation is noted for all of these types of arrivals. Examination of individual field records from the reflection survey indicate this to be, in fact, the case with little evidence of these noise types.

The source strength did not appear to be a significant problem. Quite often a good, strong reflection generally believed to be the contact between the Rome shales and underlying Precambrian was recorded. Certain areas did exist however, such as DP 170-250, DP 1390-1560 on line TC-1 and DP 2200-2690 on line TC-2 where very weak returns were apparent at all levels and very little organized signal could be observed on the basic field data. It is inconceivable that the reflectivity of the subsurface interfaces could change so rapidly as to obliterate a very strong event such as that associated with the basal Rome. One therefore must conclude that the surface conditions in these areas are such that very little energy is coupled into the ground or out of it. Another possibility is that local near surface structural complexities have produced highly distorted ray paths which defeat the common depth point stack philosophy. This latter cause can explain a local hiatus in the flatter events beneath the upturned part of the major thrusts (TC-1 DP 170-250, DP 490-560).

In some areas, the presence of near surface irregularities such as cavernous limestones or very coarse gravels may cause scattering of the seismic energy reducing the apparent penetration. This tied into coupling problems of a mechanical nature could explain the problem experienced in some broader cases. Use of more low frequency in the source signal might overcome this problem to some extent.

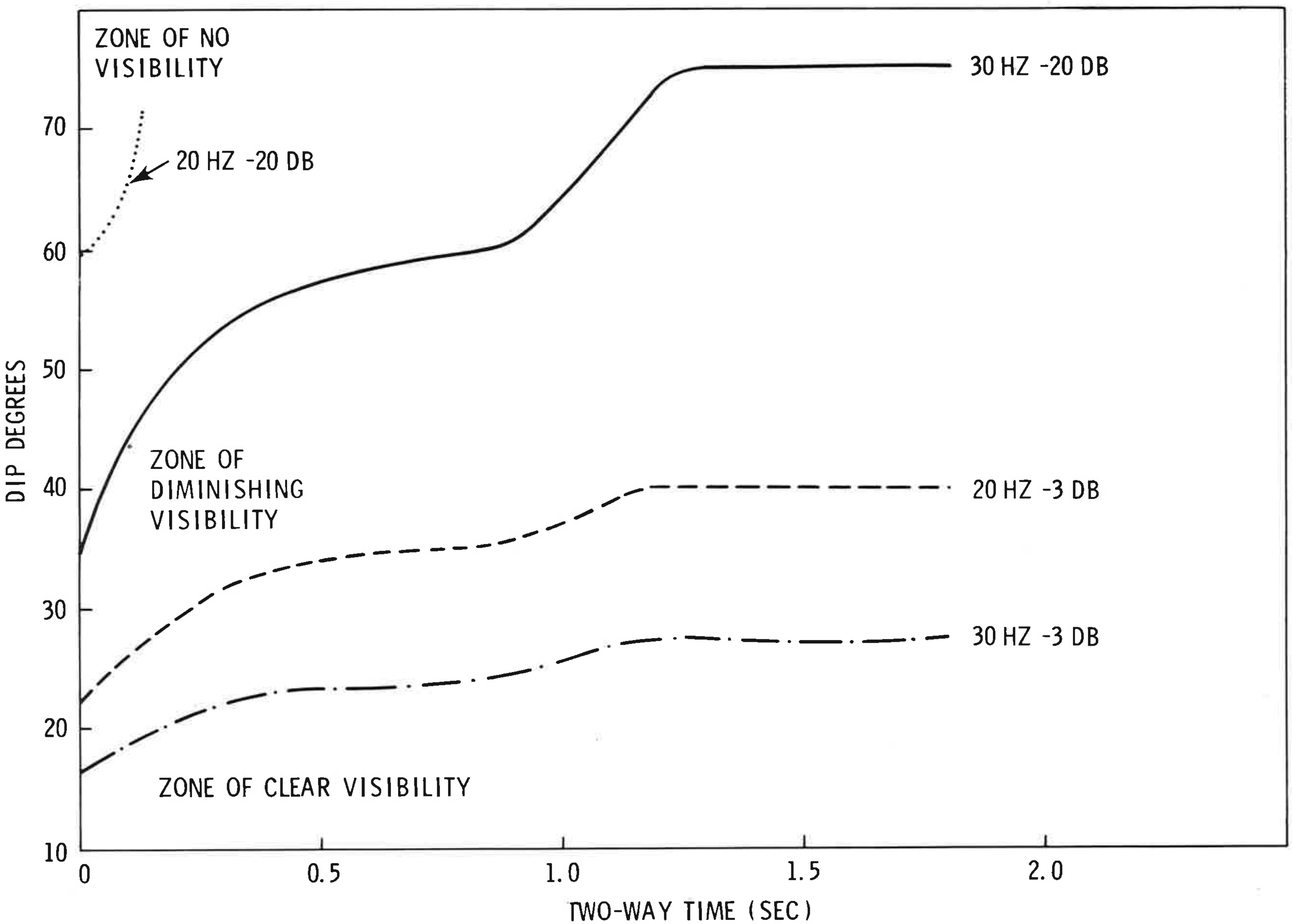
The source and receiver arrays also are a double edged sword in that the desired signal may be attenuated either due to the dip of the horizon or due to differential normal moveout across the array. In a high velocity section such as this, moveout across the array is a negligible problem. Figure 10 explores the first problem for the typical velocity situation in this area. Steep dip attenuation by the arrays is believed to be a problem in the areas where thrusts have surfaced. The deeper events generally exhibit much less time dip.

In reviewing figure 10 one should note that 3-db attenuation marks the point at which some effect can be observed while 20-db attenuation results in total lack of visibility in most cases. Twenty and thirty Hz. signal frequencies were assumed in this figure.

Future efforts should be directed at restricted features and three-dimensional techniques should be considered as a means of solving problems of structural complexity and subsurface scattering. Surface coupling problems may be solvable with a change in source type or by moving the surface positions to be occupied onto more amenable mediums.

FIGURE 10

EFFECT OF ARRAYS ON DIPPING REFLECTIONS



SEISMIC REFLECTION PROGRAM - DATA PROCESSING

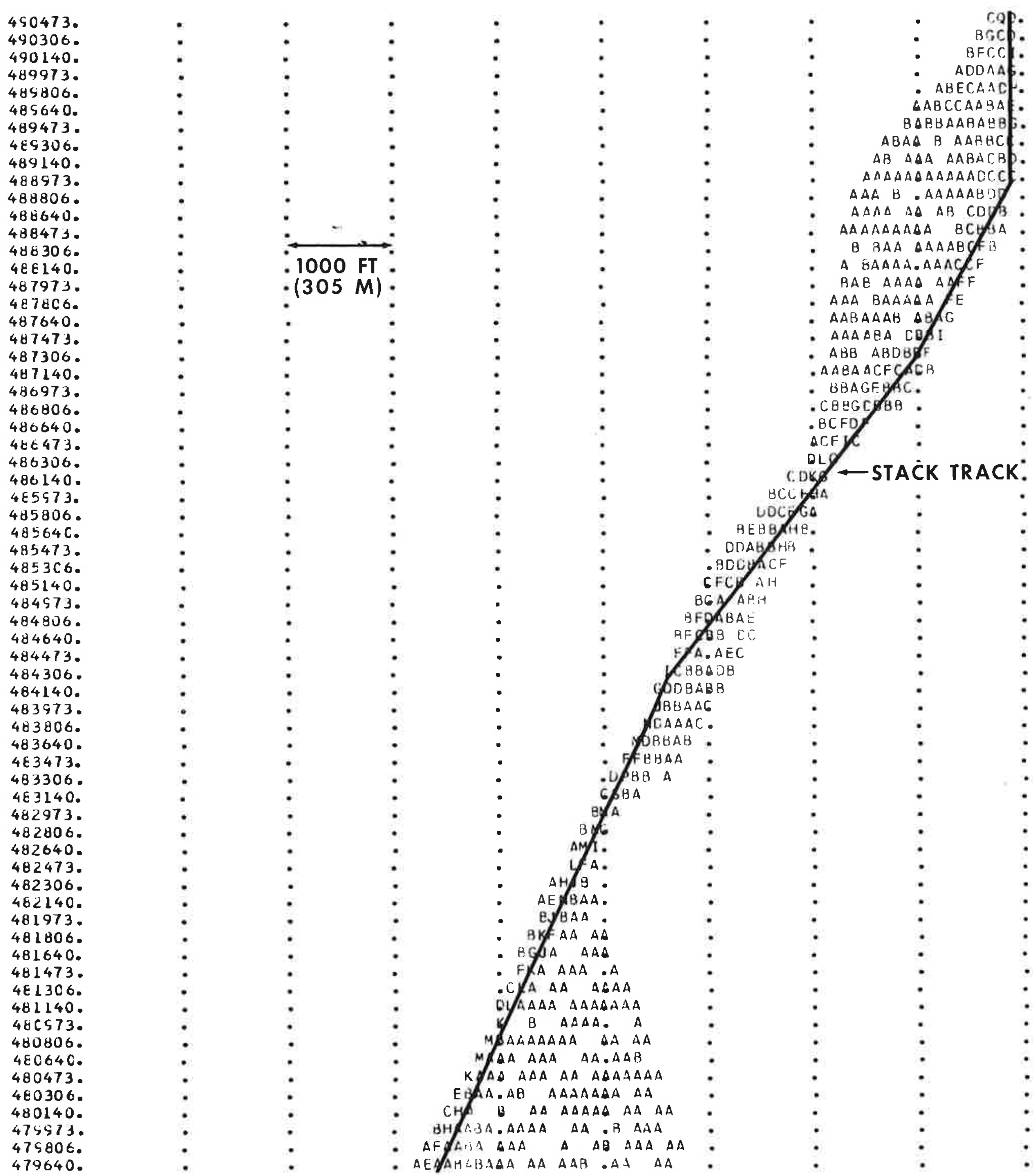
As indicated earlier, field summing and sweep removal was accomplished using the CFS-1 field computer system. The summing employed diversity stacking which weights the elements in each sum inversely proportional to the power of the individual elements in the sum. The underlying assumption in this process is that traffic and other noise producing mechanisms dominate local time zones of individual recordings. A considerable improvement in signal-to-noise ratio is generally experienced with this technique as compared to simple summation. Output amplitudes are maintained at true relative proportions.

Office processing followed crooked line techniques described by Tegland (1974). The processing sequence is outlined below:

I. Survey data reduction.
II. Subsurface distribution map display (figure 11).
III. Stack track definition and preparation of stacking tables and general data files including elevation corrections.
IV. Trace conditioning.
  a. Gain removal and trace amplitude recovery.
  b. Single gate trace amplitude equalization.
  c. Whitening deconvolution.
  d. Provisional normal moveout correction and "brute stack".
V. Residual static estimation.
VI. Velocity analysis.
VII. Final application of datum corrections, residual statics, and normal moveout.
VIII. Common depth point stack.
IX. Frequency filtering and scaling for final time displays.
X. Dip filtering to enhance desired time dip range for final interpretation.
XI. Time-depth conversion with interpreted velocity model.

FIGURE 11

SUBSURFACE DISTRIBUTION FOR SEGMENT OF LINE TC-1



Those processes which are somewhat unique will be elaborated on in the following paragraphs.

Crooked Line CDP Gathering:

As illustrated by Tegland (1974) one experiences a scattering of the common depth points contributing to a "standard" stack set when bends occur within the cable. If one is progressing in a true dip direction, i.e., the cable is generally perpendicular to strike, the scatter will not substantially degrade the result since no dip will be involved between traces contributing to a stack set. However, when traversing a strike segment the entire force of dip will be felt within a CDP set and one may experience notable signal degradation if the magnitude of the time dip across the scattered area is one-fourth period of the peak frequency or more. Of more importance is the fact that this dip within the CDP set will seriously corrupt any data-dependent time correction estimation, such as residual static determination (Step V) and velocity estimation (Step VI).

Since the seismic program in this case follows mountain roads one experiences a continual change in line direction from dip to strike and back again. To counter the inherent problems one first must understand what they are; therefore, a map showing symbolically how the subsurface scatter behaves is created, following reduction of the surface survey information to a set of cartesian coordinates. Figure 11 is a segment of TC-1 showing the subsurface scatter. The alphabetic symbols indicate potential CDP coverage in a cell the size of the letter, i.e., A=1, B=2, .. X=24 and * greater than 24.

The processing crew selects a desired path called a "stack track" for the output line to follow and a trace interval to be maintained along the line. A window about each desired stack trace location is used to select traces for each stack. The size of the window is set by the amount of expected dip and the frequency of the data. A window of 220 feet either side of the line was used in this processing.

The average "reflection point" coordinates of all contributors to a stacked trace is calculated and retained for future plotting to form the final base map. (See Plates I-A, B, C, D).

Residual Static Estimation:

The residual static estimation process is used to provide time constant corrections supplementing the datum corrections (see final time processing) and aimed at improving the stack response. Any static correction is aimed at compensating for variation in material in the immediate near surface, hence must be calculated and applied in a "surface consistent" manner. Surface consistency requires that the same receiver component correction be applied to all traces that utilized a given receiver location. In the current situation a single receiver location will be occupied 24 times by traces contributing to different common depth points. The source static must be common to all traces from a particular source location. Since a 48-channel system was used for TC-1 there are 48-traces from a single source contributing to 48 different stacked traces. In the case of K-1 S only 24-channels were used.

Raw corrections are calculated for each trace from a cross-correlation of the trace against a model trace constructed from a trial stack of the data. Suitable conditioning and averaging of the raw times is performed to produce a set of surface consistent source and receiver corrections plus an estimate of residual velocity error within the time zone used for the static estimation.

Velocity Analysis:

The raw time of a seismic trace contains two components. One is the time along a ray which runs from the mid-point between shot and receiver at the surface to the reflecting horizon and back. The other is the excess time resulting from the actual slope path taken which is induced by separation of the shot and receiver. This excess time is referred to as normal moveout or NMO. Since the collection of traces to be stacked into a given output contain a wide range of shot-to-detector distances one expects to see a variation in NMO among the contributors. Normal moveout is related to time, distance and velocity by the following relationship:

$$NMO = \left(\frac{X^2}{V^2} + T_o^2 \right)^{1/2} - T_o$$

where X = distance from shot-to-receiver

V = velocity generally taken as RMS velocity and described by Dix (1955)

T_o = normal ray (zero offset time), i.e., the normal incidence time for co-located shot and receiver.

When NMO is correctly compensated resulting trace time will be T_o.

Note: This equation assumes no structural dip and does not comprehend curvature of the rays involved. These assumptions are used in all estimation and correction schemes.

To measure NMO one may scan the gathered CDP family in constant steps of NMO coupled with stacking. As the best NMO correction for a given event is reached the amplitude reaches a maximum. Automated picking of these maxima has been implemented in a computer program coupled with dip scanning between adjacent depth points. The process plots results in time and RMS velocity as shown in the right half of figure 12. Plots of dip and amplitude against time are also part of the output. The highest amplitude event in each 100 millisecond gate is circled in all plots. Symbols related to amplitude rank are also used and their meaning is shown at the bottom of the plot. A listing of the highest amplitude event in each 50 MS is contained at the extreme right hand edge which numerically presents the time (T_0) amplitude, velocity (RMS) and NMO of the selected events.

The arcuate curves sweeping from upper right to lower left on the velocity field are curves of equal NMO computed at the reference distance (X) shown in the box. The curved lines originating in the upper left corner of the velocity plot and that sweep to the lower right and bottom are reference velocities V-1 through V-11 which were used to provide NMO corrections to the panels of stacked traces in the left of figure 12. Labeled above each stacked data set is its velocity. The two panels marked "INPUT" and "V6" are a single depth point in the middle of the analysis set with no NMO (INPUT) and with function V6 applied (V6).

Plots of this type are then interpreted to provide velocity functions for correcting NMO prior to stacking the data. One can see, for example at 0.4, an event which looks good with velocity V9. Moving horizontally to the velocity plot he finds a strong point picked by the computer between V9 and V10. The interpreted velocity must pass through this point. A second event seems to stack well at velocity V7. The computer has again made a pick matching the event located by eye. Note that as one goes toward

FIGURE 12

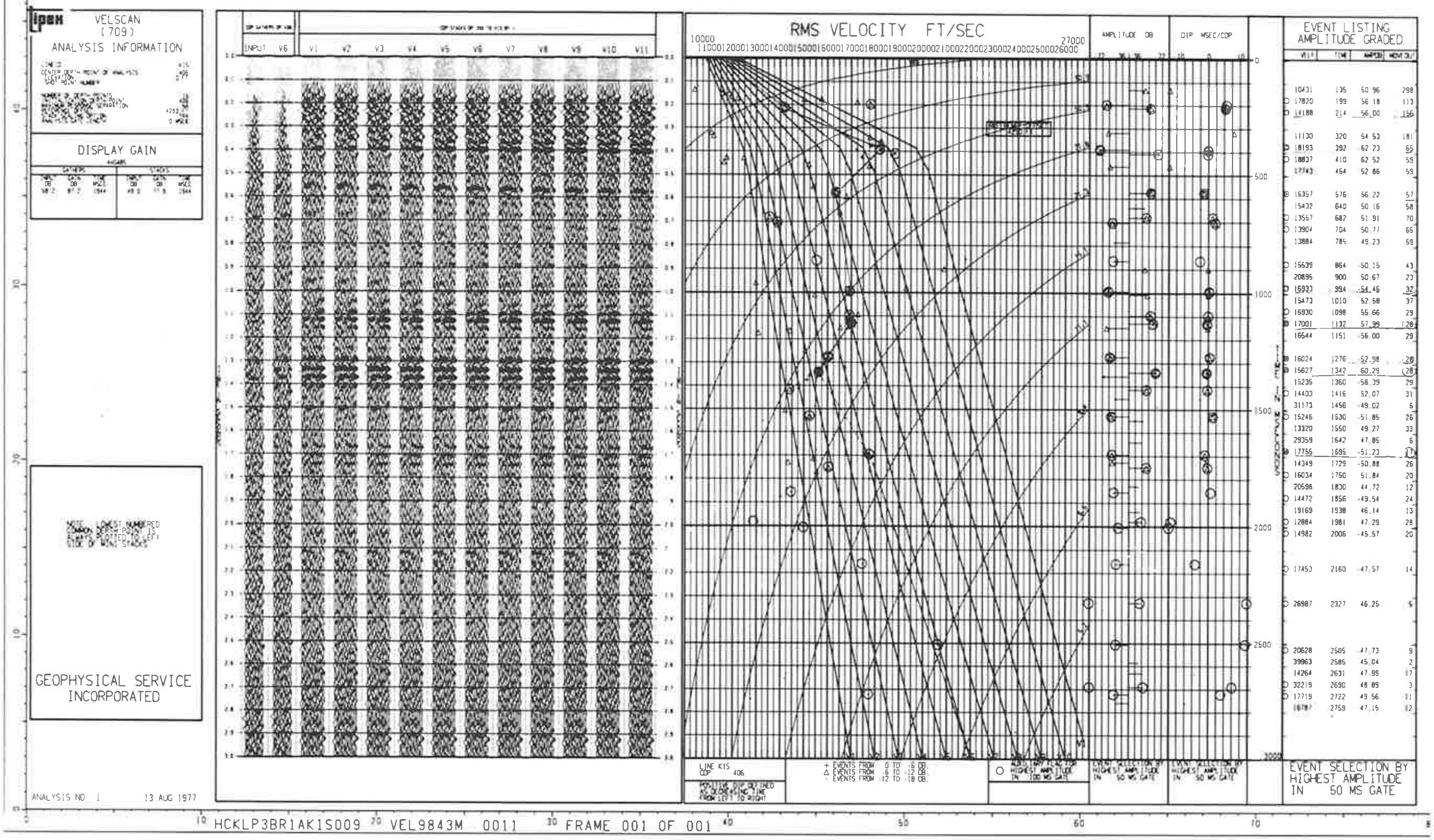
VELOCITY ANALYSIS EXAMPLE

K-1 SOUTH

TENNESSEE DEPT. OF CONSERVATION

SHOTPOINT 147

EASTERN TENNESSEE



increasing time (depths) he is always dealing with decreasing moveout i.e., successively deeper events must decrease in NMO to be valid (Embree, 1970). This phenomena also has accuracy ramifications in that an ever decreasing amount of NMO represents ever increasing velocity yielding a larger statistical error. Note, for example, the event at 1.3 seconds which stacks well at all trial velocities. Schneider (1969) addresses these error sources.

Plots of this type were created every 70-90 depth points. The exact locations chosen were dependent on the amount of fold and offset problems that had been incurred due to line bends.

Final Time Processing:

A final output time of a given seismic event is governed by two types of correction: The static (time invariant) corrections are employed to cope with near surface variations due to velocity changes in the "weathered" material which includes geologic weathering and man-made situations such as road fill and elevation variations. Since a surface source was employed, no means other than the three refraction analyses was available to define the near surface situation. The analyses made only confirm the location where they were made and cannot be expected to represent the rapidly varying geologic setting of the surface in this area. Fortunately, the velocity even of the disturbed materials is relatively fast and only small magnitude static time differences generally are observed. Since the elevation variations at the surface are relatively oriented toward structure, a datum which generally followed the surface was chosen as opposed to a flat or simple sloping type.

A smoothed plot of the minimum elevation of every 10 to 12 shotpoints was adopted for datum. In most areas only a small correctional change occurred. A velocity of 10,000 feet per second was used between surface and datum to compute correction times for each shot and receiver location according to:

$$T_c = \frac{ES - ED}{V_c}$$

T_c = correction time
ES = surface elevation
ED = datum elevation
V_c = correctional velocity = 10,000 fps

Tests were made with other V_c values ranging from 8000 to 16,000 with very little variation in data quality resulting. The refraction analysis had initially suggested this as a reasonable velocity for the first 100-200 feet which was all that was involved in most areas.

Residual corrections discussed earlier usually have only a minimal effect on the final output time since the technique used in this case generally could only comprehend near surface anomalies of less than one-half cable length.

Normal moveout corrections are of a time variant nature as indicated in the velocity analysis discussion and their effect on final output time is most notable at early record times where only a few traces are being stacked and corrections are large in spite of the restrictions to nearer offsets.

Following common depth point stacking the data are output to tape and also have time variant bandpass frequency filtering applied for display. Frequency domain processing was employed in the form of dip filtering to create a set of time sections with a slightly improved signal-to-noise ratio. The range of dips allowed to pass was of necessity quite large and only the more or less random noise was suppressed.

Auxiliary data pertinent to the processing are contained in the record section headings and side labels of all displays. Of special importance to interpretation is the graphic plot of surface (S) and datum (D) elevations on each section. These represent average values for each CDP trace. The datum elevation represents zero time on the record section.

Time-Depth Conversions:

The time-depth conversion process employed simply accepts a user supplied velocity model in terms of time and RMS velocity and calculates from it an average velocity (Dix, 1955; Tegland, 1972) with which to translate the linear time scale to a linear depth scale. If the supplied model were a single constant velocity, the transformation would be linear. However, since some natural increase of velocity with depth occurs coupled with changes due to variable lithology the transformation is non-linear and resembles the normal moveout process in the manner in which amplitude interpolations, etc. are handled.

The method used does not comprehend refraction caused by variable interval velocities and does not encompass migration of the data. The method of constructing the velocity model is covered in the following section on interpretation.

INTERPRETATION

Background Information:

Two sets of well information located near the program were available at the time of the interpretation. Unfortunately, neither well provided velocity data. The L. S. Bales well described by L. D. Harris (1967) is located in Virginia northwest of line TC-2 near the Chestnut Ridge fenster at Virginia coordinates 140075N and 575900E. The section seen by the well encompasses the Ordovician and Cambrian, with the main Pine Mountain fault and a secondary fault associated with it present in the well. Movement on both faults is in the Conasauga shales of Upper Cambrian. No Rome was drilled in the well which bottomed in the second encounter of the Copper Ridge. This well provides a good estimate of expected section in the hanging wall of the main Pine Mountain fault.

The younger section is represented in the Tidewater-Wolfs Head well in Scott County, Virginia at Carter coordinate 6-B-87, 6400 feet south of 36° 40' and 4500 east of 82° 20'. The well started in the Gasper Limestone (Mississippian) and completed in the Sequatchie (Ordovician) at 7200 feet with several reported gas shows.

Devonian rocks were encountered between 4530 feet and 6700 feet, consisting of 15 feet of Berea Sandstone with the remainder reported as shale. The Rockwood section just beneath the Devonian totaled 205 feet of mixed sandstone and shale followed by 279 feet of "hard" Clinch sandstone and total depth in "soft" Sequatchie shale. One would expect a reflection at the base and top of the Clinch in this area. Above the Devonian is an interval of mixed clastics overlain by the Little Valley Limestone, consisting of carbonates and evaporites.

In earlier work carried out by Geophysical Service Inc. to the west in Tennessee and Kentucky, several sets of well data were acquired and analyzed which had velocity data. This information was reported by Tegland (1973). The information was analyzed in terms of interval velocity and depth to provide depth conversion models for the early non-exclusive work by GSI. It was found that both the clastics and carbonate rocks fit an exponential depth relationship of the following form:

$$V_i = AZ^N$$

where V_i = the interval velocity in same incremental depth element

A = a constant describing velocity at unit depth lithologic constant

N = an exponent describing compaction behavior

Z = depth of element relative to the surface

This general form was proposed by Faust (1951), and used extensively by Tegland (1972) and others to mathematically describe velocity behavior. The carbonate velocity and shale velocity shown in Table 2 were taken from slides used in Tegland's (1973) presentation.

In addition to the well data a complete set of geologic maps on 7-1/2 min. quadrangles was available. These maps varied in type and amount of detail with some prepared by the Tennessee Department of Conservation staff specifically for this project. Table 3 lists each quadrangle and the available information. These data were transferred to the depth point location maps to form a set of "SEISMIC-GEOLOGIC" base maps. Only information within 6000-10000 feet of the line was normally transferred including contacts, fault traces, dip-strike data, and structural axes. These maps permit the user to immediately identify and project important features from the surface onto the seismic sections. All maps were then subsequently reduced to 1" = 4000' for an easier to use working scale. (See Plates I-A, B, C, D).

TABLE NO. 2

MODEL VELOCITY DEPTH FUNCTION PARAMETERS

$V = AZ^N$ $V_{MIN} = 13{,}000$ fps

LITHOLOGY	A	N	V_{MAX}, fps
100% Shale 0% Carbonate	5755	0.104	14,500
75% Shale 25% Carbonate	6031	0.110	16,250
50% Shale 50% Carbonate	6308	0.117	18,000
25% Shale 75% Carbonate	6584	0.123	19,750
0% Shale 100% Carbonate	6860	0.129	21,500

SOURCES OF GEOLOGIC DATA

TABLE NO. 3

QUADRANGLE	SEIS LINE	AUTHORS	AGENCY	STATUS - YEAR	SUPPLEMENTAL	
					GEOL. COL. + ECON. GEOL.	PROFILE
MIDDLESBORO SOUTH	K-1	K. J. ENGLAND	U.S.G.S.	COMPLETE #GQ-301 1964	YES	YES
WHEELER	K-1	L. D. HARRIS	U.S.G.S.	COMPLETE #GQ-435 1965	YES	YES
TAZEWELL	K-1/TC-1	L. D. HARRIS	U.S.G.S.	COMPLETE #GQ-465 1965	YES	YES
HOWARD QUARTER	TC-1	L. D. HARRIS R. B. MIXON	U.S.G.S.	COMPLETE #GQ-842 1970	YES	YES
AVONDALE	TC-1	E. J. HARVEY	UNIV. OF TENNESSEE	THESIS 1948	GEOL. COL.	YES
BEAN STATION	TC-1	J. W. SMITH	UNIV. OF TENNESSEE	THESIS 1968	NO	YES
MORRISTOWN	TC-1	R. L. ODER R. C. MILICI G. D. SWINGLE	TENN. DEPT. CONSERVATION	COMPLETE 1965 GM 163-NE MRS 163-NE	YES. RESOURCES SUMMARY	YES
KYLES FORD	TC-2	W. B. BRENT	TENN. DEPT. CONSERVATION	MANUSCRIPT MAP	YES	YES
PRESSMENS HOME	TC-2	JOHN SANDERS	YALE UNIV.	THESIS 1952	GEOL. COL.	YES
BUREM	TC-2	D. C. HANEY	UNIV. OF TENNESSEE	THESIS 1966	GEOL. COL.	YES
MC CLOUD	TC-2	D. CUMMINGS	MICH. STATE UNIV.	THESIS 1962	GEOL. COL.	YES
MOSHEIM	TC-2	BROKAW, DUNLAP AND RODGERS	U.S.G.S.	BULL. 1222-A 1966	YES	YES
GREENEVILLE	TC-2	D. W. BYERLY	UNIV. OF TENNESSEE	MANUSCRIPT MAP	NO (REFER TO BAILYTOWN MAP)	YES
DAVY CROCKETT LAKE	TC-2	V. E. FRENCH, JR.	UNIV. OF TENNESSEE	THESIS 1966	GEOL. COL.	YES
HOT SPRINGS	TC-2	FERGUSON AND JEWELL	TENN. DEPT. CONSERVATION	BULL. 57 1951	YES	YES

Velocity Model Building and Depth Conversion:

One might attempt to utilize the velocity analyses which were produced during processing to create a velocity model for time-depth conversion. However, only a few cases produced unambiguous results suitable for this purpose.

Figures 14A-C illustrate some of the difficulty encountered even in making qualitative geologic identifications of the reflection intervals. For example, in figure 14A one is faced with two possible choices for the event sequence at 0.792 sec. or 0.822 sec. Both are peaks. One would suggest acceleration implying a high velocity interval preceeding the event and the other suggests deceleration implying a low velocity interval. One can easily get into a similar predicament at 1.5 seconds. The sort of problems encountered here may well be related to three-dimensional effects such as reflected events from planes other than that of the profile (sideswipe) and diffraction events from local irregularities in the subsurface. A general breakdown of the common depth point philosophy which occurs in structurally complex situations also contributes to the problem.

Figure 14B in a somewhat less complex structural situation illustrates the same problem of ambiguity at 1.7 sec. In this situation the line is at a sharp bend from dominant dip to strike and some lateral dip within individual CDP trace sets may be influencing the result.

Figure 14C is from a poor data area and one can imagine all sorts of velocities, none of which make a great deal of sense. After a thorough review of the available seismically derived velocity data it was decided to employ them on a limited basis only for interval identification and not at all for absolute values of velocity, to be employed for depth conversion.

FIGURE 13
RMS VELOCITY DISTRIBUTION OF MODEL GEOLOGIC UNITS

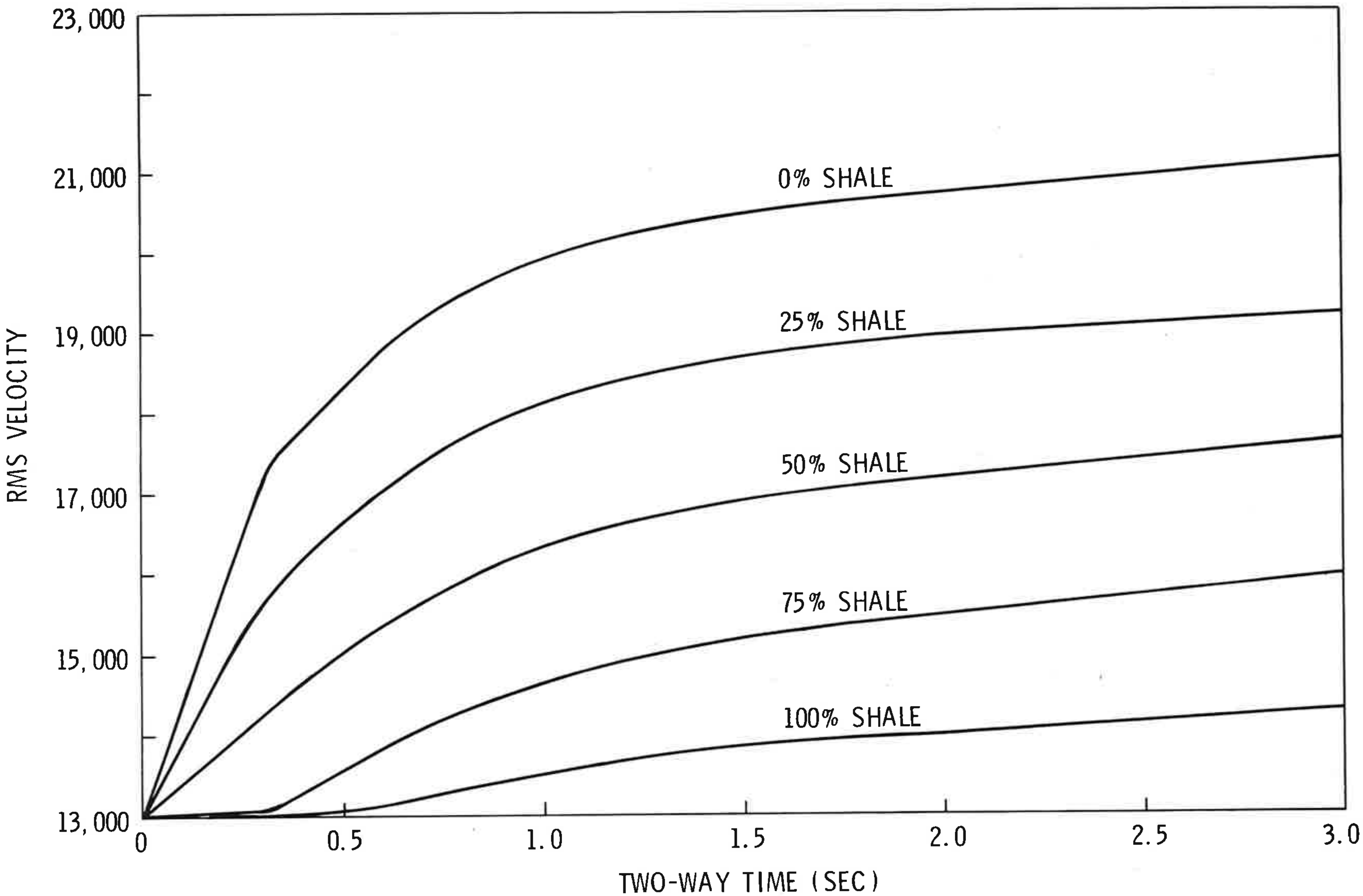


FIGURE 14A
LINE TC-1 VELOCITY ANALYSIS DP 415
CLINCH PORT AND WALLEN VALLEY THRUST BLOCKS

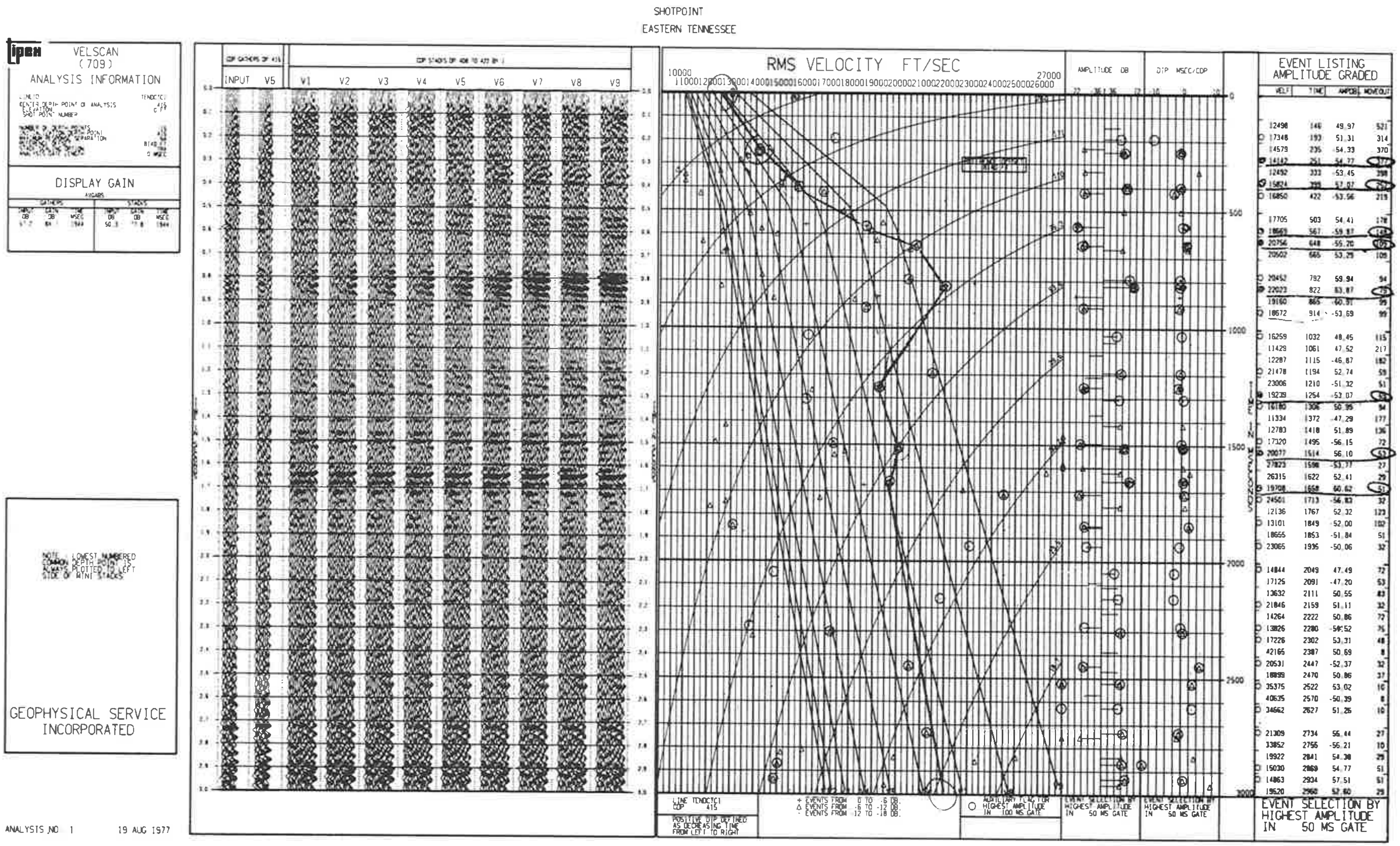


FIGURE 14B
LINE TC-1 VELOCITY ANALYSIS DP 885
NEAR CLINCH MOUNTAIN

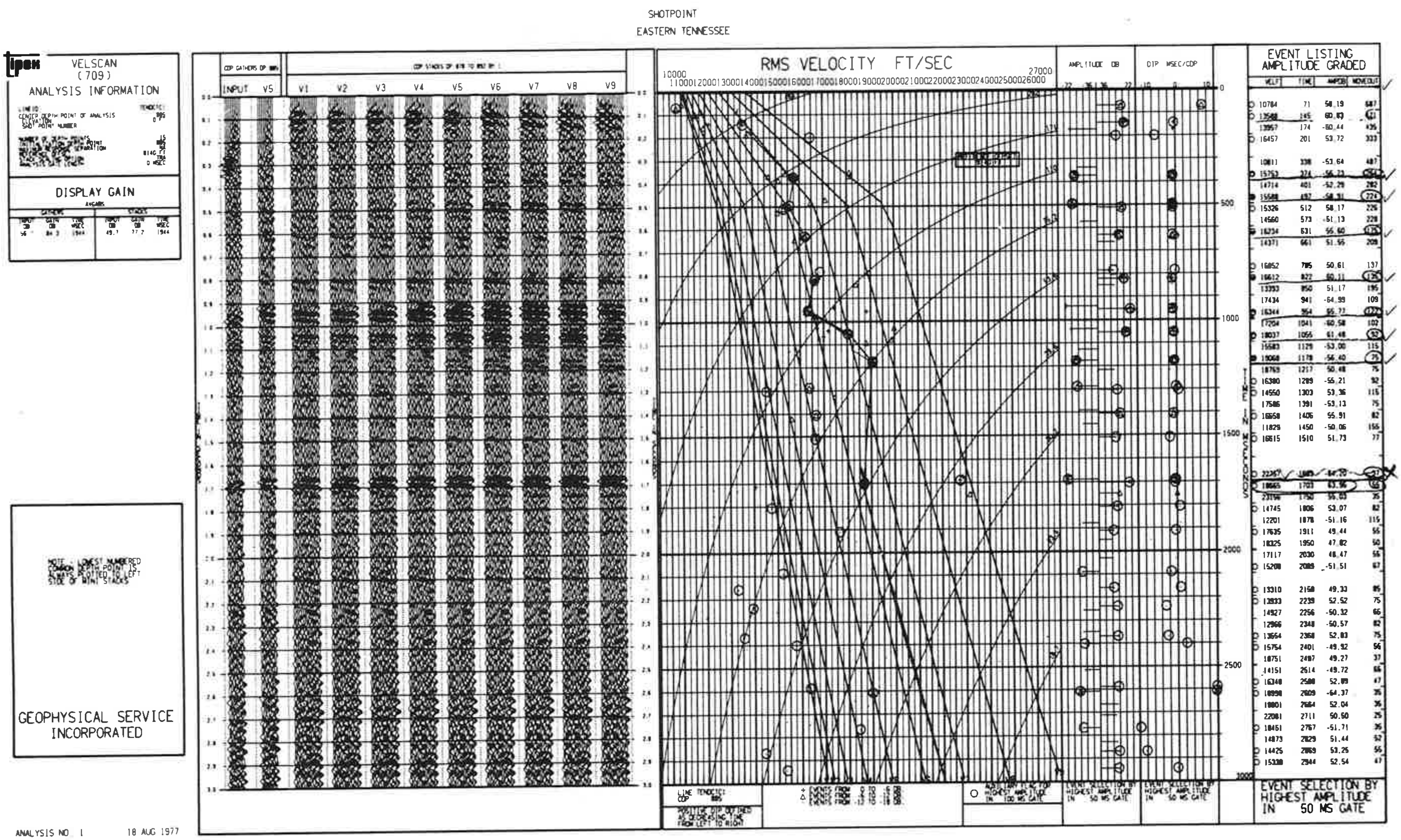
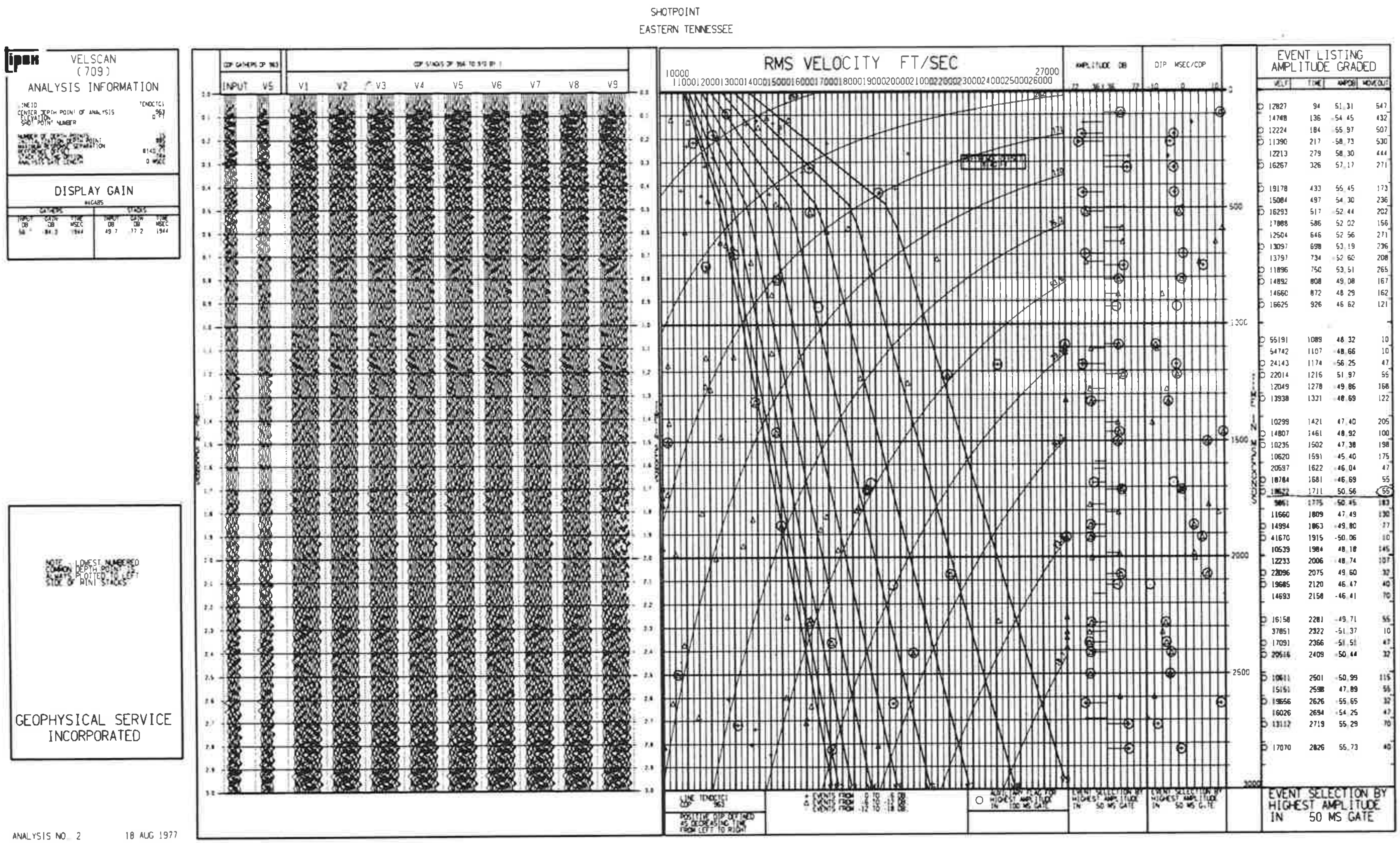


FIGURE 14C
LINE TC-1 VELOCITY ANALYSIS DP 963
SURFACE EXPOSURE OF SALTVILLE FAULT SYSTEM



The velocity data from work cited earlier by Tegland (1973) were prorated into five basic velocity-depth functions shown in Table 2 based on 25 percent changes in carbonate shale ratio. The values of V_L and V_H were used as terminal values on computed velocities. The implication in terms of RMS velocity of these model functions is shown in figure 13 while the associated time-depth functions is given in figure 15. Also shown on figure 15 is a plot of depth of several reflectors as determined from a seismic velocity analysis. The model functions cover the range of the seismic example and should be suitable for providing depth control.

The first step in the model building effort involved projecting all pertinent geologic contacts downward from the surface. Surface dip rates adjusted for the apparent dip orientation of the seismic line were plotted at early record times where available. Angular values were converted to time dips as per figure 16. Since velocity is a variable in this problem, the relationship will vary with depth somewhat. These surface dips were then extended downward and decreased as required to eventually agree with the available reflection data. Thrust planes were extended in this manner also. Downward projection of the surface data was coupled with tentative identification of the reflection sequences at depth. Two basic philosophies were used. One involved identifying a key reflection pattern such as shown in figure 17A and 17B. This is a rather "classic" pattern which can be identified in whole or in part over a large portion of the program. The second approach involved identifying a key marker, generally the base of the Rome at the pre-Rome interface, and estimating thickness upward. Another consistent reflection is associated with the interface between the Maynardville and the Nolichucky shale. Shallower in the section the interface between the Reedsville Shale and Trenton Limestone appears to be a reasonable correlation marker. Unfortunately, the base of the Sevier Shale encountered extensively on TC-2 was not a good reflector although intuitively one would expect it to be.

FIGURE 15
TIME DEPTH RELATIONSHIP FOR MODEL VELOCITIES EXPRESSED IN TERMS OF SHALE/CARBONATE RATIO

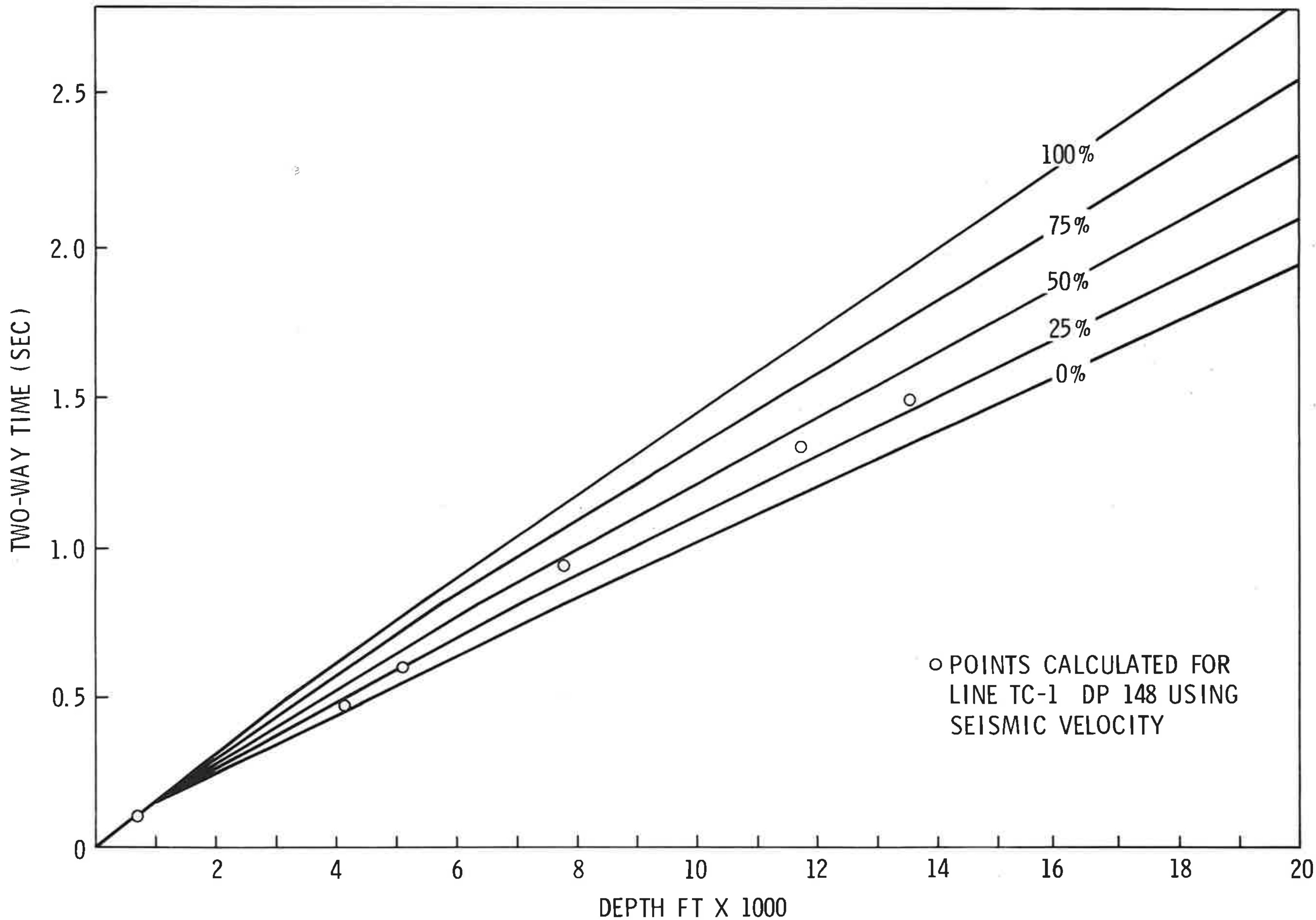


FIGURE 16
NEAR SURFACE DIP CONVERSION DEGREES TO SEISMIC TIME DIP

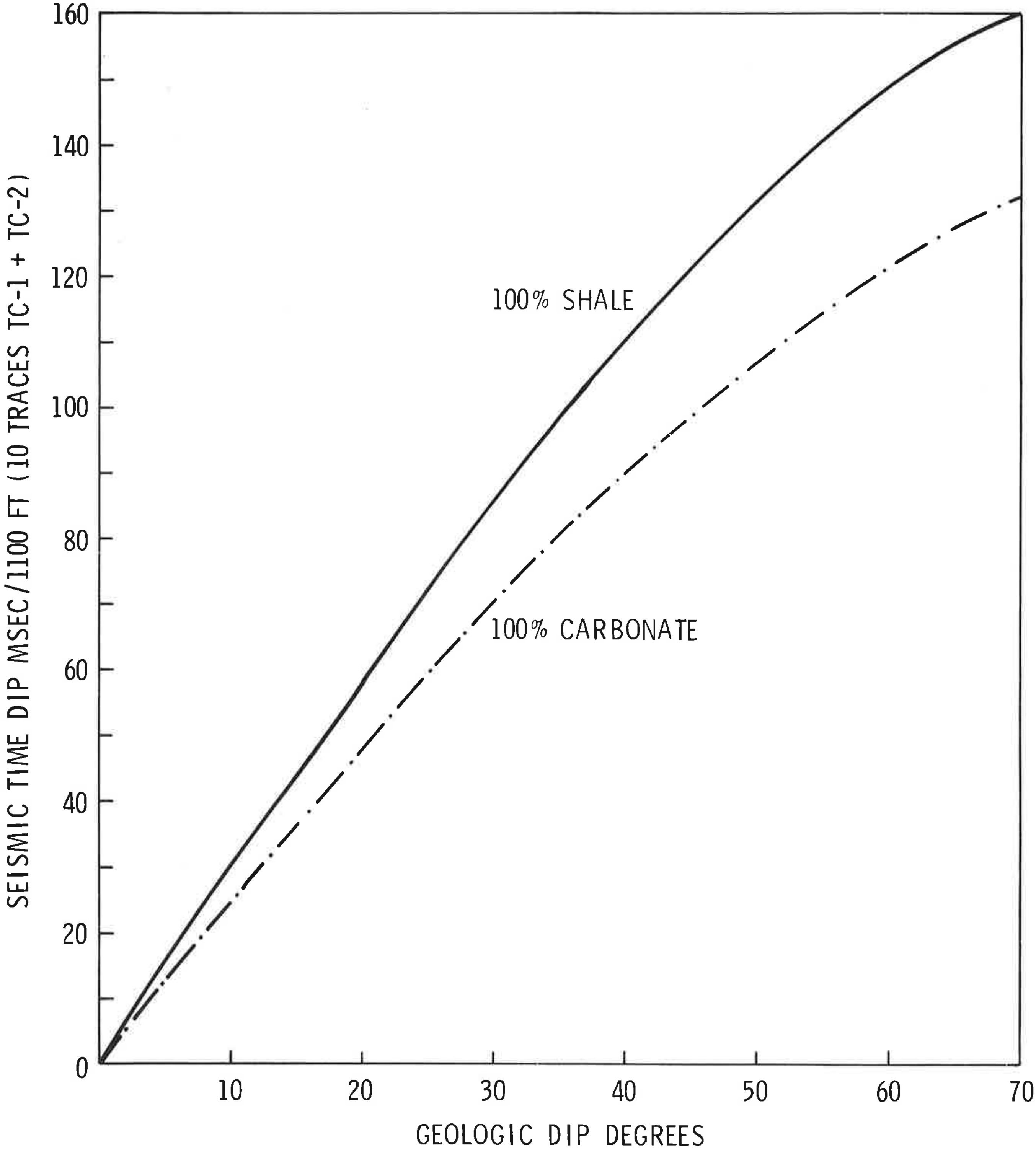


FIGURE 17A
SEISMIC TYPE SECTION LINE K-1 SOUTH
FOOTWALL OF PINE MOUNTAIN THRUST

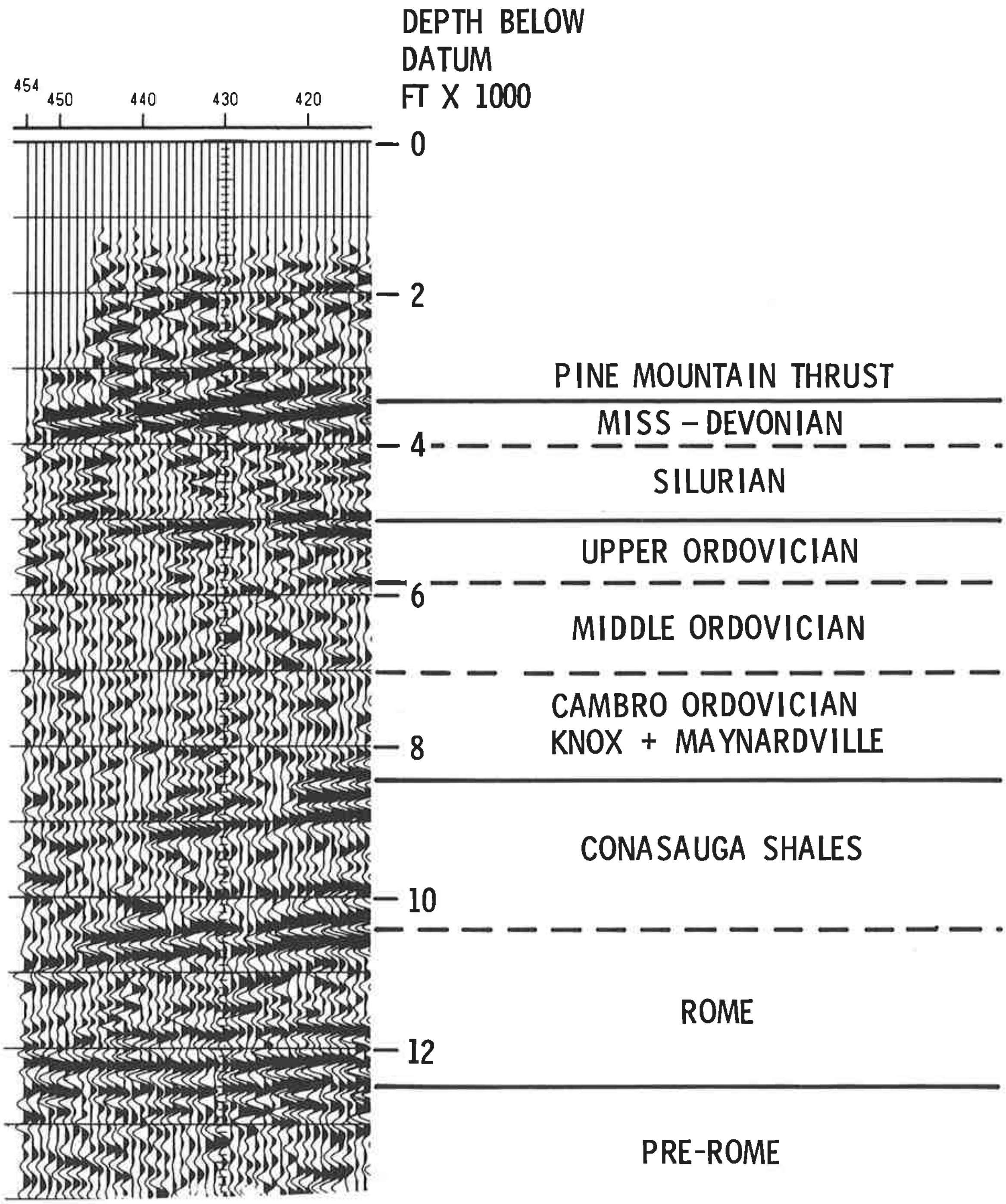
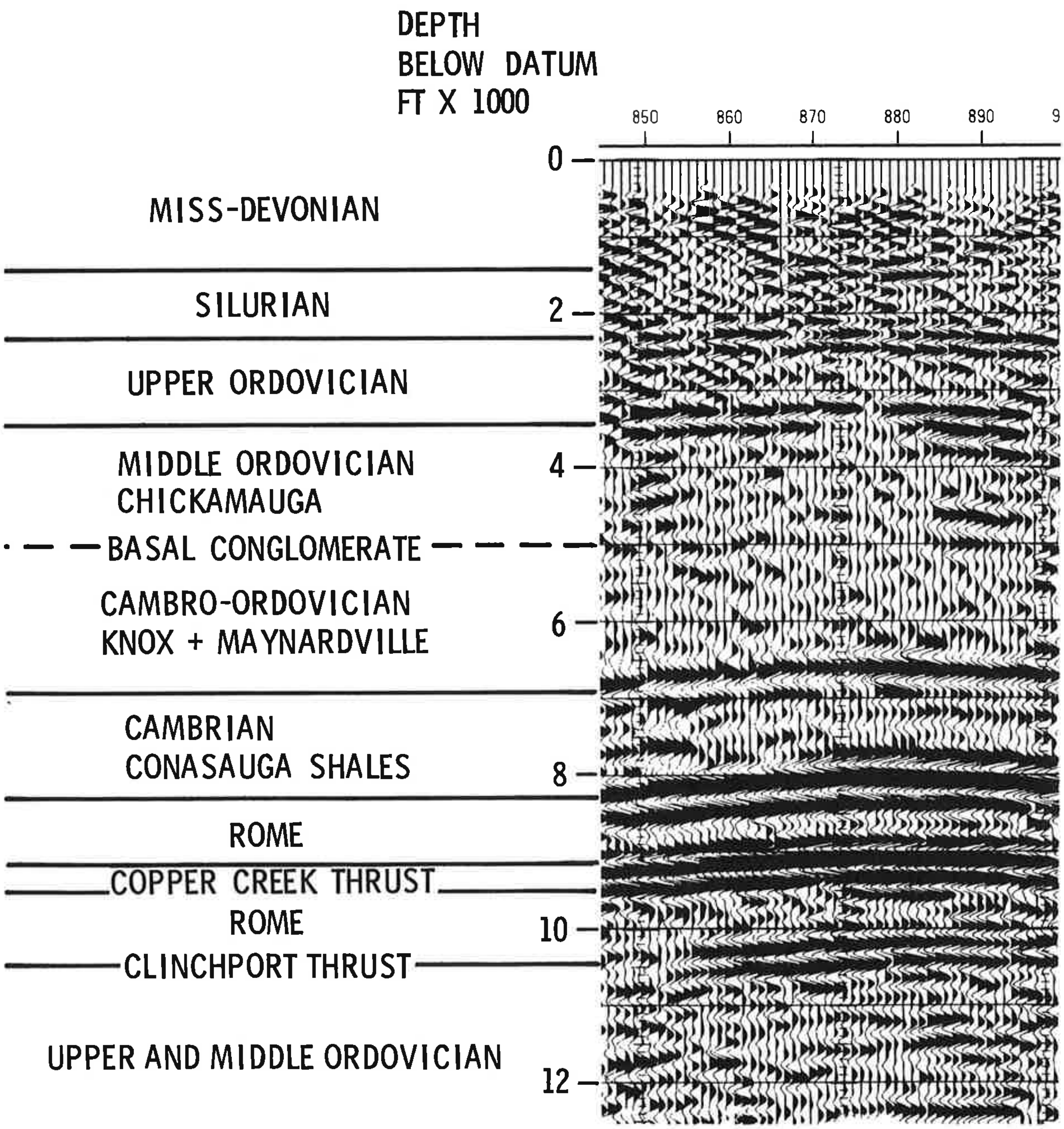


FIGURE 17B
SEISMIC TYPE SECTION LINE TC-1
NEAR CLINCH MOUNTAIN



With identifications of major geologic intervals complete and their approximate time boundaries determined, an estimation of the lime-shale ratio was made using descriptive data associated with the geologic quadrangles and wells mentioned earlier. Values estimated to nearest 25 percent were used to position each interval on one of the model velocity curves shown in figures 13 and 15, and Table 2. Generally from 5 to 10 subintervals existed between datum and the Rome/Pre-Rome interface. Since the depth conversion process used required RMS velocity-time pairs to describe each velocity, the intervals were calculated to that format and resampled to an equal number of time increments (15) over that interval. Depth to the base Rome was computed along each line from the inputs which were defined every 20 depth points (2200 ft) over much of the area and 40-80 depth points where data was poor in the south segment of TC-2. The depth to "base Rome" was plotted and adjustments made to individual velocity points to smooth out unrealistic point-to-point variations. The final resampled RMS velocities are shown in the heading panels of each depth section. Additionally, plots of the basic interval velocity data were made in depth showing the velocity interfaces used and interval velocities assigned. (Plate II series).

The resulting depth sections (Plate III series) were displayed at two scales: 1" = 2000 feet and 1" = 4000 feet with no vertical exaggeration.

Final event identification and interpretation as shown in the Plate III series was done on the larger scale sections and reduced.

Detailed Geologic Evaluation:

The final geologic interpretation followed the same general philosophical concepts of the initial time interpretation used to create the velocity field for depth conversion. Key marker horizons correlated to Early Cambrian and Late Ordovician shales in contact with carbonates, either by virtue of stratigraphic position or due to fault movements, were located at the surface and correlated downward to meet with events identified with these interfaces in the earlier effort (figure 17A, B, C). Some variation did occur in identification between the velocity work and the final interpretation in depth. Cross reference of velocity plates (Plate II) and depth section plates (Plate III) will indicate possible variances. Changes of this sort will affect only local thicknesses.

To further assist in visualizing structural features and identify "apparent" structures caused by changes in line direction (Tegland, 1974), direction vectors relative to "true dip" were posted along the interpreted depth section headings. The reference "true dip" direction was determined by averaging available surface measurements or assuming a strike-dip relationship from the outcrop orientation where no measurements existed. The angular deviation was determined as shown in figure 18. Values were recorded in five degree increments. For qualitative purposes one can consider anything from positive 20 degrees to negative 20 degrees as being dip oriented. Anything from 70 degrees upward in either direction can be considered strike oriented. Between 20 and 70 one should factor his dip judgments downward somewhat. A complete reversal occurs in the direction of TC-2 in BULLS GAP quadrangle, which could cause some very misleading structure. Often it is wise to "fold out" the strike and reversed segments when making the interpretation.

FIGURE 17C
SEISMIC TYPE SECTION LINE TC-2
FOOTWALL OF SALTVILLE THRUST

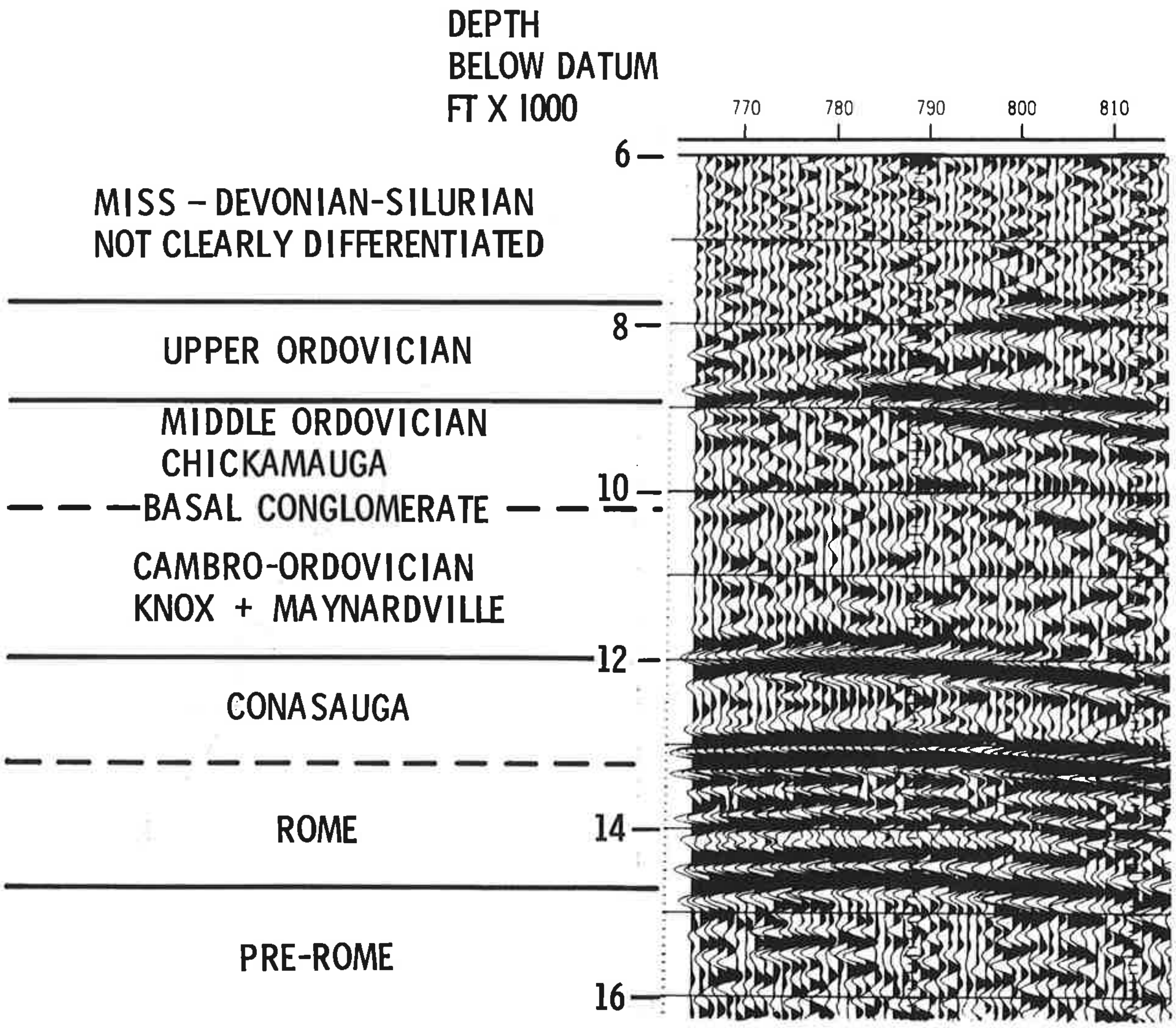
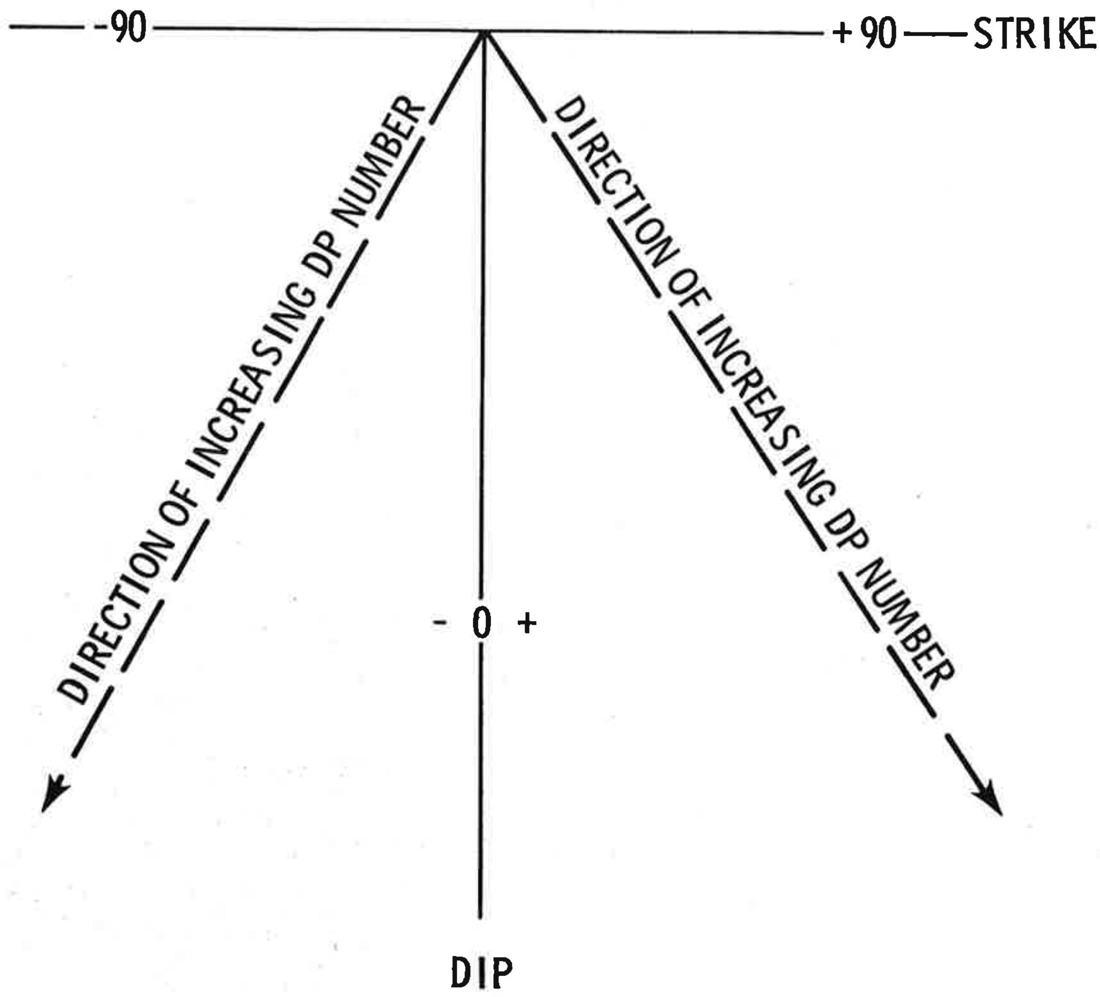


FIGURE 18
DIAGRAM OF SIGN CONVENTION USED TO DETERMINE RELATIVE LINE DIRECTION



Line K-1 South - Middlesboro South (Plates IA, IIIA):

Pine Mountain Thrust Hanging Wall

The major surface feature in this quadrangle is the Powell Valley anticline formed by the partial overturn of the hanging wall unit of the Pine Mountain thrust. The axis of this feature intersects line K-1 South at depth point 305 according to U.S.G.S. GQ 301. However, good shallow reflections are present particularly from depth point 410 (Plate IIIA) which suggest the axis may be more to the southwest (DP 285) than shown by the surface map. The stronger of the northwesterly dipping events is probably the contact between the Maynardville (€mn) and underlying Conasauga Shale (€c). Deeper events with less continuity in this area are no doubt associated with layering within the Conasauga and Rome (see figure 17).

Pine Mountain Thrust Footwall

Of more immediate interest is the possibility of some Devonian shale (Dc) section existing along the plane of the Pine Mountain fault. The type section shown in figure 17A suggests that sufficient space may exist for this to occur. Harris and Zietz (1962) and others indicate evidence that the fault has moved bedding plane wise along the Chattanooga. The strong reflection at the postulated fault plane is probably a complex response created by the relatively thin Hancock sandwiched between two shales, i.e., Chattanooga and Rockwood. One could argue that the upper shale is Rome; however, the reflection in question persists and actually becomes stronger out in front of the overturned section in an area where no Rome is present. The presence of disturbed Cambrian above appears to degrade this event.

A pre-Rome feature with approximately 1000 feet of relief occurs between depth points 360 and 464. This feature persists upward and may, in fact, have been involved in promoting the overturn that created the surface anticline discussed earlier.

K-1 South - Wheeler and Tazewell:

A normal fault of fairly high angle, down-thrown to the northwest, may exist in the vicinity of depth point 280. Displacement on this feature might reach 500 feet. The existence of this fault may explain a local syncline in the younger units. Irregularities to the northwest along all horizons (DP 380-310) are believed to be artifacts of the datum corrections applied.

Along the remainder of this line only fragmentary reflection energy can be found. The loss of signal is probably due to surface or near surface conditions which scatter the seismic signal badly. Some shallow to intermediate structure might contribute to the problem although surface dips are relatively small (10-15 degrees).

TC-1 - Tazewell and Howard Quarter:

General

The major surface features in this area are the surface expressions of the Wallen Valley, Hunter Valley, Clinchport and Copper Creek thrusts. All of these thrusts appear to involve movement at relatively high angles with contact between Cambrian shale section and younger carbonates generally marking the fault plane. These major faults were projected into the section with fair confidence.

Pine Mountain Thrust Footwall

The detachment point of the Pine Mountain fault occurs vertically beneath depth points 290-320. One can easily detect a segment of the Cambrian reflection sequence which suddenly dips upward from the 13,000 to 14,000 foot depth range at that point. This dip can be linearly extrapolated upward to a dipping segment under depth points 120-150 at 6000 feet. From that point one must extrapolate to the first positive event on K-1 South (depth point 230).

If Chattanooga exists at the fault contact, it will probably not exist southeast of depth point 140 and will be approximately 5800 feet below datum (-4500 feet sub-sea) near depth 101. The area from depth point 101 to 170 is a positive pre-Rome feature which shows approximately 1000 feet of relief above the decouple point of the Pine Mountain thrust. Harris and Zietz (1962) suggest this feature as the triggering mechanism which deflected the fault upward. This author feels there may be a high angle normal fault in the pre-Rome in the zone between depth points 180 and 250 which gives rise to the basement high.

Wallen Valley Thrust Hanging Wall

Dips on the seismic section indicate that an overturned section of the Cambrian may exist at 3000-4000 feet depth between depth points 240-300. The southeasterly dipping limb (depth points 300-330) definitely exhibits Cambrian reflection characteristics easily extrapolated into certain Cambrian at depth points 390-420 (depth 5000-6000). This overturn may be caused by a secondary fault associated with the main Wallen Valley thrust.

Wallen Valley Thrust Footwall - Hunter Valley Fault

The postulated footwall section of the Wallen Valley fault in the vicinity of depth points 370-460, and depth 7500-15,000 feet appears to have a reasonably complete sequence from Silurian to pre-Rome. The hanging wall sequence appears to be greatly foreshortened due to activity of the Hunter Valley thrust. The "good" reflection at 4000 feet depth in this area is postulated as associated with basal Chickamauga.

The hanging wall section of the Hunter Valley fault cannot be readily established until one picks up the nearly strike area from depth points 380-420. Here an event at 2500 feet seems to identify with the thrusts.

Clinchport - Copper Creek Thrusts

The Clinchport thrust seems to align with a series of dipping segments which join the projected Hunter Valley plane at 3000 feet below depth point 480. The plane of fault movement is uncertain with movement possible along two planes which join at 8500 feet below depth point 600. Movement along both planes lies within postulated Cambrian clastic section. The first positive marker is the interface between the Maynardville and the Conasauga Shale. A wedge of Cambro-Ordovician section then forms the footwall of the Copper Creek thrust above this marker. No identifiable reflections occur in this wedge until one is within 1000 feet of the projected fault plane. Some weak but consistent events roughly paralleling the fault exist in the upper 1000 feet of the footwall which are believed associated with the Copper Creek fault belt sequence (Geologic Map Howard Quarter GQ-842).

TC-1 - Avondale, Bean Station, and Morristown:

Copper Creek Hanging Wall - Saltville Footwall

The hanging wall sequence of the Copper Creek fault appears to be complete from Mississippian (Grainger) through Conasauga (figure 17B). Time removed by datum corrections for the portion of line across Clinch Mountain in all probability removed the Silurian outcrop leaving the Upper Ordovician as the effective surface material from depth points 740-790. A fair high frequency reflection appears to mark the base of the projected

Chattanooga at 1500 feet between depth points 860 and 940. The base Silurian appears to be a good reflector for a slightly greater distance along the footwall of the postulated Saltville fault. Using the Silurian thickness (figure 17B) and extrapolating upward suggests that the Saltville may be moving along the Chattanooga in much the same manner as the Pine Mountain fault. It is postulated that this fault decouples in the Conasauga at a depth of approximately 14,000 feet near depth point 1465. Sharp up-dip of the top Conasauga event occurs at that point. Unfortunately, this sudden dip change cannot be readily extrapolated. However, it is estimated that the fault achieves lower dip rates, possibly coincident with the Chattanooga, in the vicinity of depth point 1260.

The Ordovician-Cambrian sequence in Copper Creek hanging wall down to the strong event marking the Copper Creek fault plane appears normal through depth point 1190. From that point to 1270 only weak returns are visible. The reflection sequence returns again to south of 1270, however, the depth position has altered in such a manner that one might postulate a down to the north normal fault. This leaves some doubt concerning the decoupling point of the Copper Creek fault. Possibly the basement movement post dates the Copper Creek fault activity which is suggested by the reflection correlation across the weak zone. Other possibilities are that the weak zone is strike oriented, which is completely opposed to the surface information, or that the segment south of 1270 represents another thrust plane which is also hard to explain with the current data.

Saltville Hanging Wall

All aspects of the hanging wall section of the Saltville fault are questionable. One can detect evidence of events dipping upward toward the imbrications in the vicinity of depth points 1040-1050. There is also some evidence of the syncline near 1150 and the anticline suggested at 1190 by the surface maps, but more likely at 1225, as seen on the reflection data. This anticline and syncline are believed to be the result of shallow folding in the Cambrian along a thrust which seems to be nearly flat at around 3500 feet in the vicinity of depth points 1360-1450. The small faults at 1270 are thought to be secondary breaks from this main zone. A major break upward from this shallow system occurs below depth points 1480-1510 where the plane sharply deflects upward from 5000 feet with a continuation to the surface at depth point 1460. There is fair evidence for this fault system in the seismic data.

It is postulated that the normal sedimentary section including Silurian and Mississippian-Devonian might exist below the shallow fault at depth points 1450-1550. The projected depth to the MISS-DEV section would be nearly 8000 feet. The upturned northern limb of this block is believed to subcrop against the shallow fault system at depths of 3500-5000 feet between depth points 1180-1410. Exact configuration of beds along this subcrop zone is highly speculative.

TC-2 - Kyles Ford, Pressmens Home, Burem and McCloud:

General

The northern area of Line TC-2 exhibits surface exposures of the Hunter Valley, Clinchport, Copper Creek and several small faults. It is believed that the general degradation of data quality seen between depth points 101 and 390 is the result of steep shallow dips and the ray path problems caused by shallow complexity of the sort seen in this area.

A good Cambro-Ordovician reflection sequence occurs at depth points 390-470 in the 7000-12,000 foot depth range. This window of information was used to project the fault planes and basal Knox reflections to the surface. The decoupling point of the Clinchport thrust was inferred from the sudden loss of quality in this sequence.

Wallen Valley Thrust Zone

The Wallen Valley thrust outcrops beyond the north end of Line TC-2, however, it is believed that the plane of this fault lies in the Rome at approximately 9200 feet beneath depth point 101. A sharp upturn deflection of this plane is believed to have occurred at depth point 250 near a depth of 10,500 feet. The decoupling point of this fault appears to be at depth point 545 (depth 14,000). The footwall zone south of depth point 250 indicates probable lower Ordovician about 1000 to 1500 feet thick overlying a complete Cambrian section. There is a pre-Rome high with axis near depth point 320. On the northern flank of this high there is up to 3000 feet of Ordovician below the fault plane, with indications that the fault is associated with Upper Ordovician near the end of the line.

The hanging wall unit of the fault at the extreme north end of the line indicates section which may extend up to the Devonian. The Hunter Valley fault system extends over this area and uncertainty exists regarding shallow identification. The hanging wall thins abruptly to the south and is cut off by the Clinchport thrust at depth point 400.

Clinchport Thrust Hanging Wall

The Clinchport thrust plane appears in this section to decouple from the hanging wall Cambrian section of the Wallen Valley thrust and dip sharply to the surface. A fairly complete section of Cambrian and approximately 2000 feet of Cambro-Ordovician section are preserved in the hanging wall. This section is cut off to the south by the Copper Creek thrust at depth point 570-620.

Copper Creek Thrust Hanging Wall

The Copper Creek fault plane on line TC-2 decouples and ramps to the surface much more abruptly than on line TC-1. A zone of possible high angle normal faulting involving the Cambrian exists in the vicinity of the decoupling point (depth points 710-730). There is evidence of these postulated faults in the Upper Ordovician and they may have influenced the configuration of the shallow syncline.

The shallow syncline (depth points 540-750) is not defined by any reflection evidence, however, this author believes the folded MISS-DEV section exposed at the surface, will be underlain in part by normal MISS-DEVONIAN section in the area from depth points 540-760. The author believes the surface section has been moved into its current position from some distance to the east by action of the Saltville fault system.

One can extrapolate the Upper Ordovician outcrops into the section quite readily and tie them into the type seismic section (figure 17C) at depth point 770. Additional normal faulting takes place at depth point 830 and possibly 940. If one extrapolates a "normal" section from Cambrian through MISS-DEVONIAN, it fits into short reflection segments quite well through depth point 1170 where one encounters a very obvious fault plane ramp.

Saltville and Associated Fault Systems

There appear to be two possible fault planes. One, the Saltville fault surfaces with a number of imbrications between depth point 760 and 880 limiting the surface exposure of MISS-DEVONIAN. This plane appears to move in the Cambrian shales and involve only Cambrian section. It appears to decouple in the area between depth points 1400-1510. The thickened zone between 1290 and 1400 above the normal Cambrian section is believed to be an erosional remnant of the Ordovician. The movement of this plane may follow an earlier erosional surface giving rise to the undulations.

The second thrust which has been named the "990" thrust appears to decouple from the Cambrian at depth point 1590. The deep seated feature in the Cambrian appears to be the truncation of an earlier overturned feature with a possible doubling of the Cambrian section at depth.

The hanging wall section of the "990" fault is believed to exhibit a reasonably complete section of Cambrian and some Lower Ordovician. This is postulated on outcrops between depth points 990 and 1130 and by upward section measurement from the "type" reflection interpreted as the top of the Conasauga shales.

Line TC-2 - McCloud, Mosheim and Greeneville:

Mosheim Anticline

The surface features in this area are largely covered by the Sevier Shale of Middle Ordovician age which is reported to obtain thickness up to 7000 feet by Swingle et al (1966). The Mosheim anticline is encountered at depth points 1884 to 1944 with exposure of Lower Ordovician carbonates. The shallow seismic section shows little interpretable information through this zone although the contact between the Sevier and underlying carbonates should be a potentially good reflector.

At depth below the Mosheim anticline there appears to be a buried thrust which decouples at the base of the Rome at depth point 1990 and ramps upward sharply to depth point 1880. The thrust then appears to have a rather low dip as evidenced by sporadic high amplitude events up to depth point 1600 where its identity is lost. A definite angular unconformity between the suggested fault plane and the events interpreted as the top of the Conasauga Shale occurs at a depth of 10,000-11,000 feet in the area of depth points 1600-1650.

In short, this author believes that the surface anticline is the expression of a buried overturned block of Cambrian and Lower Ordovician section.

Deep Seated Features

Additional buried thrusts of similar nature can be postulated on somewhat less information to the south. A potential unconformity appears in the 8000-11,000 feet depth range beneath depth points 1950-2110. Here steep dips to the south associated with the ramp upward of the fault just mentioned encounter some short lower relief segments to the south. Short, high energy, steep dip events between depth points 2170-2190 may indicate the upward ramping of still another thrust. These steep events can be extrapolated southward to coincide with the dip fragments marking the south flank of a pre-Rome high in the vicinity of depth point 2260.

The stratigraphic section involved in each of these buried blocks can at best only be guessed at, but must in total account for 7,000-10,000 feet of section. The anticline of Lower Ordovician strata exposed at Mosheim is believed to be the hanging wall of the proposed thrust decoupling at 2260.

Line TC-2 - Greeneville, Davey Crockett Lake, Hot Springs:

The principal surface features in this area are the PULASKI fault outcrop and associated surface anomalies from depth point 2160-2370 and several widely spaced thrusts to the south. The line encounters Precambrian Ocoee near depth point 2825.

The Cambrian exposures are dominated by carbonates throughout this area in the form of Honaker and Conococheague, which may account for the general lack of organized signal in the shallow sections. Some thin exposures of Nolinchucky do exist but are probably not thick enough to provide a clear reflection pattern.

There is a very weak moderately dipping energy pattern extending from the Pulaski exposure to a visible reflection sequence at 15,000 foot depth in the vicinity of depth point 2730. It is proposed that movement along this plane or one 3000-4000 feet deeper has resulted in the Pulaski and associated features which are the result of secondary thrusts breaking upward from the main block. The leading edge of this block would then be obscured by the Sevier Shale in the area of depth points 2100-2160. Thrusts as far south as the one at depth point 2370 are believed associated with this movement.

Southern Thrust Features

The thrust at depth point 2505 appears to be associated with dipping events which decouple from an apparent buried overturn at 12,000 feet below depth point 2820.

The thrust at 2576 seems to relate to an almost common root with the fault just mentioned.

Weak reflection evidence suggests that thrusted and folded sequences may overlay the basic Cambrian in this area yielding a total of 23,000 feet of section.

Deep Features

A fair to good quality reflection occurs below 20,000 feet from depth point 2710 to 2996 which is quite similar in most respects to the basal Rome as seen elsewhere. At depth point 2335 this zone suddenly dips upward approximately 3000 feet to depth point 2265. Sporadic good quality events north of 2265 appear to correlate well with the high quality event at 2710. Correlation against the type section in figure 17C suggests that the Rome as seen at 2710 may be very similar, however, no good correlatives to the Conasauga can be seen. This agrees with the anticipated shift to carbonates noted earlier.

LIMITATIONS OF CURRENT WORK AND RECOMMENDATIONS FOR FUTURE WORK

Investigators following up this work should bear in mind that the author has proposed this interpretation with only a rudimentary knowledge of the mechanics of the thrust faulting and a local geologic background largely limited to surface information. No attempt was made due to limitations of time and economics to prepare and study reconstructions of the sections with geologic time. One should also bear in mind that depths and thicknesses as portrayed by the interpreted plates may b somewhat in error due to the velocity assumptions which were made and due to the fact that the data were not migrated. Horizontal placement and apparent dip rates of steep dip features would be materially altered by migration of the data.

Migration of the seismic data can be approached in several ways. However, unless one is working with "true dip" line segments some error will result unless a three-dimensional approach is undertaken. Manual techniques involving wavefront charts or plotting arms may be used to plot time segments picked from the stacked time sections where good reflection quality permits. Unfortunately, some data quality problems are believed associated with three-dimensional effects which can only be solved by migrating the seismic traces themselves. In local areas with significant line bends creating a wide swath of subsurface coverage, future work might involve reprocessing in such a manner as to provide a "grid" of low fold traces suitable for such migration. Where longer stretches of line with only gentle bends exist the approach suggested by Tegland (1974) involving projected segments simulating true dip might be appropriate.

In those areas believed to be disrupted at depth by near surface structural anomalies, i.e., Line TC-2 depth points 101-420, one might give consideration to working with sections containing single fold data with limited offset ranges. By this means it might be possible to determine the nature of ray path distortions which are degrading the final result.

Any new field work undertaken as an extension of this effort should be limited to specific areas of interest and should be accompanied by initial experimental work designed to optimize source arrays, receiver arrays, group intervals, and source signal characteristics. Three-dimensional swath techniques should definitely be considered in planning any such activity.

Future efforts might include gravity and magnetic data and employ computer modeling techniques, such as described by Tegland (1973) and Carlson (1976). Methods of this sort can provide valuable understanding of the pre-Rome surface, and lithology.

Ray trace seismic modeling of some typical fault structures would also be beneficial in understanding and overcoming data quality problems, associated with shallow structural complexity.

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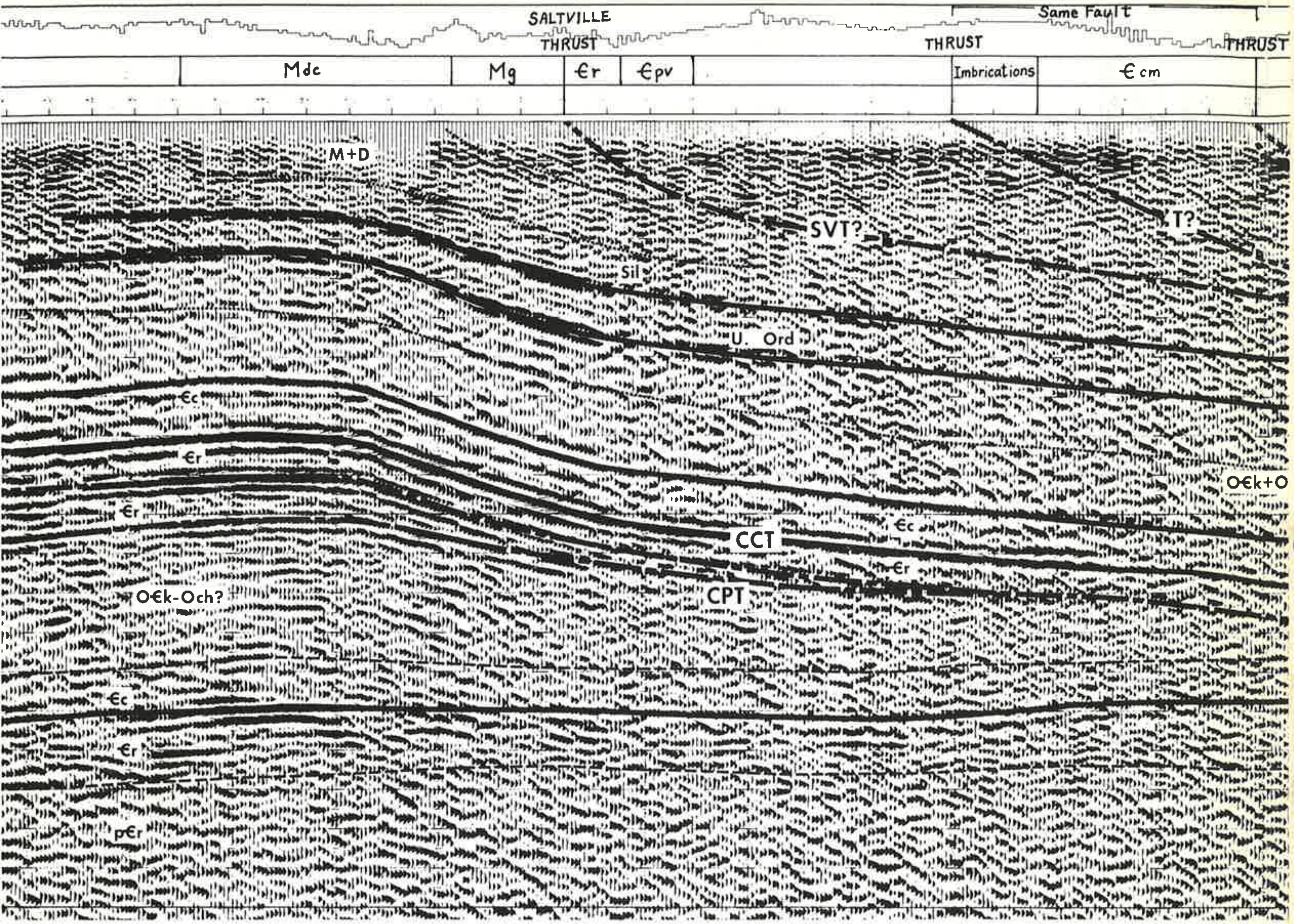
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