DOWCON JR.:
A Method for Determining Near Surface Velocities from First Arrivals

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ABSTRACT

A method for determining the near surface, velocity-depth profile using a first arrival method is investigated. By taking one to six time-offset picks of first arrivals per seismic shot record for between 30 to 50 shots per seismic line, a refraction velocity model is derived with considerably less human and computing effort than with other refraction methods. In one example, an expenditure of appoximatly 5 SUP hours of UNIVAC computer time, 4 hours of human time, and total elapsed time of about a week is required to obtain a reasonable velocity model. Agreement within 5% on two way surface to datum corrections of 100-700 msec is found between this method and the BRC research program DOWCON. DOWCON JR. is tested on two lines -- 82-120-119 in the Wyoming Folded Belt and 83-120-132 in the Snake River Basin.

TABLE OF CONTENTS

INTRODUCTION

A. Overview

As subsurface structure is mapped, a critical consideration in areas of large surface to datum correction is the correction velocity. Serious apparent alteration of subsurface structure on a seismic section can be caused by: (1) an incorrect constant correction velocity coupled with surface topography, or (2) long wavelength changes in the correction velocity if a constant correction velocity is assumed. DOWCON JR. is a technique to determine the long-wavelength component of the near surface velocity profile (≤5000 ft. from the surface) which prevents apparent alteration of subsurface structure. The method is based on a multiple flat layer velocity model and the profile of first arrivals that it generates. An interpretive step is needed to: (1) remove effects of dipping isovelocity lines with respect to the surface of the earth, and (2) post the velocities at the subsurface, not the shot point. The final velocity model is in PREMAC format, able to be used to migrate a seismic section or averaged over time to generate correction velocities to any given datum.

B. Theory

Generation of a DOWCON JR. near surface velocity model involves the synthesis of several assumptions and first order approximations. First, assume that changes in velocity are limited to spatial frequencies that are greater than or equal to a spread length. If this is true, the velocity profile can be viewed as a slowly changing series of velocity profiles as shown in figure 1.

Now, make a temporary assumption that the profile at each shot is that of a sequence of flat layers. This assumption will be relaxed at a later point by either (1) averaging models derived from positive and negative offsets or (2) iterating -- using a first order model derived assuming flat layering to estimate the dip, then using this estimate of the dip to derive a more refined model (see appendix A for more details on the dip iteration scheme).

For a sequence of flat layers which are monotonically increasing in velocity, the first arrivals will appear as a series of connected line segments with gradually increasing offset-time slope (figure 2). The points which connect the lines are referred to as kink points. The slope of the N-th segment will be that of the N-th velocity layer. The thickness of the N-th layer, d_n, is given by the following formula:

$$d_{n-1} = \frac{\left[\frac{X_{n-1}}{2} - \sum_{k=1}^{n-2} d_k \tan\frac{1}{2}\left(i_{k,n}+i_{k,n-1}\right) \right] \times}{\tan\frac{1}{2}\left(\frac{\pi}{2}-i_{n-1,n}\right)}$$

where $\sin i_{j,k} = \dfrac{v_j}{v_k}$

X_n = the offset of the N-th kink point

Applying the above formula to the kink point picks for a series of shot panels along a seismic line results in two sets of stair-case velocity profiles (figure 3) -- one for positive offsets and another for negative offsets. If the velocity profile is not that of flat layers along the line, the down-dip refractions will have a velocity less than that of the refracting layer and the up-dip refractions will have a velocity greater than that of the refracting layer [1.1]. A close approximation to the true velocity of the refractor is the average of the up-dip and down-dip apparent refraction velocities.

METHOD

A. Process

The DOWCON JR. process is divided into five steps which are shown in figure 4. These steps are: (1) preparing of shot panels on the UNIVAC, (2) digitizing the kink points, (3) generating the positive and negative offset velocity models, (4) generating an interpreted model, and (5) gridding the interpreted model to calculate average velocities to a datum, and to create a PREMAC model.

The preparation of the shots consists of three parts. The first is to select 40 to 60 shots from the seismic line. Second, the selected shots are depulsed to remove the reponse of the geophones and the recording instrument. The final preparation consists of a geometric correction that compensates for two things: (1) the burial of the shots, and (2) the posting of the traces at their X-distance, not the distance from the shot. This correction is called the TXTR correction since it attempts to transform the shot panel from the T-X domain to the T-R domain by applying a static shift to the traces. The theory behind this correction and the way it is applied to the data is discussed in appendix B.

Displays of the prepared shots are generated and the kink points of the first arrivals digitized. Accurate kink point picking is not critical (see appendix C). Less than 10% errors in average velocity to a datum are caused by 5% time and offset picking errors. A 5% offset error is 5 stations out of 100, shot end on, and a 5% time error is 50 msec if the first arrival occurs at 1 second for maximum offset.

The kink point picks are used to generate positive and negative offset velocity models. These models are gridded by a depth variant two dimensional smoother to remove random error. This allows the models to be more easily interpreted since the long wavelength velocity trends are not distorted by the short spatial frequency random error. The details and theory of this smoothing are discussed in appendix D.

Compensation for two separate distortions of the positive and negative models must be made in the interpretation step. The first is the placement of the deeper velocity points. Direct arrivals and shallow velocity layers are sensed by the short offset portion of the shot. This causes greater resolution of the shallow velocity layers since the refracted ray travels over a smaller area, accurately placing the velocity near the shot. Deeper refractions are sensed at the longer offsets. This conversely leads to lower resolution. The velocity layer should not be placed at the shot. It should be placed at the point where the refracted wave starts to travel along the top of the layer. Since all velocities for a shot are placed at the shot, the deeper layers should be moved to a point midway between the shot and maximum offset. (A less interpretive way of making this correction is outlined in appendix A.) To remain consistent with the degrading resolution, the width of the two-dimensional smoother applied to the positive and negative models should be increased with increasing depth. The width of the smoother should be about a spread length at the depth of the last layer.

The second distortion that must be compensated for in the interpretation step is that of dipping refractors. As alluded to in the section on theory, a method for compensating for the dip is to simply average the positive and negative models. This is equivalent to placing the contour line of a particular velocity for the interpreted model half way between the contour lines of that velocity from the positive and negative models. Once enough contours are drawn for the interpreted model to sufficiently capture the essence of the model, the contours are digitized so that the interpreted model can be processed by the second phase of DOWCON JR.

The processing done by DOWCON JR. Phase II consists of (1) gridding the digitized contours of the interpreted model, (2) integrating this model to produce average velocities to a datum, and (3) using the gridded model to generate a PREMAC format velocity model that can be used to migrate, to generate APLICON color plots, and to generate average velocities to a datum [2.1].

B. <u>Time Required</u>

Both the computer time and man hours required to generate a DOWCON JR. near surface velocity model are very limited. To do the preparation of the shots before picking kink points, between 2 to 8 UNIVAC SUP hours are required. Appoximately one hour of professional time is needed to pick the kink points and form the interpreted model. An additional 3 hours is needed to digitize and generate graphs of the velocity models. The total elapsed clock time between the start and the end of the process averages one week. In a rush situation, the model can be generated in less than three days.

C. Integration into Processing

The picking of kink points and the generation of a DOWCON JR. velocity model can easily be integrated into routine seismic processing between phase I and phase II. This leads to better correction velocities, and easier DORSUE [2.2] picking of first arrivals. Figure 5 presents a block diagram showing the integrated processing. As a routine part of Phase I processing, the selected shot displays are generated. Before Phase II starts, a DOWCON JR. velocity model is generated, and correction velocites to the datum are obtained. These correction velocities are used in Phase II to update the preliminary corrections. The raw kink points can be used to derive a static shifts which will coarsely align the first arrivals. These static shifts can then be refined using DORSUE. The refined picks can be used for one of three things: (1) aligned space filtering [2.3,2.4], (2) refraction statics, and (3) generation of a DOWCON model [2.5,2.6].

APPLICATION

DOWCON JR. has been applied to two lines and the resulting velocity models compared to the velocity model generated by the BRC program DOWCON. DOWCON is a program which downward continues refraction rays obtaining an estimate of the near surface velocities.

A. Line 82-120-119 (Wyoming Folded Belt)

Line 82-120-119 is located in the Northern Wyoming Folded Belt (see figure 6). It crosses two major thrust faults -- the Darby and the Prospect faults (see figure 7). The surface elevations range from 6,500 to 10,500 ft. above sea level. The processing datum chosen is 6100 ft. The station spacing is 150 ft and the maximum offset is 36,000 ft.

Sixty shots are selected, and their kink points picked. The positive and negative offset velocity models are shown in figure 8. Both the dip effect and misplacement of deep velocities are evident in these models. The slow velocity areas in the near surface are offset 15 to 20 stations to the right on the positive model from where they appear on the negative model. Also, the pod of fast velocity located between station 700 and 1000 at a depth below 2000 ft. is offset almost 200 stations to the left on the positive model from where it is located on the negative model. Both of the above velocity differences between the positive and negative offset velocity models is what is expected from the dip effect and velocity posting error, respectively. The interpreted model which removes both of these effects is shown in figure 9.

The DOWCON velocity model is compared to the DOWCON JR. model (figures 10 to 12) by examining the average velocity to the 6100 ft. datum and the corresponding time correction. Both the time correction and the correction velocity have an average percentage error of 5%. The average percentage error of velocity is reduced to 2.5% when only the long spatial wavelength (greater than a cable length) portion of the velocity models are compared.

B. Line 83-120-132 (Snake River Basin)

Line 83-120-132 is characterized by small elevation changes about a linear trend which drops 2000 ft. along the line. The datum chosen for this line is 1300 ft below the average of the surface elevations with the linear trend removed. This datum is chosen because above this level an undulating water table 200 ft. below the surface marks a velocity contrast of 3,000 to 12,000 ft/sec. The velocity is a constant 14,000 ft/sec below the datum . The station spacing is 75 ft. and the maximum offset is 18,000 ft.

Plots comparing average velocity and time to the datum appear in figures 13 to 15. The average percentage error of both the average velocity and time is 8.2%. The average percentage error is reduced to 5.3% when the long wavelength component of the average velocities are compared.

CONCLUSIONS

DOWCON JR. and DOWCON agree within 2% to 5% of the average velocity's long wavelength component. In contrast, the line 82-120-119 DOWCON model took over 250 UNIVAC SUP hours and 250 calendar days to be generated. DOWCON JR. took only 10 UNIVAC SUP hours and 10 calendar days to generate its model -- a ratio of 25 to 1.

In addition to quickly and cheaply giving an estimate of long wavelength, near surface velocities; DOWCON JR. gives, as a by-product, kink point picks that can be refined and used for refraction statics and aligned space filtering.

For areas with long wavelength near surface velocity changes and/or large elevation to datum corrections, DOWCON JR. gives a useful estimate of the near surface velocity with a small expenditure of time and money.

ACKNOWLEDGEMENTS

The author wishes to acknowlege the help of various people who contibuted to the development of DOWCON JR. and the preparation of this report: L. D. Buonasera who provided the inspiration for the process; J. H. Robinson who suggested ways to attack the problem and pointed out possible improvments to the process; S. Lopez-Mora for his expert assistance in generating and manipulating the DOWCON models; J. L. Menold and his staff for the expert preparation of many of the figures for the text and the transparencies for the oral presentation; and Macintosh for its patience and skill in preparing both the text and many of the figures.

FIGURES

13. Plot of unsmoothed average velocity to a -1300 ft. datum for line 83-120-132.

14. Plot of smoothed average velocity to a -1300 ft. datum for line 83-120-132. Smoother length is 200 stations. Average velocities for both Dowcon and Dowcon Jr. are shown.

15. Plot of time from surface to -1300 ft. datum for line 83-120-132. Times for both Dowcon and Dowcon Jr. are shown.

A1. Flow chart of dip correction scheme.

A2. Arithmetic for dipping layered refraction model.

B1. Derivation of the TXTR correction.

B2. Parabolic mound TXTR correction (Model).

B3. TXTR correction for parabolic mound.

C1. Effect of bad kink point picks (Model).

C2. Error in effective velocity at a depth of 1.5*Do due to bad kink point picks.

C3. Model for the study of the effect of sampling a continuous velocity function discretely and then applying a smoother to the discrete model.

C4. Error in Ve from error of estimating Vi = Vo + K*Z model by discrete velocity regimes.

D1. Velocity interpolation scheme.

FOOTNOTES

1.1 Slotnick, M. M., Lessons in Seismic Computing, published by SEG, Tulsa, 1959 (page 103-114).

2.1 Lytle, M. A., Program CVEL, Western Exploration Seismic Techology, Volume 4, No. 2, Shell Western E&P Inc., Houston, June 1984.

2.2 DORSUE, Seismic Production Library Processing Manual, Information Center, Houston.

2.3 Lytle, M. A., Johnson, A.C., Robinson, J. H., Use of First Arrivals in the Wyoming Folded Belt, presented to Shell Geophysical Conference, Houston, Paper No. 60, 1983.

2.4 Howell, J. I., Johnson, A. C., Lytle, M. A., Robbins, C. A., Robinson, J. H., Alignment Techniques for Coherent Noise Removal In Shot Sort and Receiver Sort Domains, presented to Shell Geophysical Conference, Houston, Paper No. 15, 1984.

2.5 Biegert, E. K., Velocity Models from First Arrivals Using the Program DOWCON, Part I-Theory, Techical Progress Reprot, BRC 41-82, Shell E&P Research, Houston, 1982.

2.6 DeMartini, D.C., Lopez-Mora, S., Near Surface Velocity Models from Picked First Arrivals with Program DOWCON, Presented to 1983 Shell Geophysical Conference, Houston, Paper No. 40, 1983.

A1.1 Ginzbarg, A. S., Notes on Kriging and BLUEPACK III.

C1.1 Wood, C. A., Seismic Wavefronts and Applications, Shell Oil Co. Training Manual, 1980.

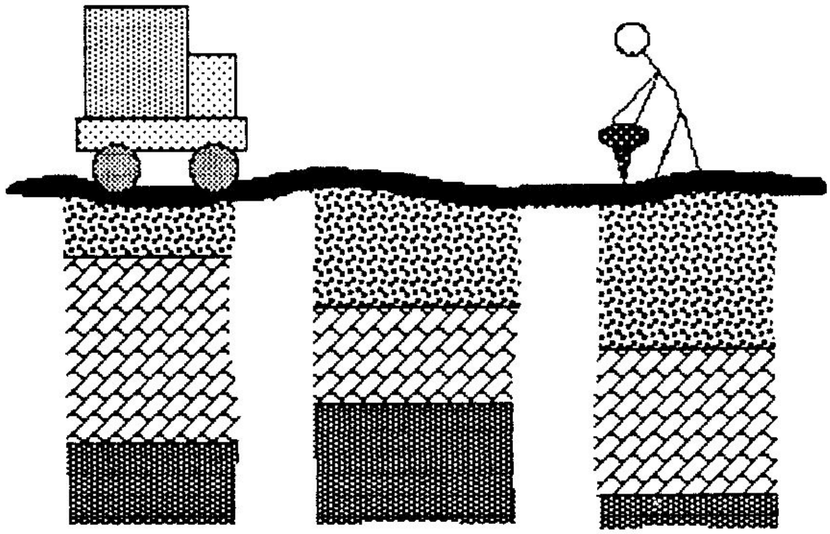

Figure 1. Simulated set of slowly varing velocity models along a seismic line with recording crew.

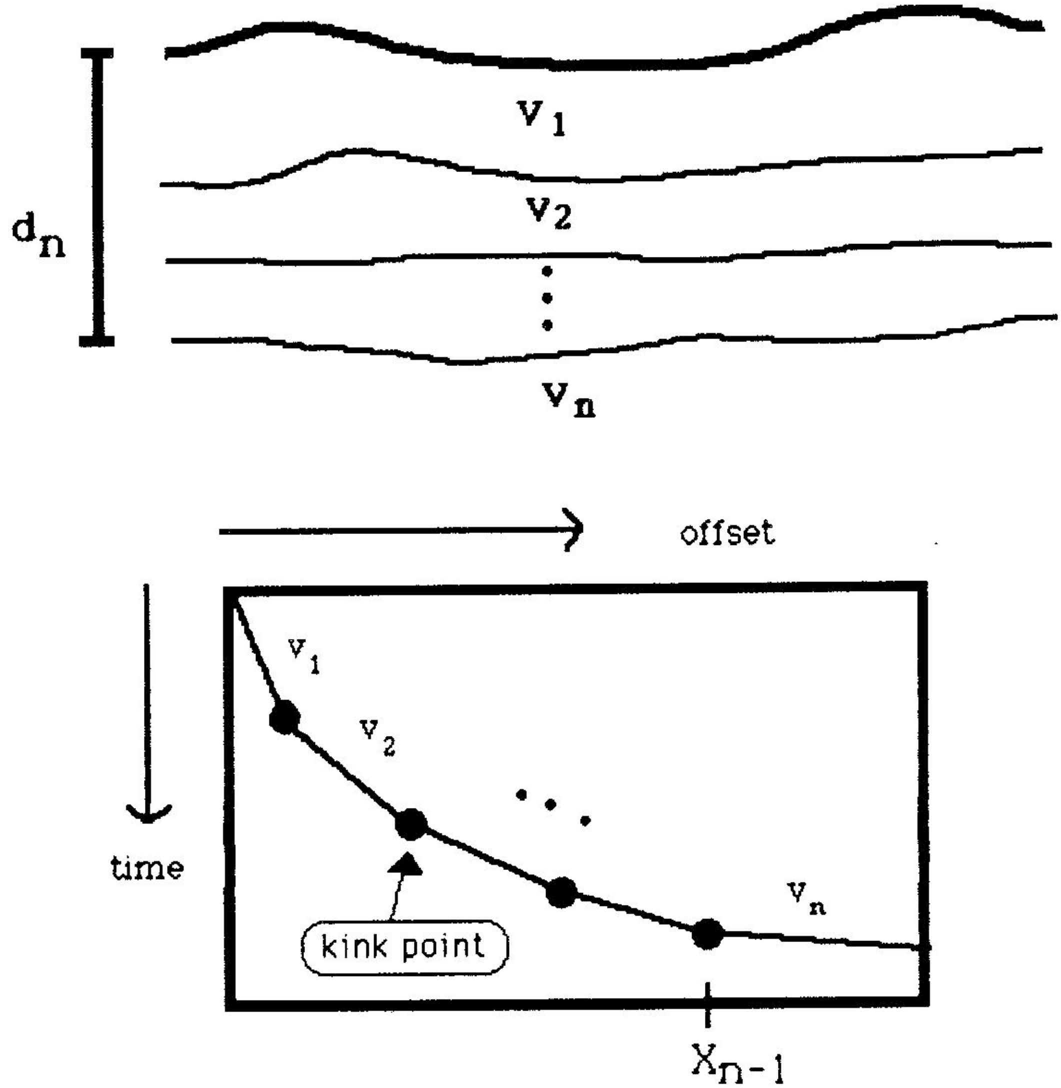

Figure 2. Flat layered refractor model and its corresponding time-offset panel of first arrivals.

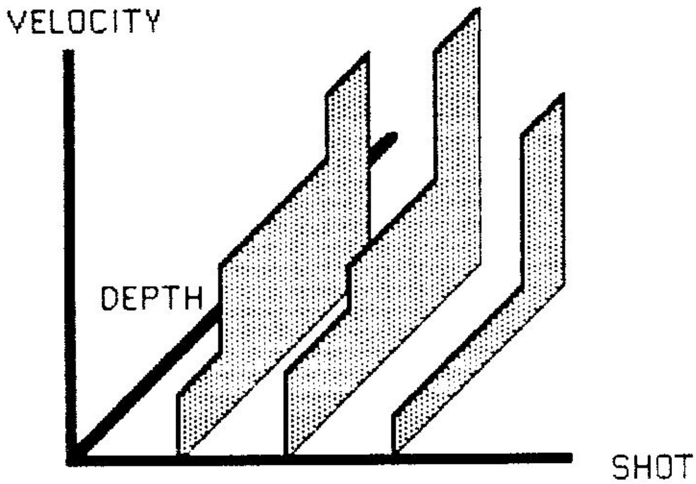

Figure 3. Simulated stair case velocity model for either positive or negative offsets.

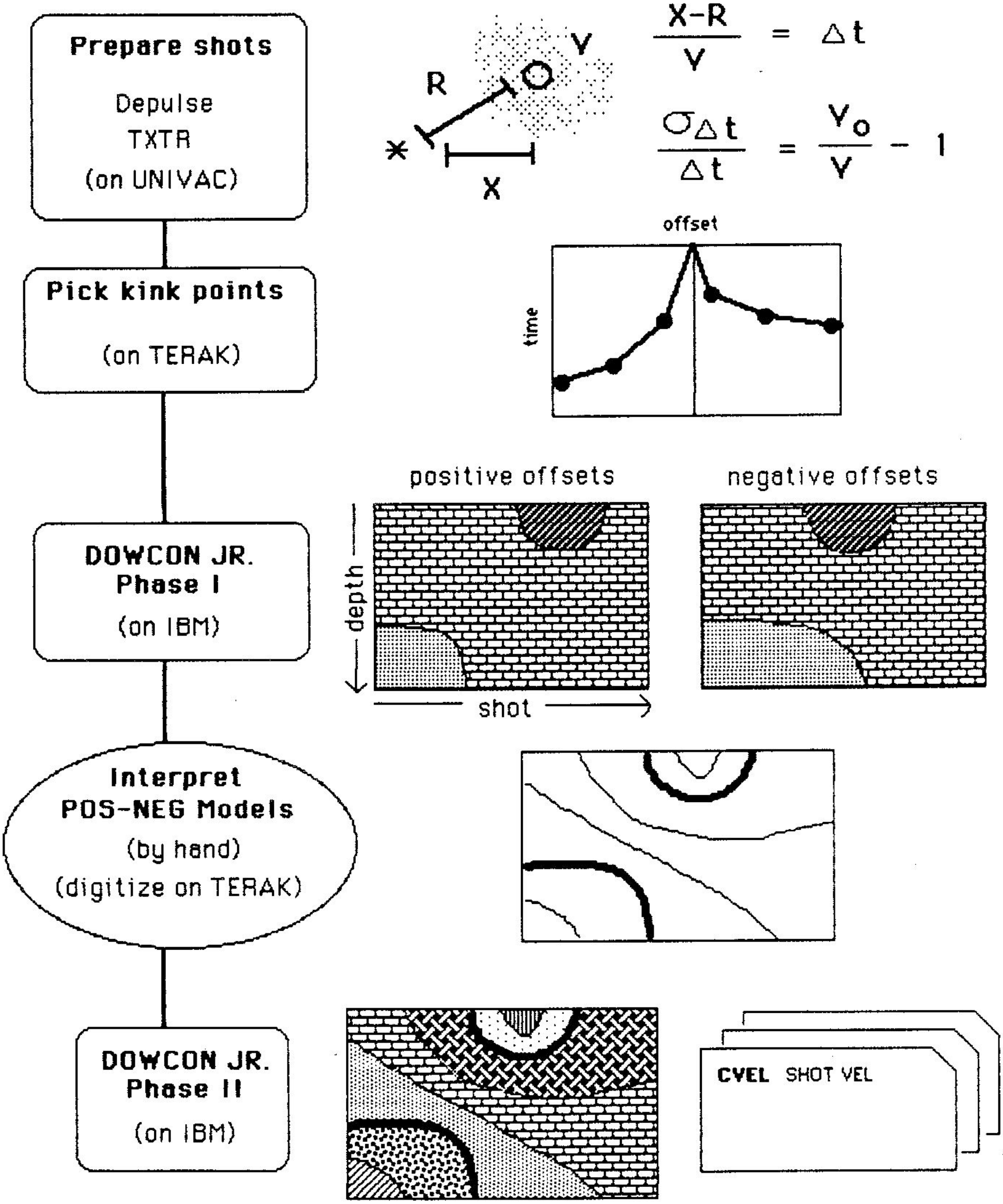

Figure 4. Flow chart of Dowcon Jr. process.

INTEGRATION of DOWCON JR. into PROCESSING

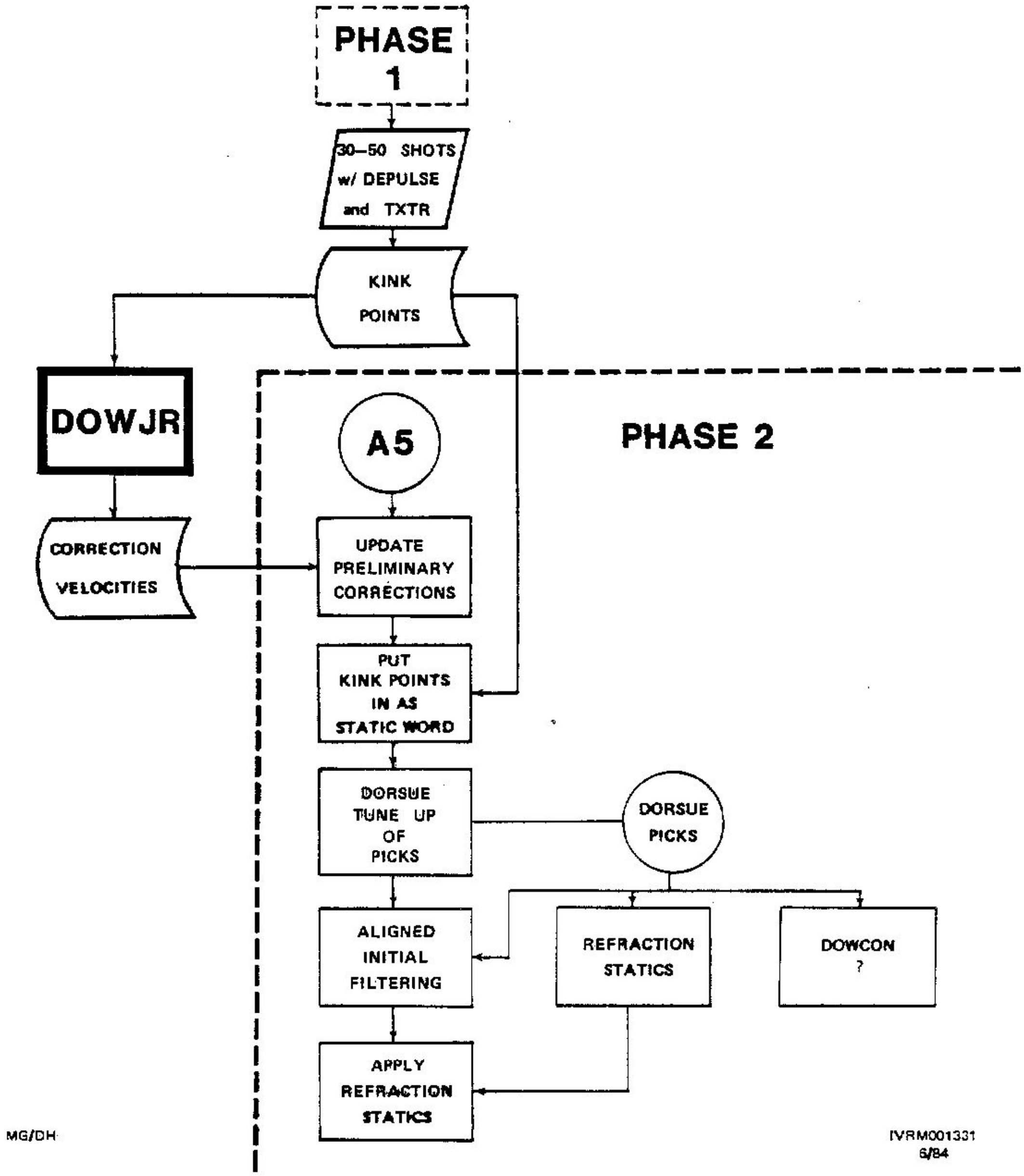

FIGURE 5. Block diagram showing the integration of DOWCON JR into seismic processing.

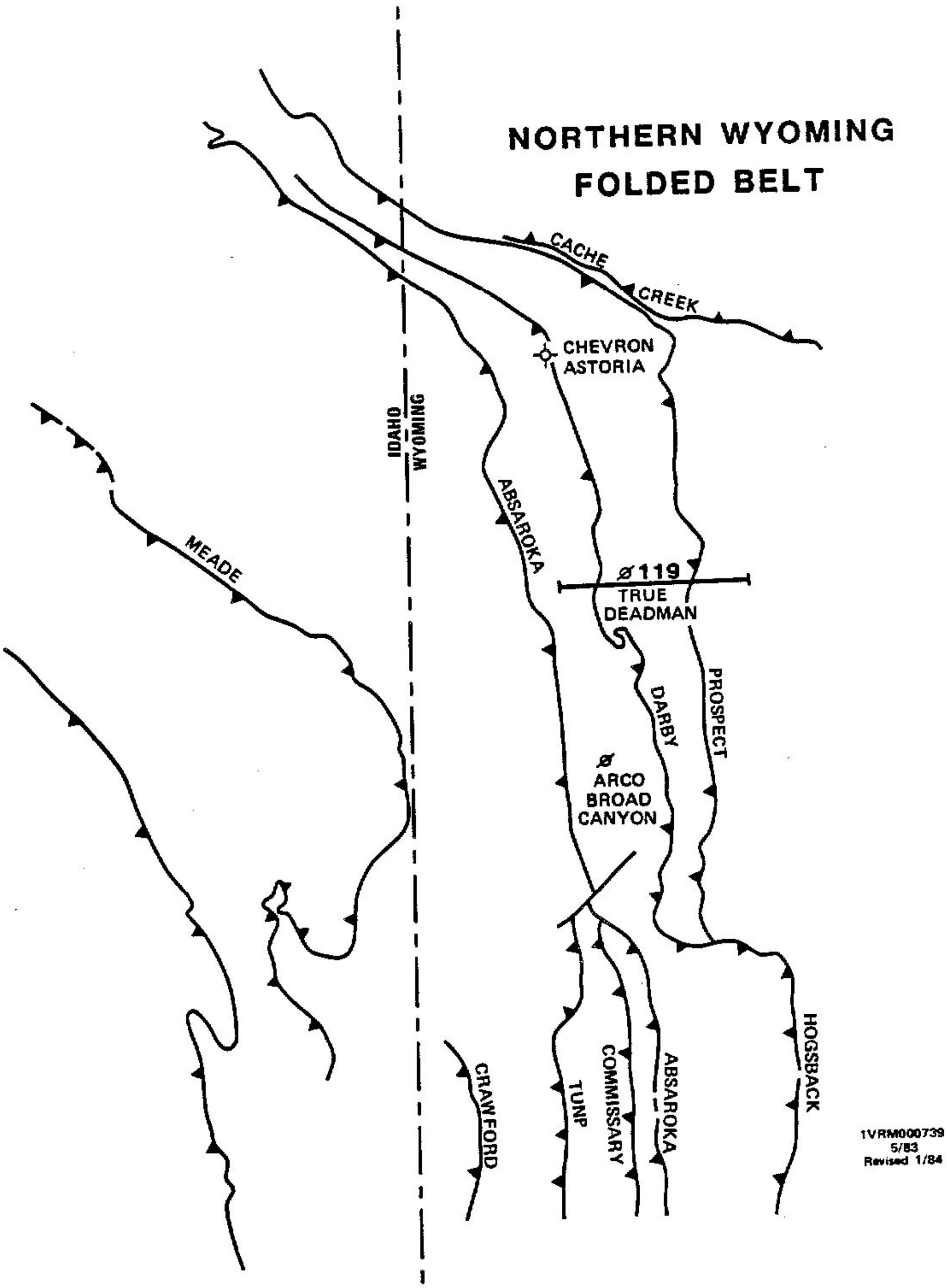

FIGURE 6. Location of Line 82-120-119 in the Northern Wyoming Folded Belt.

LINE 82-120-119

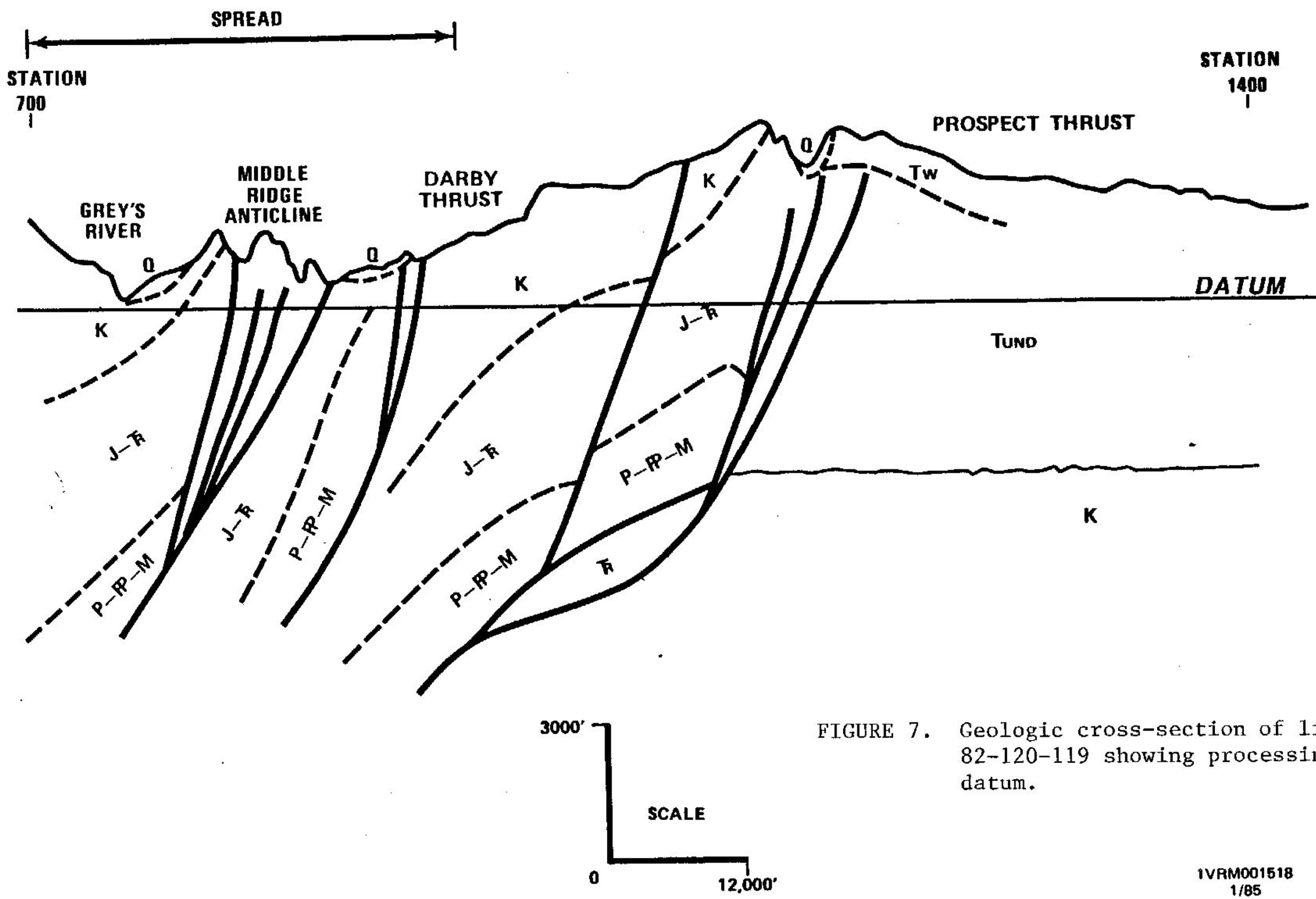

FIGURE 7. Geologic cross-section of line 82-120-119 showing processing datum.

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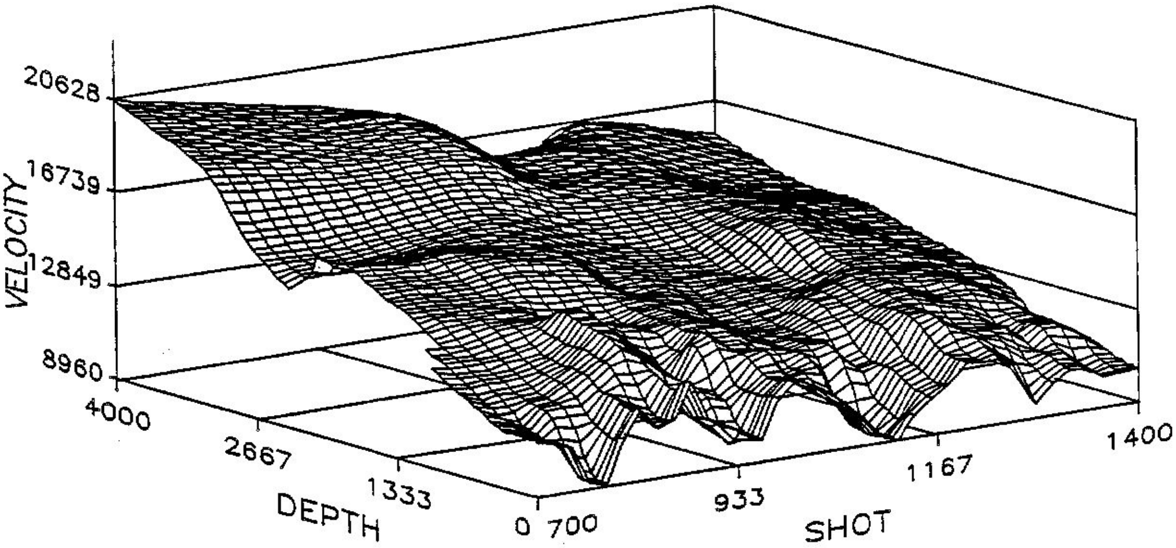
DOWCON JR. NEGATIVE OFFSET MODEL

LINE 82-120-119



DOWCON JR. POSITIVE OFFSET MODEL

LINE 82-120-119

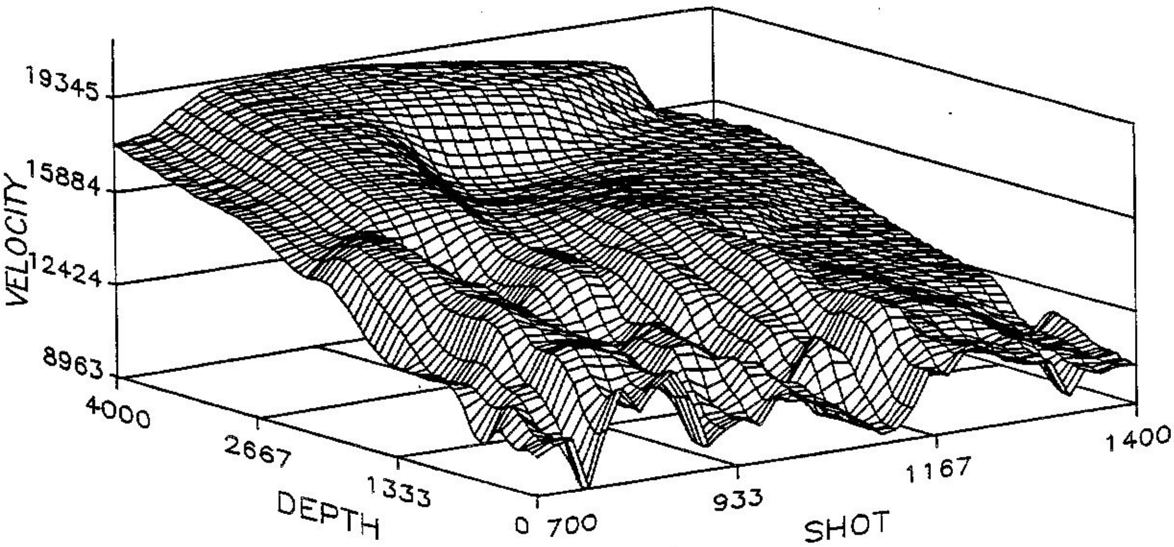


FIGURE 8. Two dimensionally smoothed positive and negative offset velocity models for Line 82-120-119.

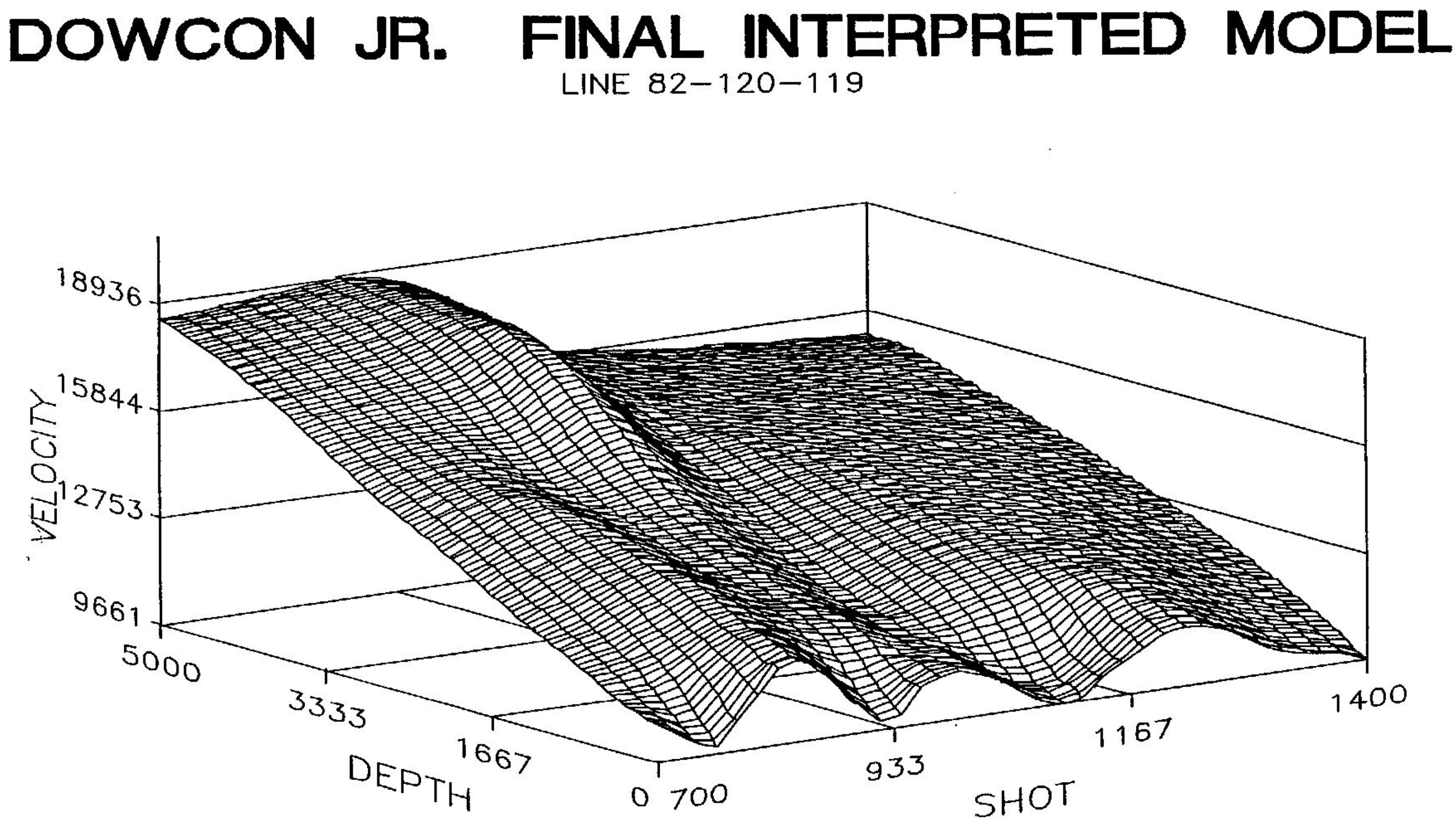


FIGURE 9. Interpreted DOWCON JR velocity model for Line 82-120-119.

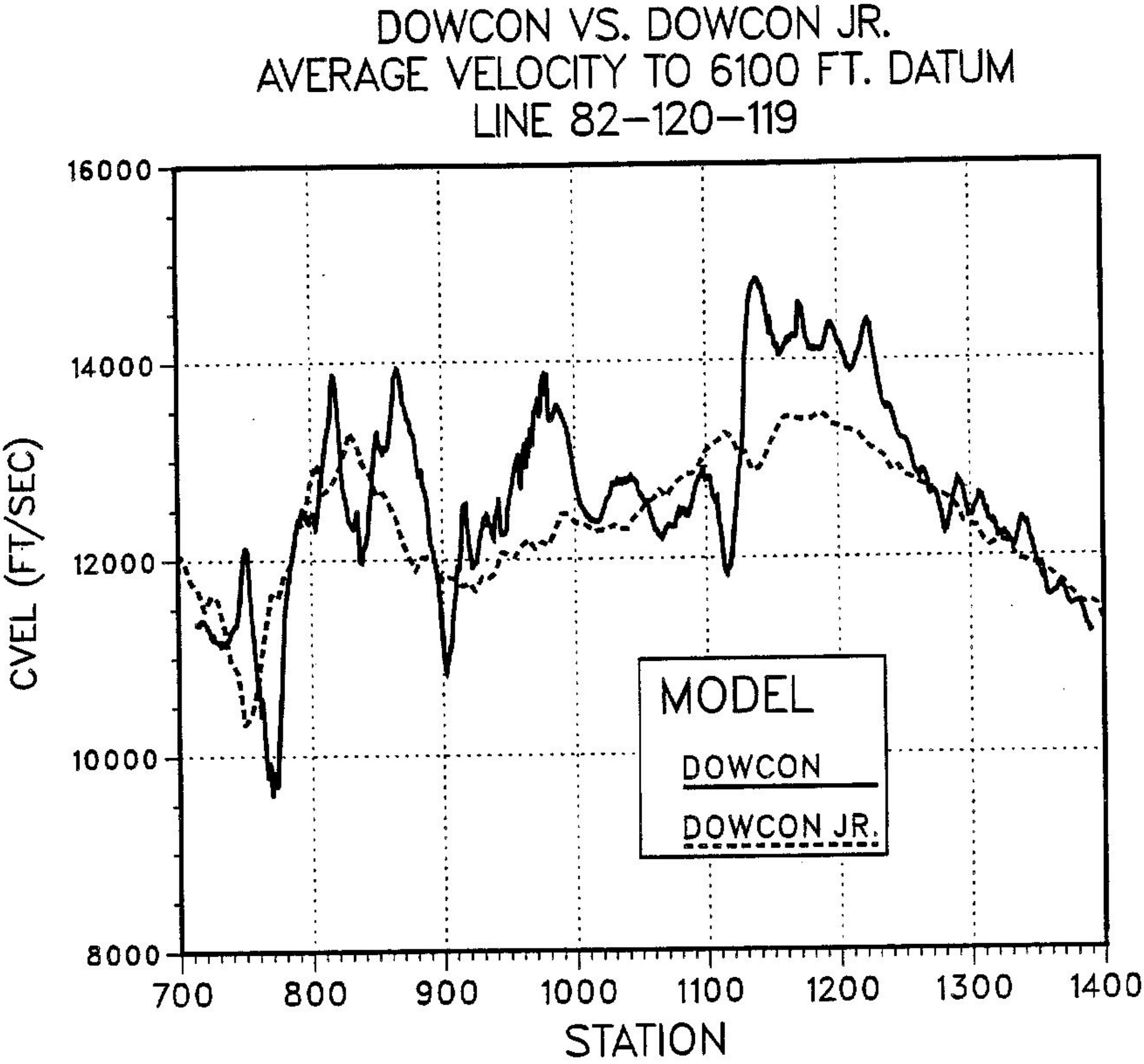


FIGURE 10. Plot of unsmoothed average velocity to a 6100' datum for Line 82-120-119. Average velocities for both DOWCON and DOWCON JR are shown.

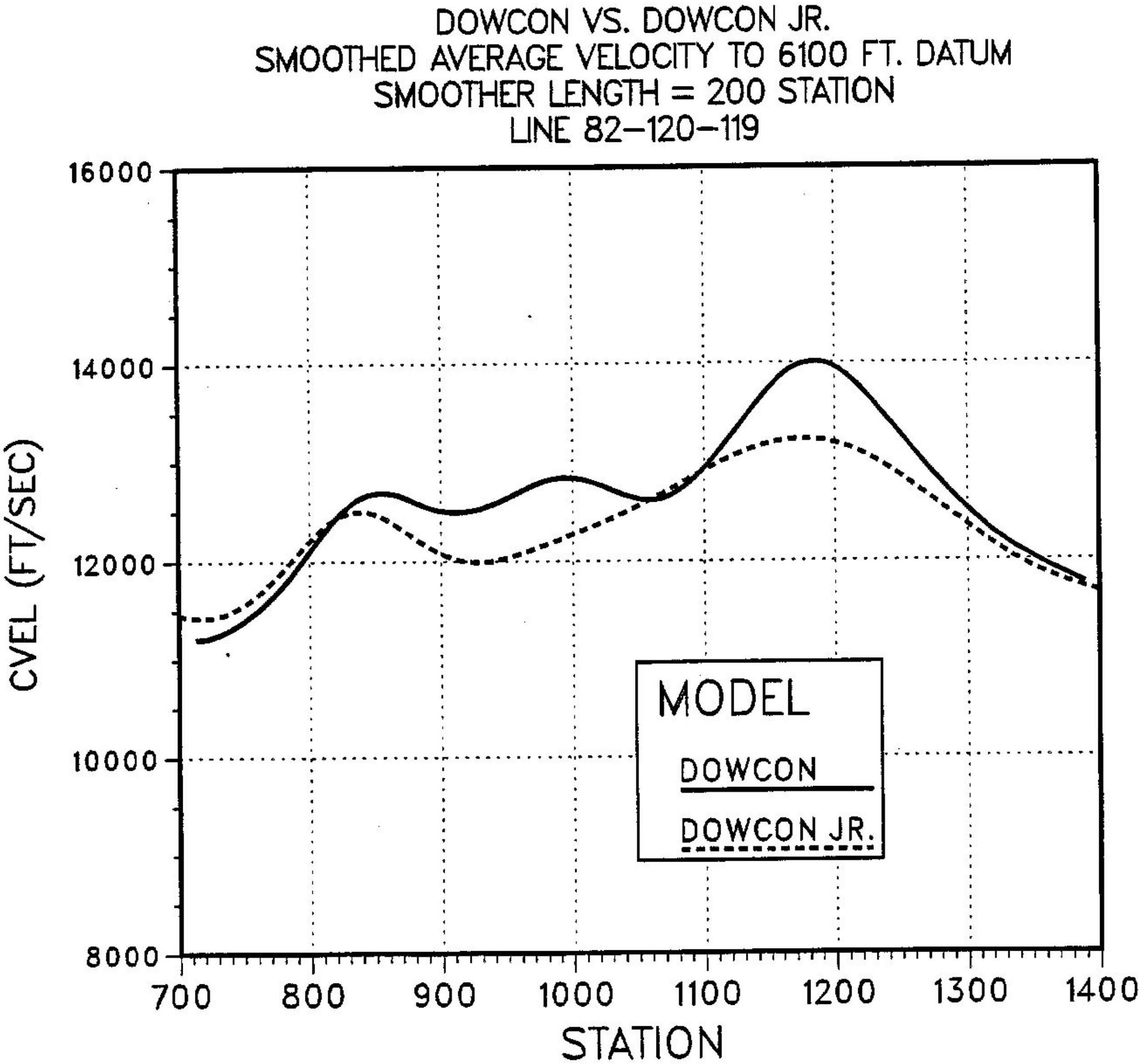


FIGURE 11. Plot of smoothed average velocity to a 6100' datum for Line 82-120-119. Smoother length is 200 stations. Average velocities for both DOWCON and DOWCON JR are shown.

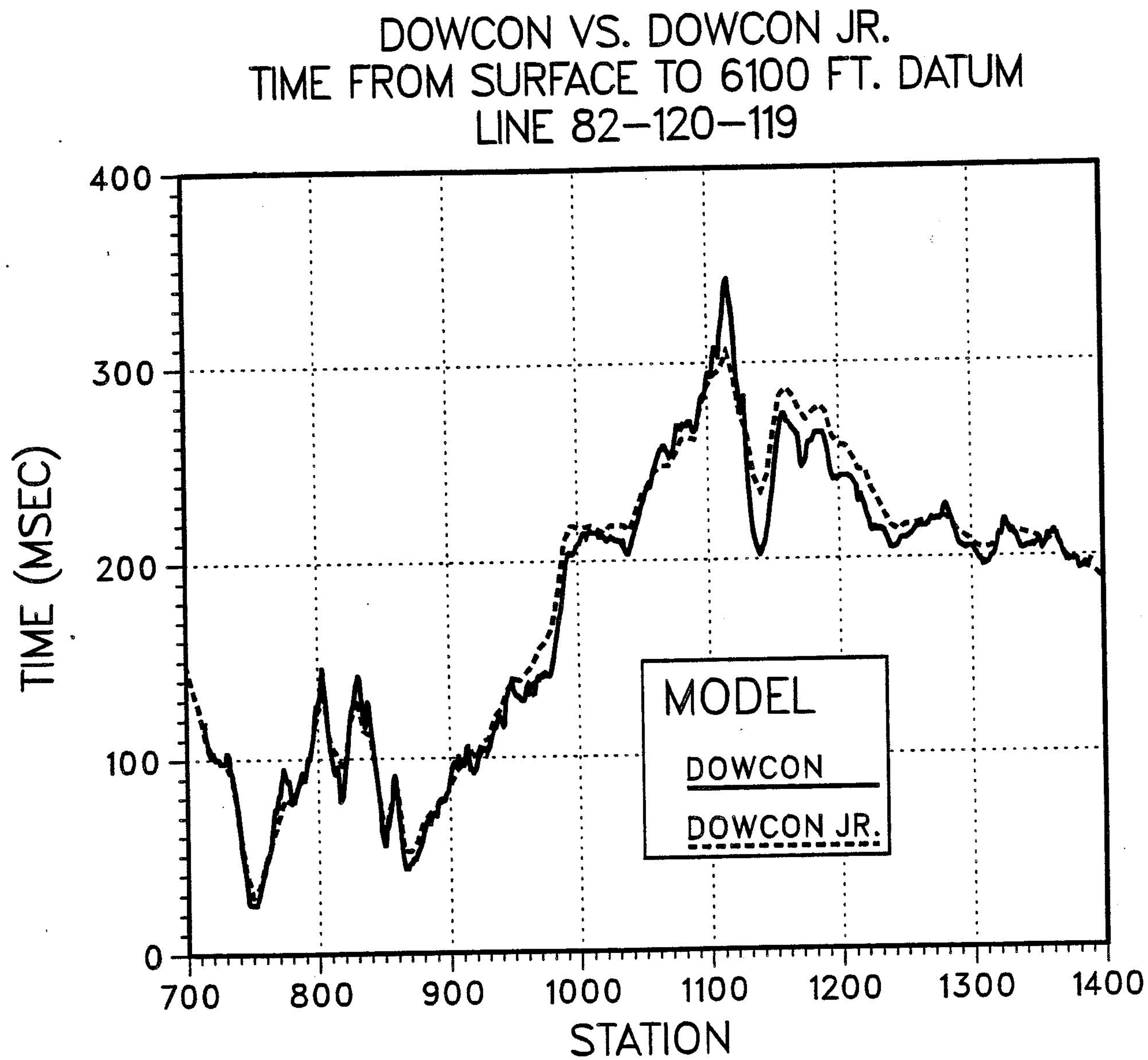


FIGURE 12. Plot of time from surface to a 6100' datum for Line 82-120-110. Times for both DOWCON and DOWCON JR are shown.

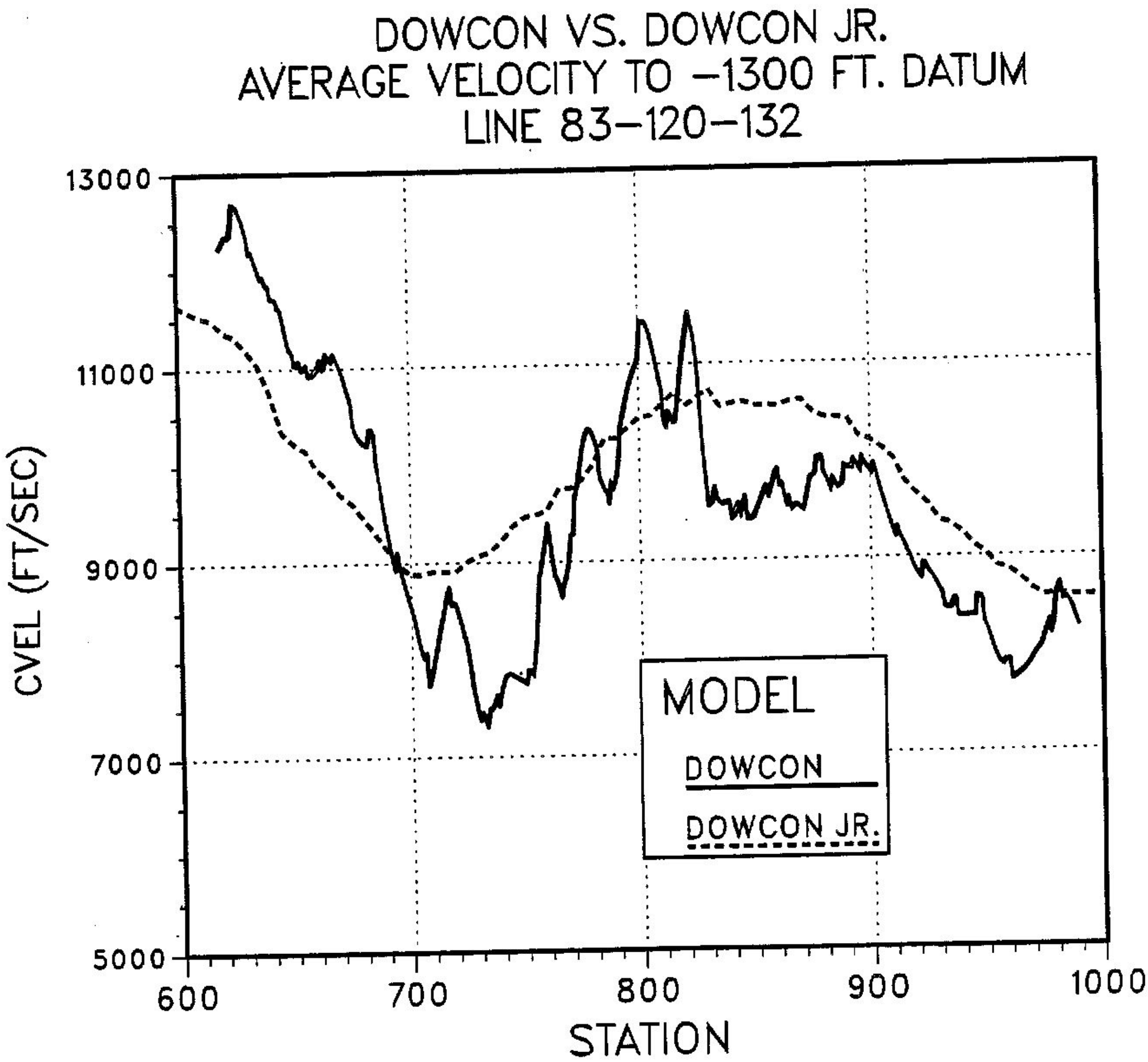


FIGURE 13. Plot of unsmoothed average velocity to a -1300 ft. datum for Line 83-120-132.

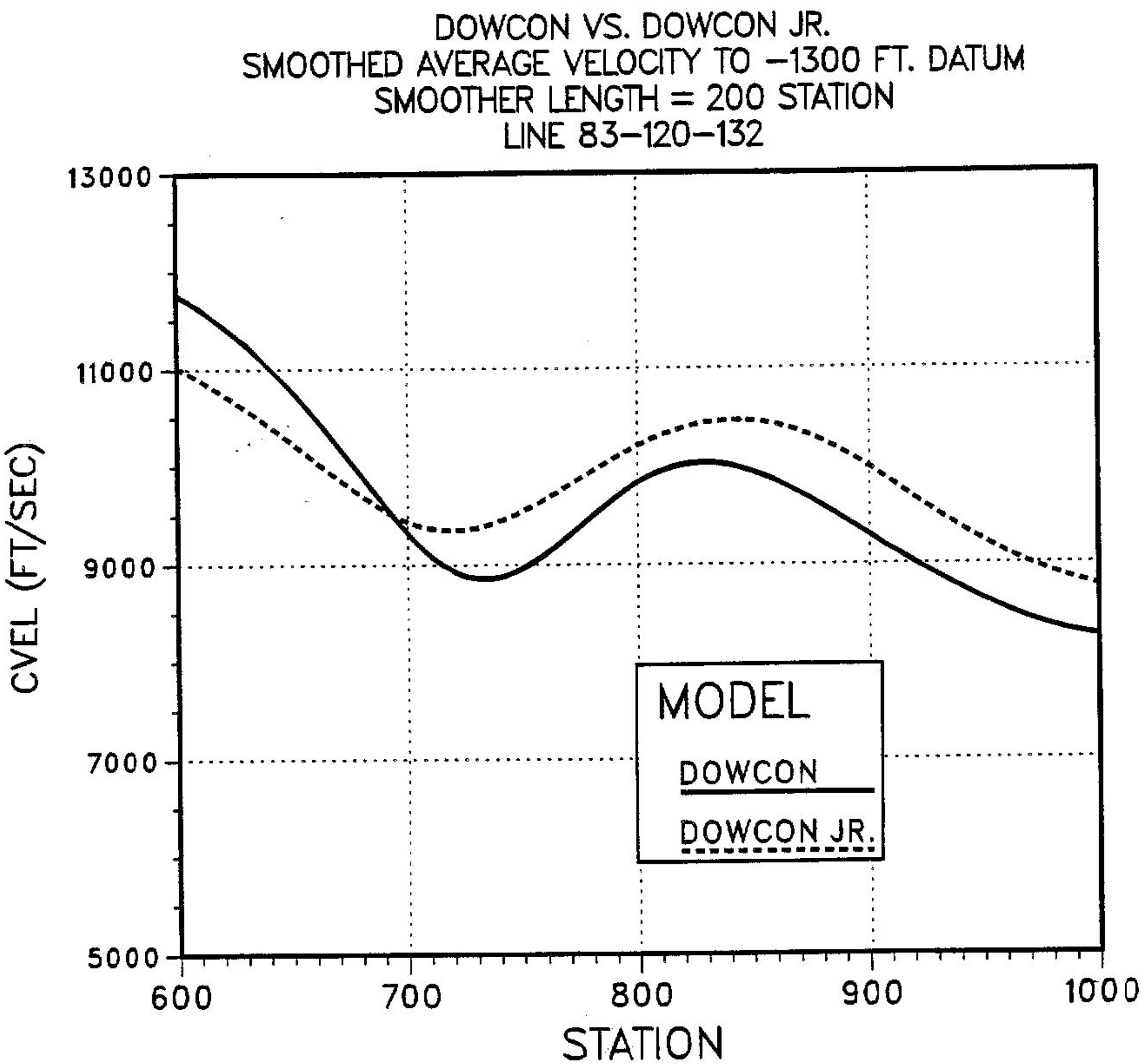


FIGURE 14. Plot of smoothed average velocity to a -1300 ft. datum for Line 83-120-132. Smoother length is 200 stations. Average velocities for both DOWCON and DOWCON JR are shown.

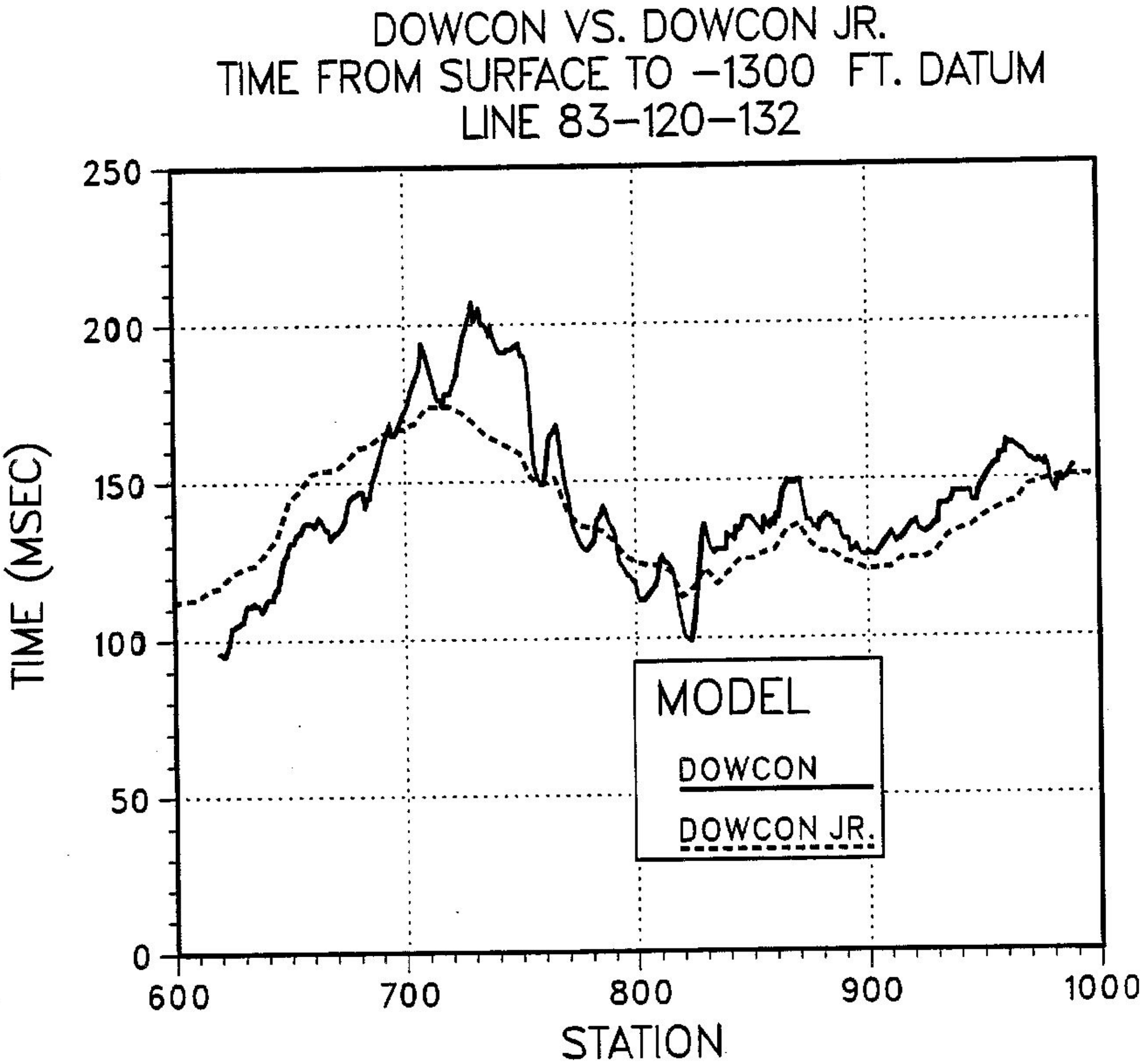


FIGURE 15. Plot of time from surface to -1300 ft. datum for Line 83-120-132. Times for both DOWCON and DOWCON JR are shwon.

APPENDIX: A
DIP ITERATION

A. Process

The DOWCON JR. process is dependent on an interpretive step to remove two effects (1) dipping beds, and (2) improper lateral placement of deeper velocity layers. A possible replacement for this interpretive step is a more elaborate scheme which incorporates a model with dipping layers into an iterative cycle of dip estimation. Figure A1 shows the flow of this iterative scheme.

For the first iteration, the dip of the model is assumed to be zero. The velocity of the layers are calculated and posted at the position where the seismic wave energy starts to move along the interface of that layer and the velocity layer above it. The two velocity models derived from the kink points of the positive and negative offsets are gridded and their error estimated by kriging [A1.1]. The weighted average of the two velocity models, Va, and the error of that average, σa, is formed according to the equation in figure A1. Averaging the two models will decrease the error of the velocity estimate and make a first order correction for dip.

For the second iteration the dip of the model at any point can be estimated by a local least squares fit of a plane to the velocity model generated by the first iteration. Using this estimation of the dip and a model which allows for dipping refractors will give a more reliable estimate of the layers velocity and placement of that velocity layer in the subsurface. The velocity model obtained from this iteration can be used to estimate the dip for the next iteration. This process can be continued until additional iterations no longer decrease the difference between the positive and negative offset velocity models.

B. Model

A more sophistcated model which incorporates dip but still has a simple solution for the velocity of the layers is shown in figure A2. This model consists of multiple layers of refractors, each with the same dip. Given the dip of the layers, the apparent velocities of the first arrivals, and the offset locations of the first arrival kink points; the velocity and thickness of the layers can be derived. The equations which tell where the refracted ray first encounters the n-th velocity layer and the velocity of that layer are respectively equation A1 and A2 in figure A2. The thickness of the velocity layers is given by equation A3 in the same figure.

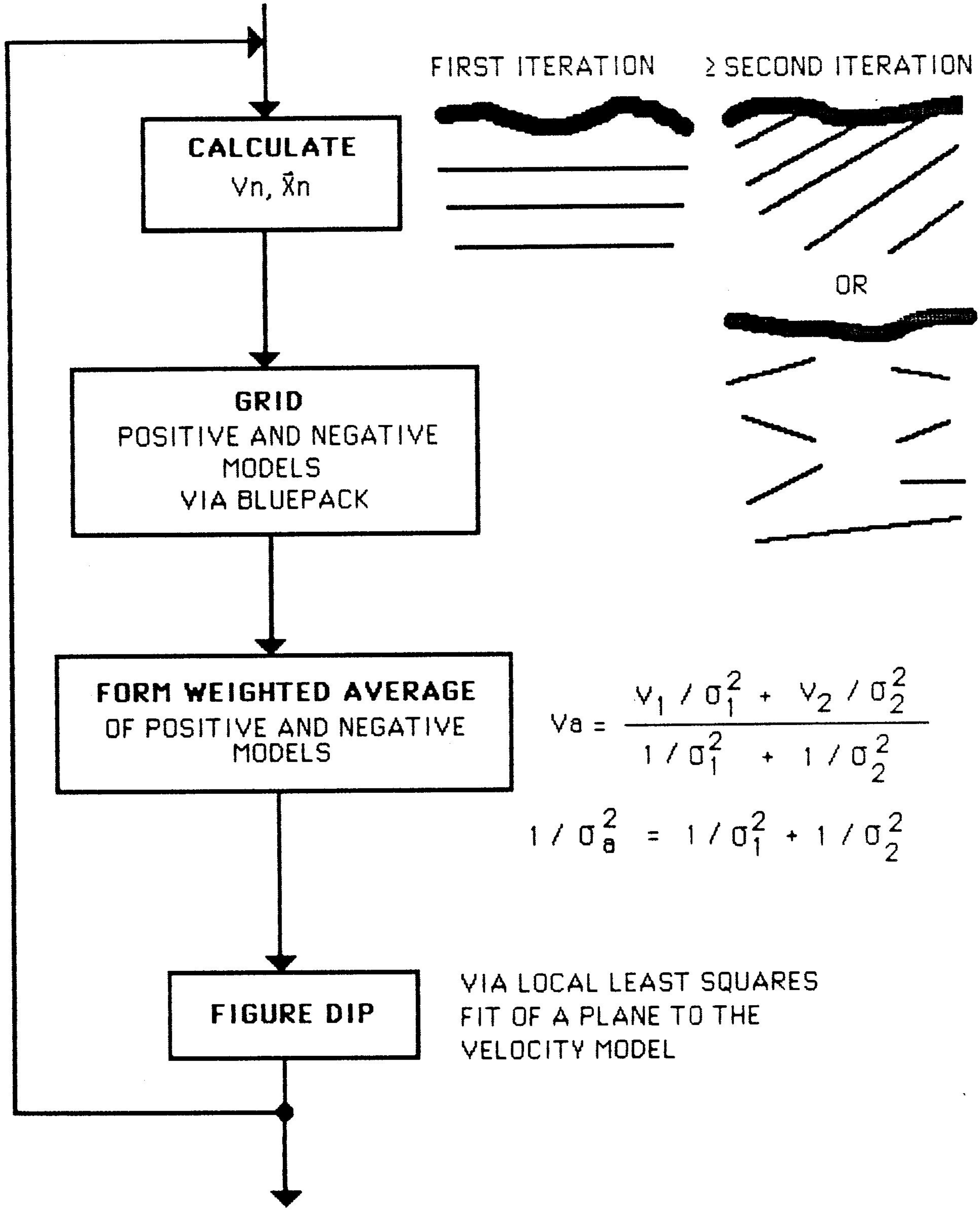
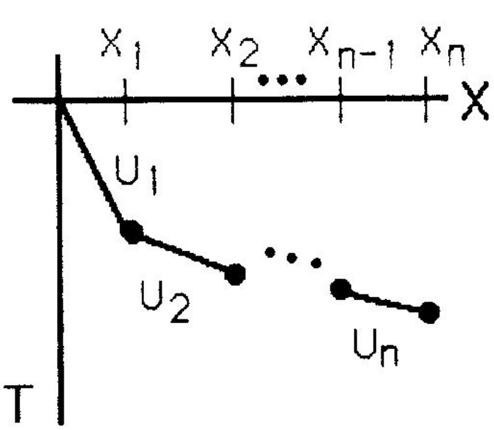
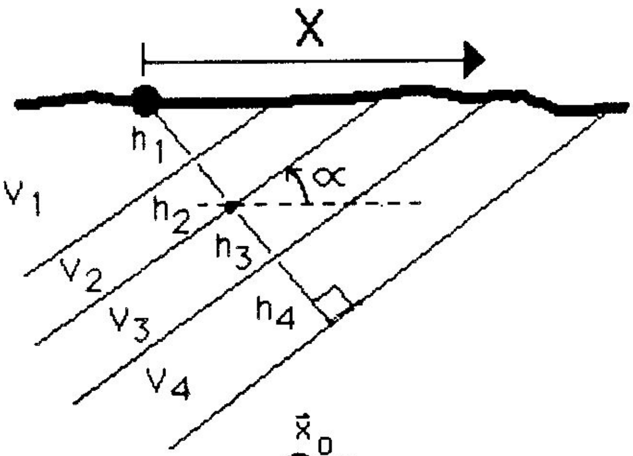
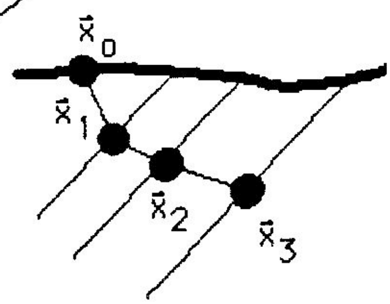


Figure A1. Flow chart of dip correction scheme.







$$\sin i_{n,m} = \frac{V_n}{V_m}$$

$$U_1 = V_1 \qquad U_n = \frac{V_1}{\sin(i_{1,n} - \alpha)}$$

$$\vec{x}(n) = \vec{x}_o + \sum_{k=1}^{n-1} h_k \left[\sin(\alpha + i_{k,n}), \cos(\alpha + i_{k,n}) \right] \qquad \textbf{(A1)}$$

$$V_n(U_1, U_n, \alpha) = \frac{U_1}{\sin\left[\arcsin \frac{U_1}{U_n} + \alpha \right]} \qquad \textbf{(A2)}$$

$$h_{n-1} = \frac{\frac{X_{n-1}}{2} - \sum_{k=1}^{n-2} h_k \, f(k,n,\alpha)}{f(n-1,n,\alpha)} \qquad \textbf{(A3)}$$

$$\text{where } f(k,n,\alpha) = \frac{\cos i_{k,n} - \cos i_{k,n-1}}{\Gamma_{n-1} \sin i_{k,n-1} + \Gamma_n \sin i_{k,n}}$$

$$\text{where } \Gamma_n = \frac{\sin(i_{1,n} - \alpha)}{\sin i_{1,n}}$$

Figure A2. Arithmetic for dipping layered refraction model.

APPENDIX: B
TXTR CORRECTION

Due to buried shots and a non-horizontal earth, the shot panel does not have the kinked linear profile of first arrivals, even if there is parallel layering to the surface. To correct for this one of two things can be done. The traces can be moved to their true R-distance on the display or the traces can be shifted in time to correspond to the R-distance at which they are posted. Because it is easier to shift a trace in time than in position the latter is chosen. Given an estimate of the instantaneous slope of the first arrival, Vo, the time shift, (X-R)/Vo, can be derived as shown in figure B1. R is the distance between shot and receiver and X is the X-componant of that distance. The error introduced to the time shift by using an estimate of the instantaneous slope is shown by the second term in equation B3 (figure B1). The percentage error in the time shift is equal to 100*(Vo/V - 1), which is approximatly equal to the percentage error in the estimate of the velocity.

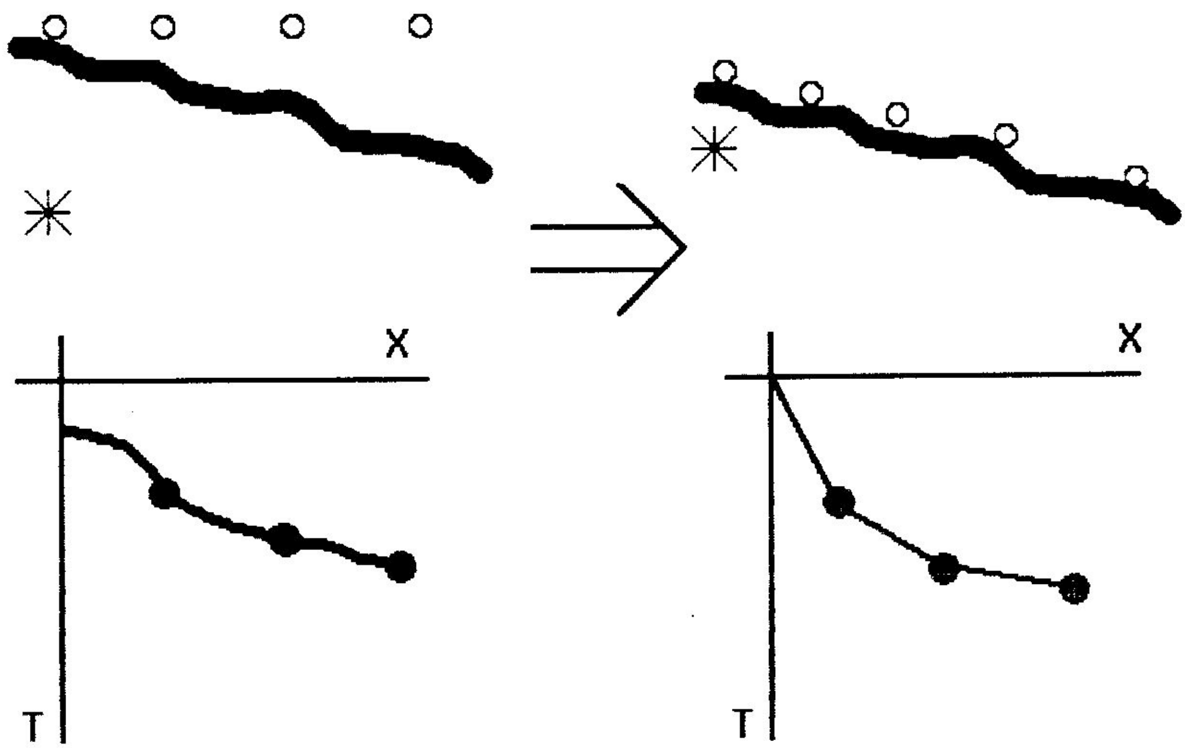
When the TXTR corrections for the typical seismic line are figured, they range from the uphole time at near offsets to fractions of a millisecond at large offsets. This effect can be seen by examining the TXTR correction for a parabolic mound (figure B2 and B3). For long offsets the aspect ratio of the mounds along the lines studied is no more than 0.15. The TXTR corrections are well below 1% of the time of the first arrival at maximum offset. Short offsets with buried shots present a more severe problem. The virtual mound created by burying a shot can have an aspect ratio of greater than one. The TXTR correction is close to the uphole time, an error of 100%.

Because of the trend in TXTR corrections, the following scheme is employed to estimate the instantaneous slope of the first arrivals. The depth of shot is divided by the uphole time to derive the velocity for the zero offset trace. This velocity then approaches a constant for longer offsets. For near offsets, where the time shift is largest, the velocity is derived from measured data. As the TXTR time correction becomes smaller the velocity approaches an estimate of what it should be. Let Xup be the range over which the velocity derived from uphole information is valid. Vg is the estimate for large offsets. The velocity to use is then calculated by the following formula:

$$Vo = Vup * w(R) + (1 - w(R)) * Vg \qquad \textbf{(B1)}$$

with,

$$w(R) = e^{-\left[\frac{R}{X_{up}\sqrt{2}}\right]^2} \qquad \textbf{(B2)}$$



To make this transformation apply a time shift which will place the trace at the time which corresponds to the X-distance not the R-distance.

Given is the $t = t(R)$ shot profile with $R = R(X)$ for the line

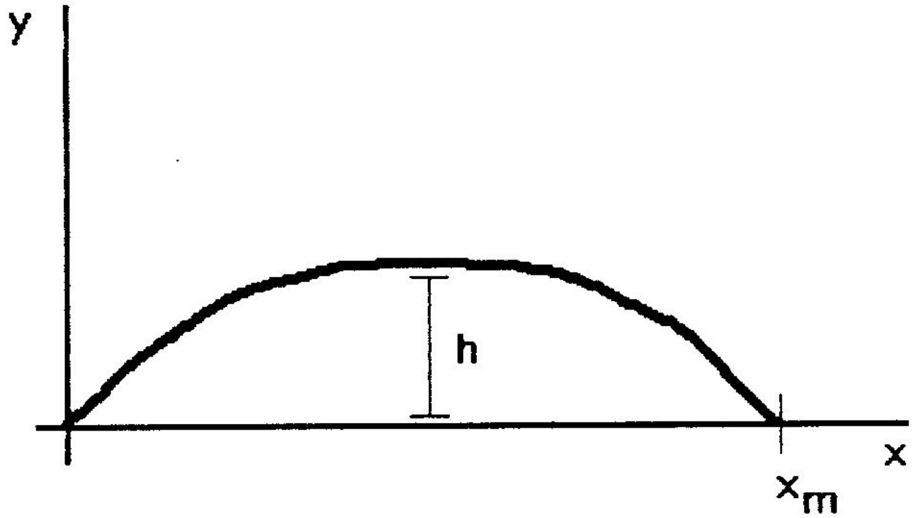
Assume $t(R)$ is piece wise linear (i.e., $t(R) = A + R/V$)
V = instantaneous slope

Let V_o be an estimate of V.

$$\Delta t(X) = t(X) - t(R(X)) = (A + X/V) - (A + R/V)$$

$$= \frac{(X - R)}{V_o} + \frac{(X - R)}{V_o}\left[\frac{V_o}{V} - 1\right] \qquad \text{(B3)}$$

Figure B1. Derivation of the TXTR correction.



$$y(x) = h\left[1 - \left(2\frac{x}{x_m} - 1\right)^2\right]$$

$$r = \sqrt{x^2 + y^2}$$

$$\Delta t = \text{TXTR correction} = \frac{r - x}{V}$$

Dimensionless variables

$$H = h / x_m$$
$$X = x / x_m$$
$$Y = y / x_m$$
$$T = \frac{V\,\Delta t}{x_m}$$

$$T(X,H) = \sqrt{H^2(1 - (2X - 1)^2)^2 + X^2} - X$$

Figure B2. TXTR Correction for parabolic mound (Model).

TXTR CORRECTION FOR PARABOLIC MOUND T CONTOURED AS A FUNCTION OF H AND X

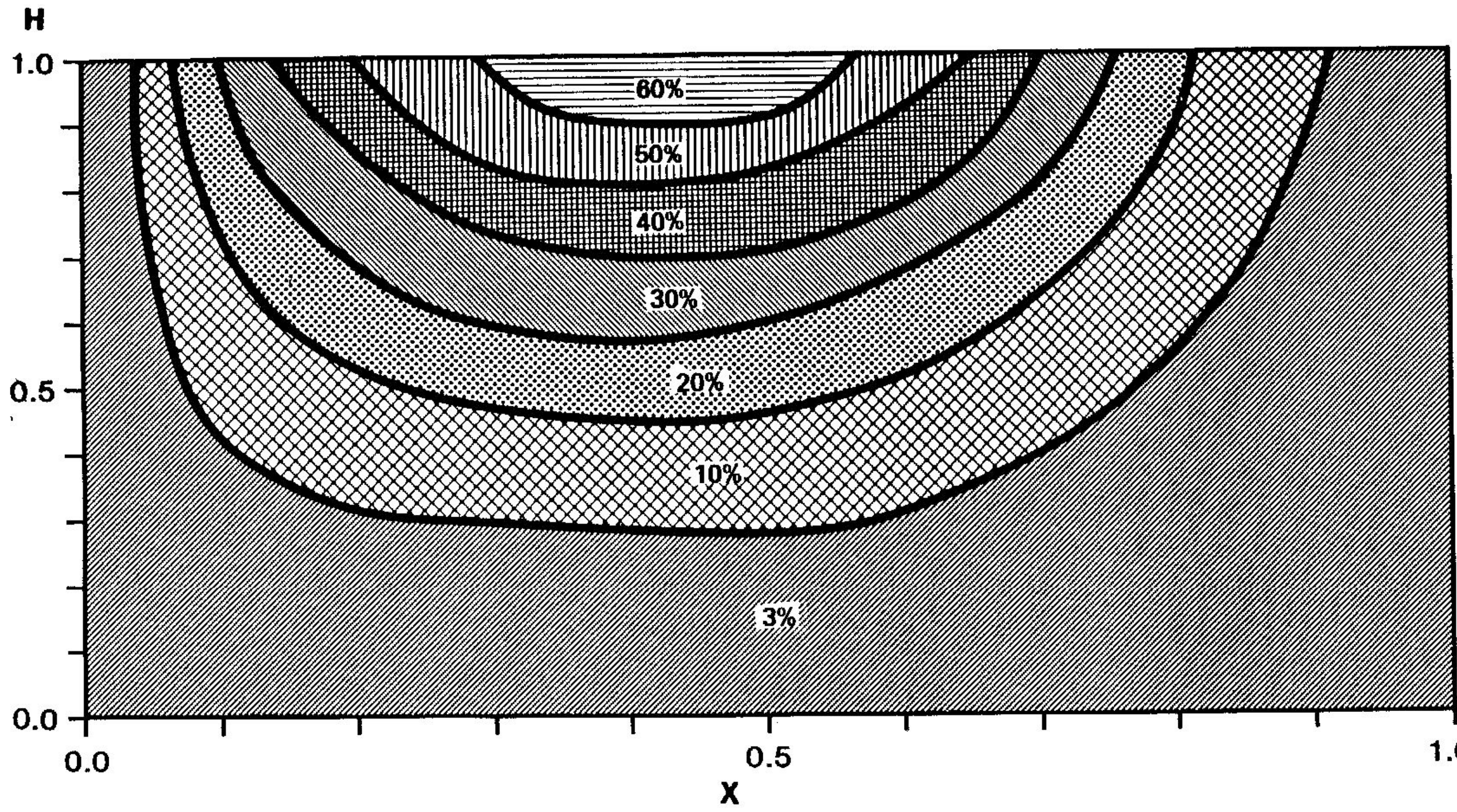


FIGURE B3

APPENDIX: C
SENSITIVITY STUDIES

A. Effect of bad kink point picks

In digitizing the kink points of the first arrival profile there will always be some error. The sensitivity of the DOWCON JR. process to this type of error is investigated. The model used is that of a two layer earth shown in figure C1. The resulting profile of first arrivals will have one kink point. Two kink points will be picked -- one at the change in slope and the other at the maximum offset.

Four dimensionless parameters are used: X is the offset of the kink point divided by the maximum offset, T is the time of the first kink point divided by the time of the first arrival profile at maximum offset, ϵ_X is the offset error in the kink point pick normalized like X, and ϵ_T is the time error in the kink point pick normalized like T.

Figure C2 is a contour plot of the percentage error in effective velocity to a depth 1.5 times the thickness of the first layer as a function of the kink point time and offset error. The true placement of the kink point should have been X=0.333 and T=0.666. Errors in effective velocities are less than 10% for 5% errors in placing the kink point. Reasonable expected errors of 2 stations and 20 msec are well below 5% errors for most seismic data acquisition geometries.

B. Effect of discrete kink point picks and smoothing

If velocity varies continuously as a function of depth, the profile of first arrivals will have a continuous first derivative and no kink point will exist. DOWCON JR. requires that a kink point be picked. Therefore, the continuous velocity profile will have to be approximated by a discrete block model. This sensitivity study is designed to tell how much this approximation will effect the effective velocity.

The model used is an earth with velocity that increases linearly with depth [C1.1]. The effective velocity to a depth Z for this model is compared to that for the block model obtained by using N discrete kink points (see figure C3). A smoother is then applied to the block model and the effective velocities calculated from the smoothed velocities are compared to those of the original model.

Figure C4 shows the results of this sensitivity study. Fractional error in effective velocity is contoured versus depth, Z, and number of kink points picked, N. The heavy black lines show how the contours change when a smoother is applied to the block velocity model before effective velocities are calculated. The depth, Z, and the length of the smoother, **Xsmo**, are both normalized by the maximum offset of the line, **Xm**. The parameter **Xmax** is the maximum offset divided by the depth below the surface where the velocity is twice that at the surface. The example shown in figure C4 has an **Xmax** of 5 and shows the effect of a 5% smoother. This smoother is equivalent to a 500 ft vertical smoother for a seismic line with a maximum offset of 10,000 ft.

Two important things are shown by the sensitivity study: (1) less than a 10% error in effective velocity is incurred at all depths if greater than 3 kink points are picked, and (2) the error of the effective velocity is not affected by the application of a smoother to the interval velocities before calculation of effective velocity.

EFFECT OF BAD KINK POINT PICKS
(MODEL)

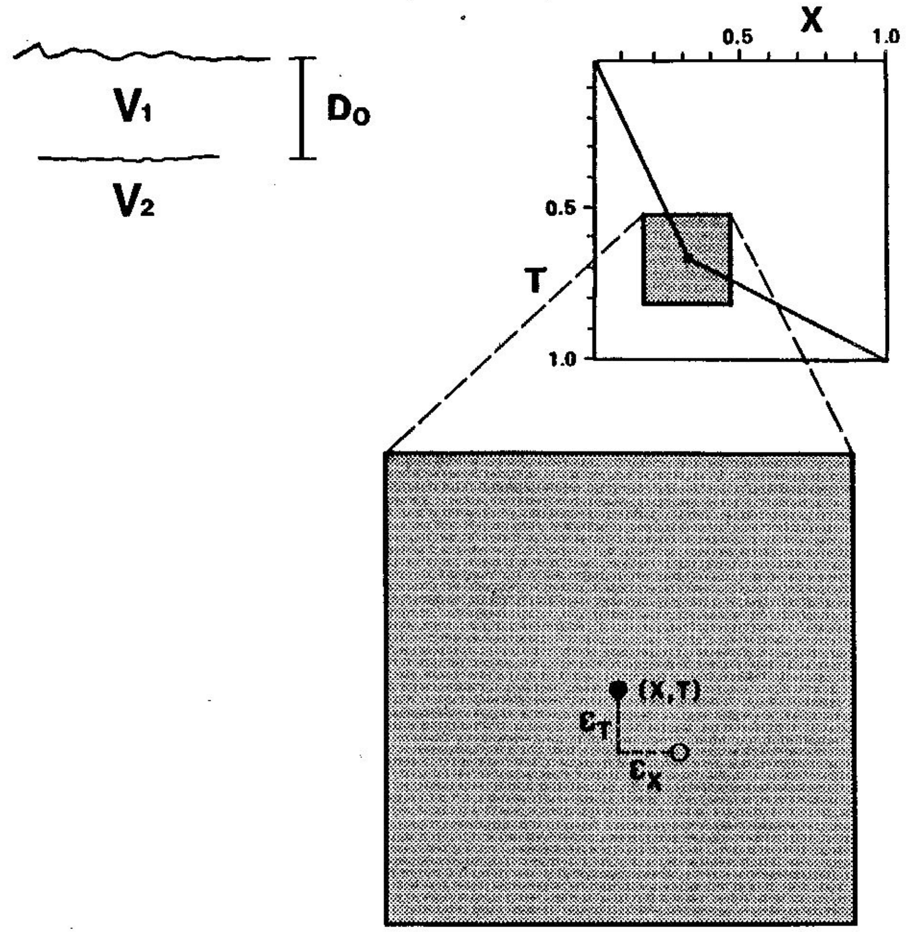


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FIGURE C1

ERROR IN EFFECTIVE VELOCITY AT A DEPTH OF 1.5 * D_O DUE TO BAD KINK POINT PICKS

X = 0.333 T = 0.666

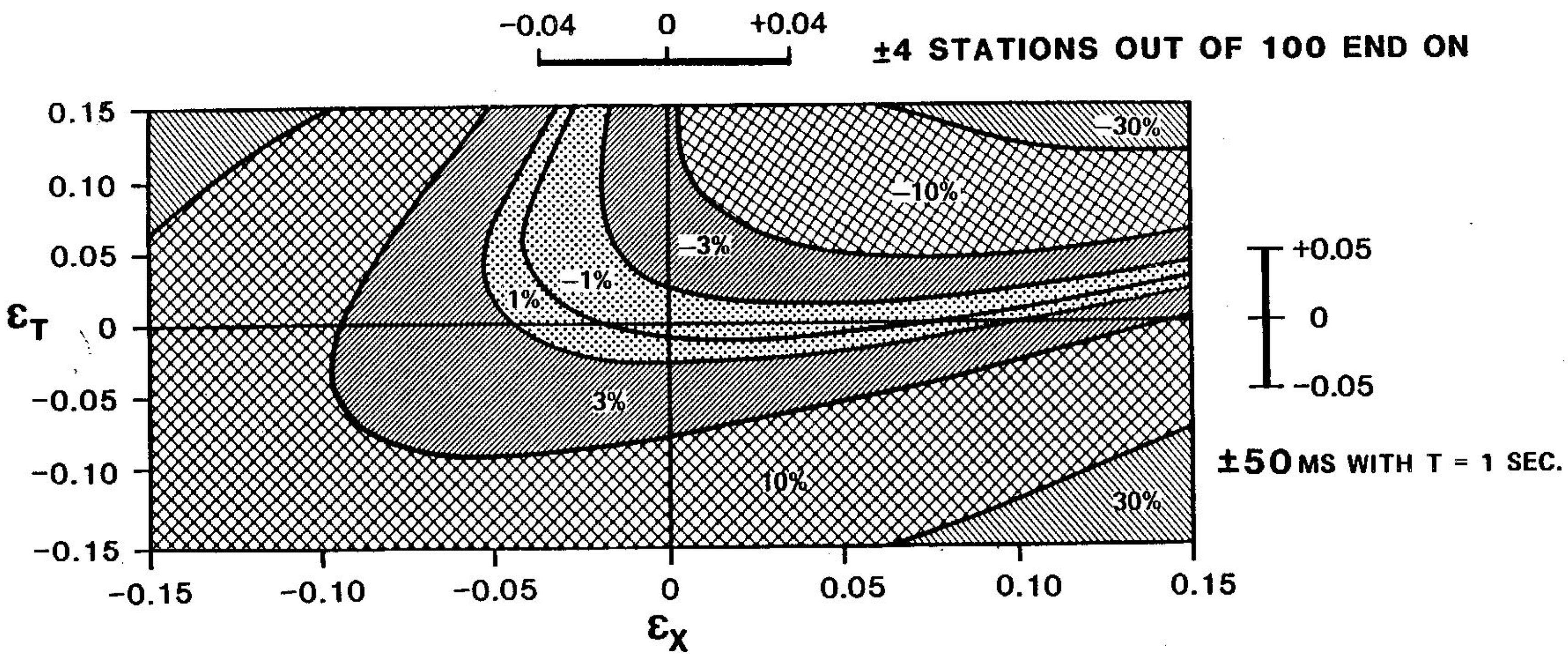

FIGURE C2

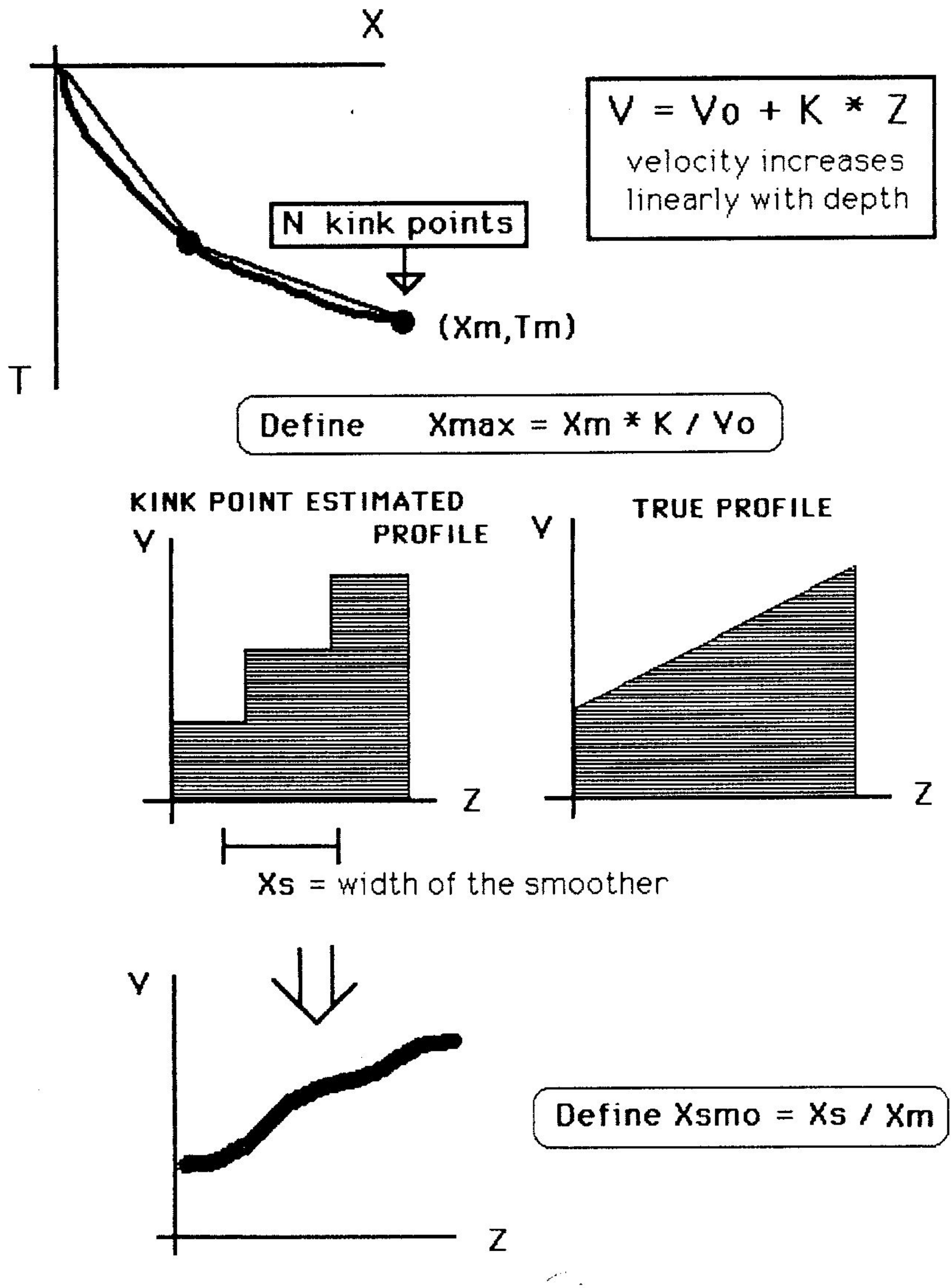

Figure C3. Model for the study of the effect of sampling a continuous velocity function discretely and then applying a smoother to the discrete model.

ERROR IN Ve FROM ERROR OF ESTIMATING
Vi = Vo • K * Z MODEL BY DISCRETE VELOCITY REGIMES.

Xmax = 5
Xsmo = .05

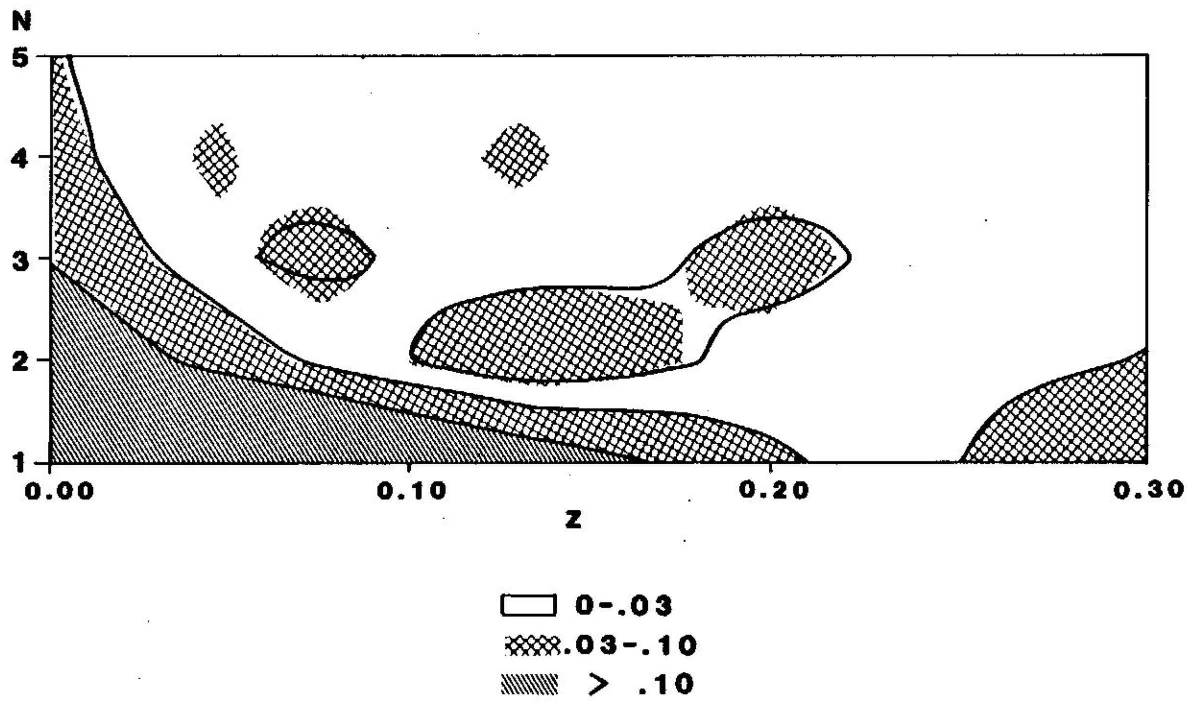

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FIGURE C4

APPENDIX: D
VELOCITY SMOOTHING

The spatial frequency content of velocity models that are derived from surface information is limited to progressively lower spatial frequecies as the model extends deeper into the earth. This is related to effective spread length. As the effective spread length gets larger, the velocity is averaged over a longer distance limiting its spatial variation. To be consistant with this effect, any smoother designed to eliminate high frequency noise from signal of a lower frequency must vary as a function of depth. Any smoother of constant length will either filter out useful information at shallow depths or allow noise to remain at deeper depths.

In response to this problem, a depth variant two dimensional interpolation scheme is presented. Figure D1 outlines this interpolation scheme. For purpose of generality, the variables X, Y, and Z(X,Y) are used instead of subsurface point, depth and velocity.

Input consists of: (1) A set of randomly sampled (X,Y,Z) points and (2) the X and Y lengths of the smoother which vary as a function of Y. For any point (X,Y) an estimate of the value of Z can be obtained by forming a weighted average of the input Z-values. The weights are determined by the X-Y distance of the input (X,Y,Z) points from the point an estimate is desired at. This distance is normalized by the X and Y lengths of the smoother.

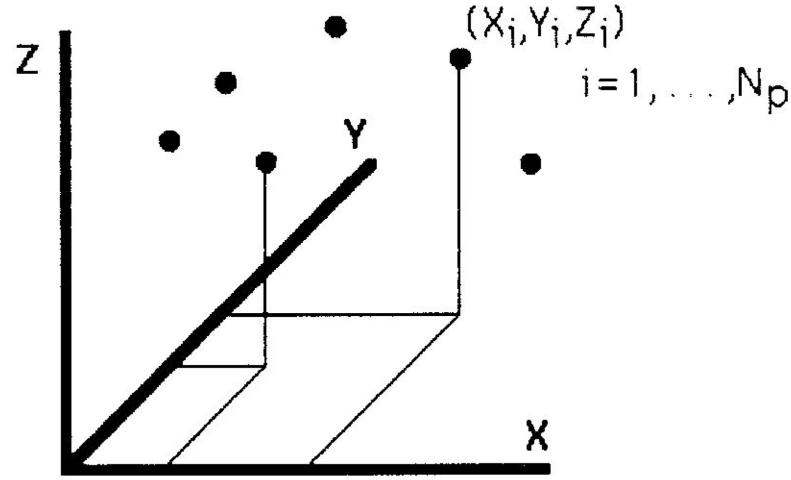
This scheme is further refined by subtracting out a polynomial drift from the Z-values before the weighted average is formed and adding the polynomial value to the interpolated Z-values. This prevents data at the edges of the sampled area from being biased if a trend exists in the data. To understand how this could happen, suppose there is a significant increasing trend in Z-values with increasing X. Since an average cannot be larger or smaller than the respective maximum and minimum of a dataset, the Z-value for the largest X-value must be less than the maximun but it should be equal to the maximum. The opposite will be true for the estimate of Z for the smallest sampled X-value -- it will be too large.

An estimate of the error in the interpolation can also be generated if a Z-values weight is assumed to be proportional to the reciprocal of the square of its error.

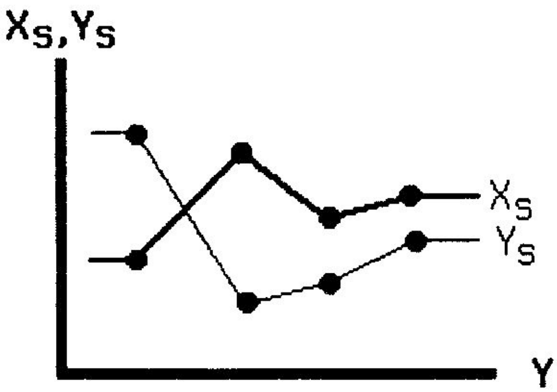
Figure D1. Interpolation Scheme

INPUT:

→ Randomly Sampled (X,Y,Z) points



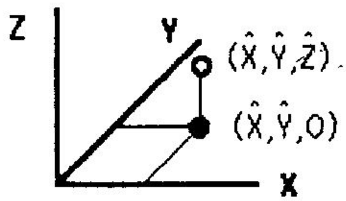
→ Tie points to define X and Y width of smoother as a function of Y



$(Y_j, X_s(Y_j), Y_s(Y_j))$

$j = 1, \ldots, N_s$

→ Point $(\hat{X},\hat{Y})$ at which to obtain an estimate of $\hat{Z}$



OUTPUT: $\hat{Z}$ as defined by

$$\hat{Z} = \frac{\sum_{i=1}^{N_p} w_i(D) * Z_i}{\sum_{i=1}^{N_p} w_i(D)}$$ where

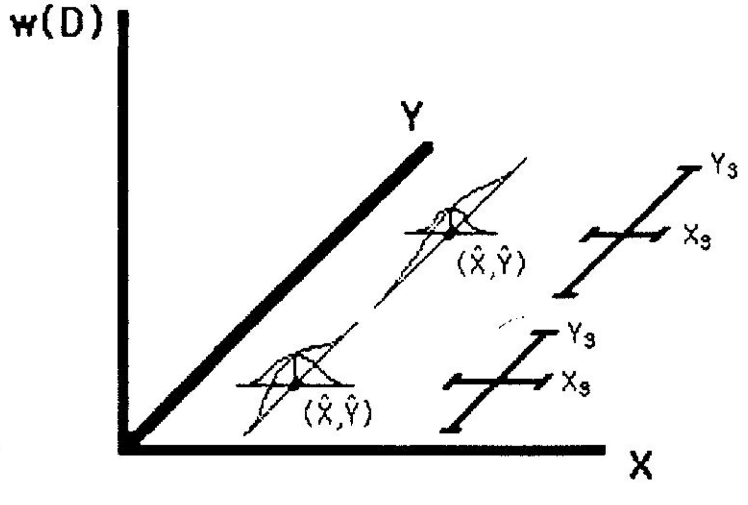
$$D(X_i, Y_i, \hat{X}, \hat{Y}) = \sqrt{\left[\frac{X_i - \hat{X}}{X_s(\hat{Y})}\right]^2 + \left[\frac{Y_i - \hat{Y}}{Y_s(\hat{Y})}\right]^2}$$ and,

$w_i(D)$ is an arbitrary weighting function. Some examples of possible weighting functions are:

gaussian: $w_i(D) = e^{-D^2}$

exponential: $w_i(D) = e^{-D}$

0% flat hanning: $w_i(D) = \begin{cases} 0 & D > 2 \\ \cos^2(\frac{\pi}{4} D) & D < 2 \end{cases}$



→ The weighting function in MEGIN is a hybrid of a function which goes to 0 at large D and a constant.

$$w_i(D) = f_i(D) * (1 - NSR) + NSR$$

where $\lim_{D \to \infty} f_i(D) = 0$

$$NSR = \left[\frac{\sigma_i(\hat{Y})}{\sigma_{pop}} \right]^2$$

$\sigma_i(\hat{Y})$ = estimated error of $z_i(\hat{Y})$

σ_{pop} = standard deviation of all z_i

→ an n^{th} order drift is subtracted from before interpolation and added back after interpolation. This drift is calculated by fitting a polynomial to the whole dataset.

→ points used in interpolation are limited to to those with **D** less than a user specified value.

→ an estimated standard deviation of $\hat{z}$ is calculated by the following formula:

$$\sigma_{\hat{z}}^2 = \frac{\sum_{i=1}^{N_p} w_i(D) * (z_i - \hat{z})^2}{(N_p - 1) \sum_{i=1}^{N_p} w_i(D)}$$