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INVERTING FOR INTERVAL VELOCITIES FROM REFLECTION VELOCITY ANALYSIS ON THE WIDE OFFSET MRGP DATA SET

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ABSTRACT

In this paper we describe a method for inverting for interval velocities from the stacking velocities determined from reflection velocity analysis for CLP (Common Lateral Point) reflection imaging. The results show finely detailed interval velocity profiles. We do this for a full range of reflection depths for three reflection point locations: at the source and receiver wells, and in the middle of the survey.

INTRODUCTION

One of the principle components of the CLP reflection imaging method is the reflection velocity analysis. This procedure consists of finding the stacking velocities that will optimize the stack of the reflection data. The stacking velocities are the rms. or average velocities used in the HNMO and VLMO (Smalley, 1992) moveout corrections. The determination of stacking velocities for reflection imaging is the forward problem. The determination of interval velocities from the stacking velocities is the inverse problem.

FORMULATION OF STACKING VELOCITIES AND INTERVAL VELOCITIES

The concept of stacking velocities for crosswell data is taken from the variable velocity HNMO and VLMO moveout equations (Smalley, 1993). The variable velocity HNMO equation is:

$$t^2 = t_{ho}^2 + C_1 f^2, \qquad (1)$$

where

$$C_1 = \frac{\sum_{Z=Zs}^{Z=Zr} s_i \Delta z_i + \sum_{Z=Zg}^{Z=Zr} s_i \Delta z_i}{\sum_{Z=Zs}^{Z=Zr} \frac{\Delta z_i}{s_i} + \sum_{Z=Zg}^{Z=Zr} \frac{\Delta z_i}{s_i}}, \qquad (2)$$

and

$$t_{ho} = \sum_{Z=Zs}^{Z=Zr} s_i \Delta z_i + \sum_{Z=Zg}^{Z=Zr} s_i \Delta z_i, \qquad (3)$$

where s_i is the interval slowness, f is the horizontal well offset, Zs is the source depth, Zg is the geophone or receiver depth, Zr is the reflection depth, and Δz_i is the interval layer thickness. C_1 is equivalent to the inverse of the rms. velocity squared of the transversed layers. We can rewrite equation (3) in the crosswell reflection polar coordinates (Smalley, 1992):

$$t_{ho} = \bar{s} \cdot [1 + \sin 2\alpha(Zr)]^{\frac{1}{2}} \cdot r(Zr), \tag{4}$$

where $\bar{s}$ is the average slowness, defined by

$$\bar{s} = \frac{1}{[|Zr - Zs| + |Zr - Zg|]} \left(\sum_{Z=Zs}^{Z=Zr} s_i \Delta z_i + \sum_{Z=Zg}^{Z=Zr} s_i \Delta z_i \right). \tag{5}$$

Equation (4) is the VLMO equation in variable velocity media. We have written the HNMO and VLMO moveout equations in terms of the rms. velocity and average of the slownesses of the transversed layers. As we see in equations (2) and (3), and in figure 1, the HNMO and VLMO stacking velocities or slownesses are a function of the source and receiver pair. While this makes the forward problem of determining stacking velocities more complicated, it gives us additional information about the interval velocities which make up the stacking velocities.

VELOCITY ANALYSIS PROCEDURE (FORWARD PROBLEM)

The reflection velocity analysis procedure is shown in figure 2, and detailed in a previous paper (Smalley, 1993). The data set used in this paper is the wide offset MRGP. The location of velocity analysis nodes (Smalley, 1994) for this survey is shown in figure 3 . In doing the velocity analysis, we assumed that the HNMO and VLMO stacking velocities are equal. Determining a different HNMO and VLMO stacking velocity for a given source - receiver pair and reflector depth would be very impractical. Additionally, we quantify these values in terms of velocities instead of slownesses. Figures 4, 5, and 6 show the stacking velocities for reflection depths 2410, 2560, and 2660 feet. Figures 4 and 5 are for a reflection lateral location at the source well. Figure 6 is for a reflection lateral location in the middle of the survey.

SOLVING FOR INTERVAL VELOCITIES (INVERSE PROBLEM)

The matrix inversion formulation to find the interval velocities or slownesses is given by

$$\begin{pmatrix} \Delta z_w & & & \\ \Delta z_w & \Delta z_1 & & \\ \Delta z_w & \Delta z_1 & \Delta z_2 & \\ \Delta z_w & \Delta z_1 & \Delta z_2 & \Delta z_3 \end{pmatrix} \begin{pmatrix} s_w \\ s_1 \\ s_2 \\ s_3 \end{pmatrix} = \begin{pmatrix} S_w \\ S_1 \\ S_2 \\ S_3 \end{pmatrix},$$

where Δz_w is the thickness of the wide angle reflection layer where no velocity analysis is performed, Δz_i is the thickness of the layers over which velocity analysis is performed, s_w and S_w is the slowness of the wide angle reflection layer, s_i is the slowness of the i th layer, and S_i is the stacking slowness from the reflection depth to the i th layer. The thickness of the layers Δz_i is determined from the velocity analysis procedure (figure 1). This system of equations is most easily solved by Gaussian elimination.

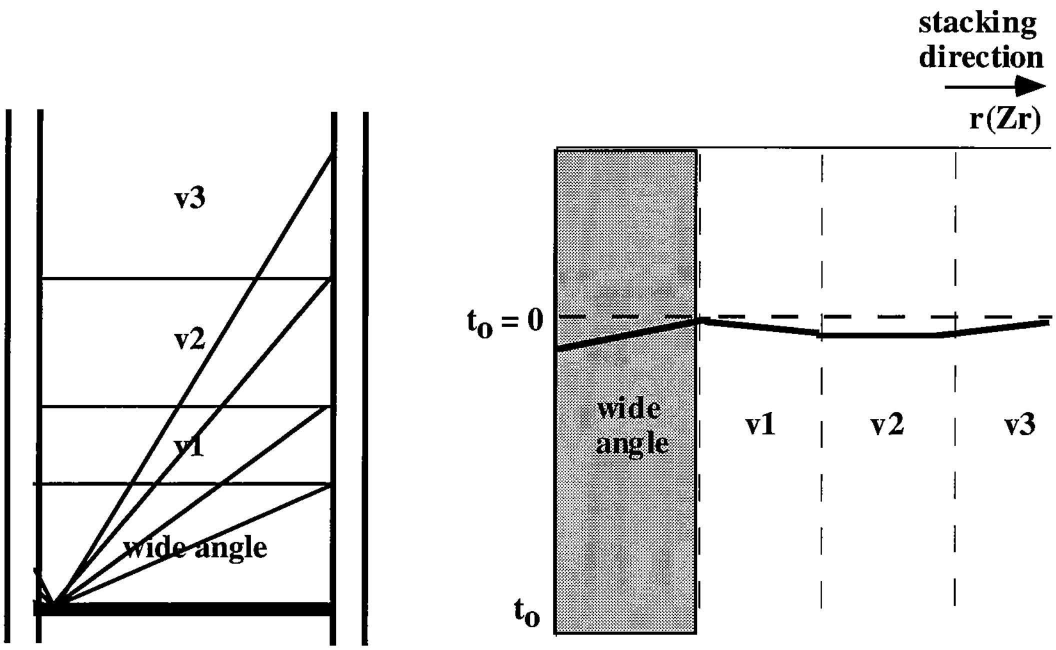

Figure 1. Raypaths for a CLP transcending different layers (left), and the corresponding CLP-VLMO gather before velocity analysis.

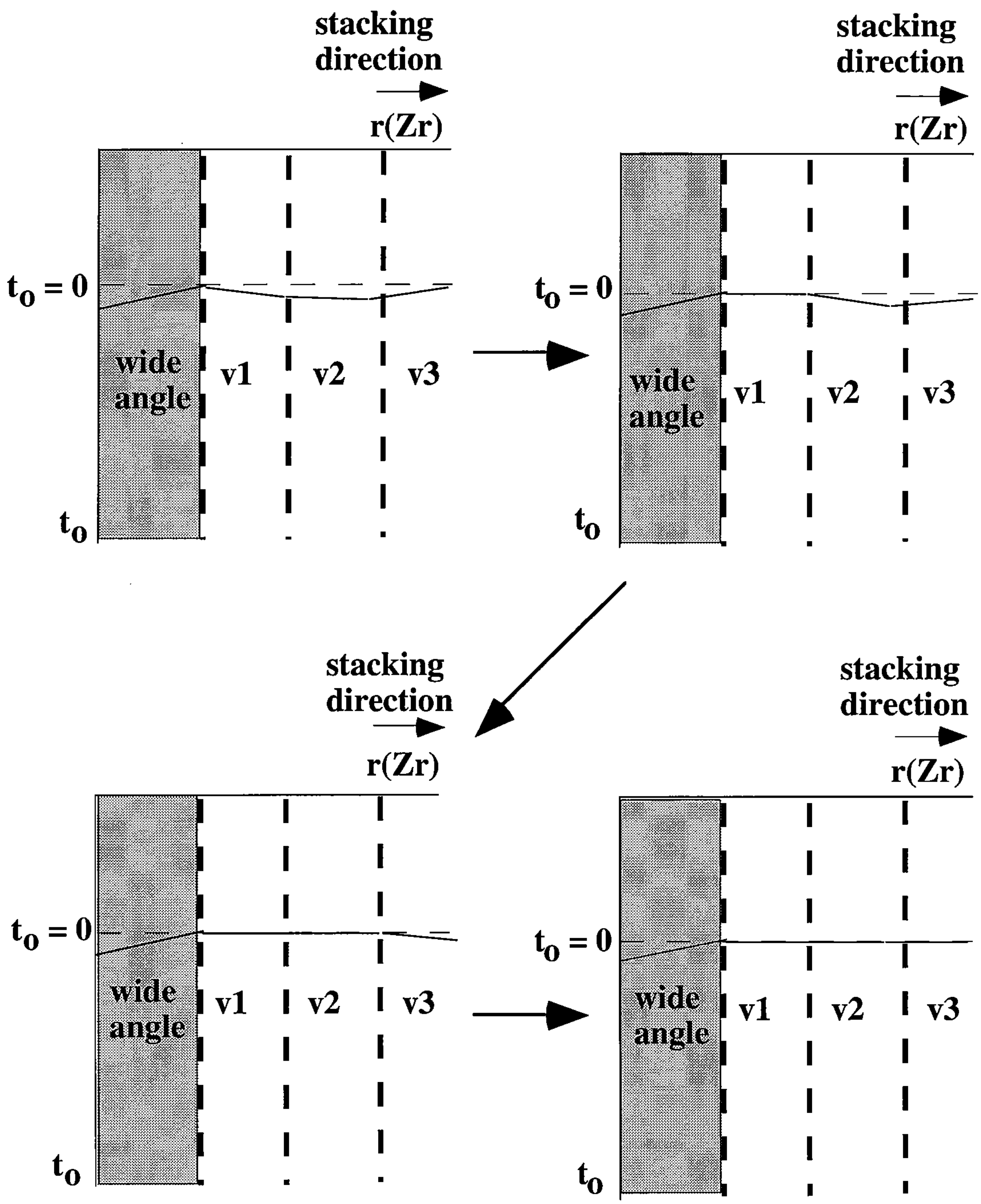

Figure 2. Reflection velocity analysis sequence.

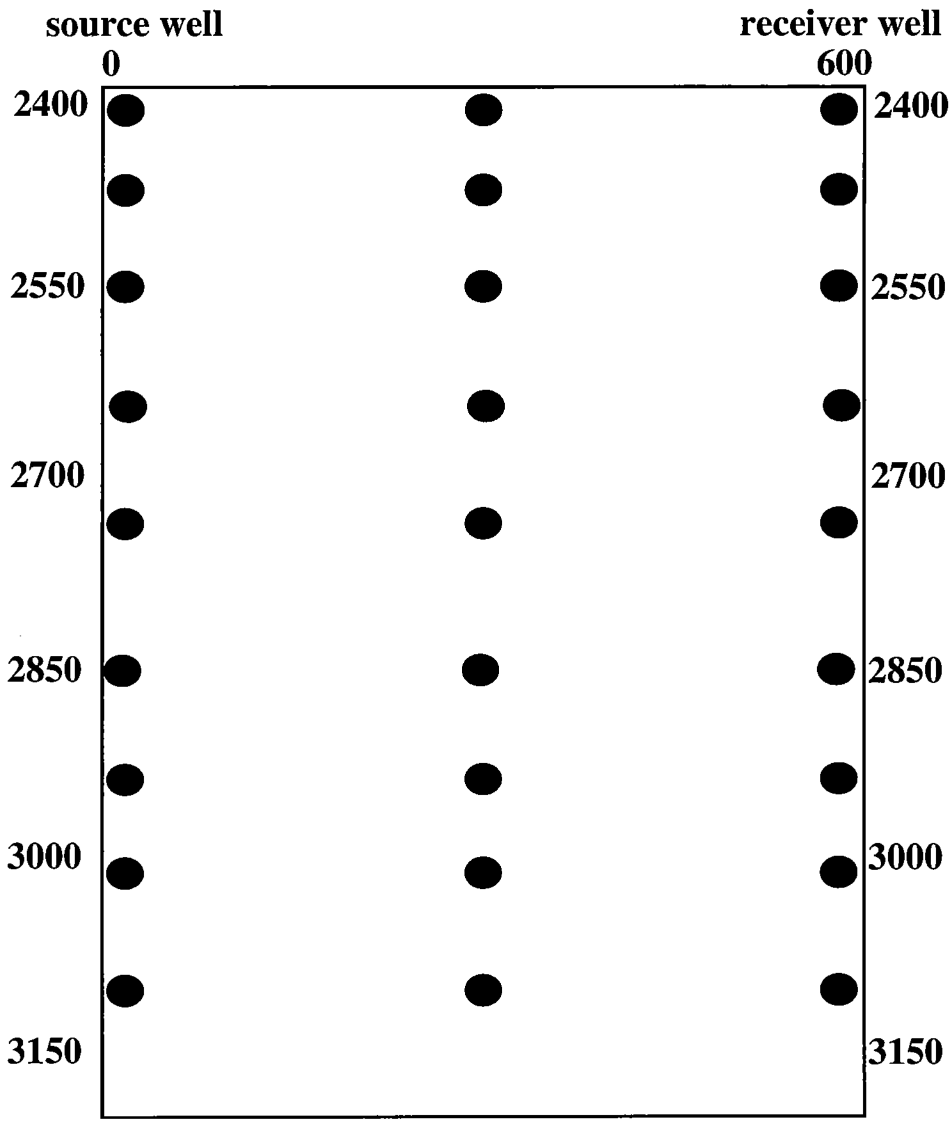

Figure 3. Location of reflection velocity analysis nodes (units are feet).

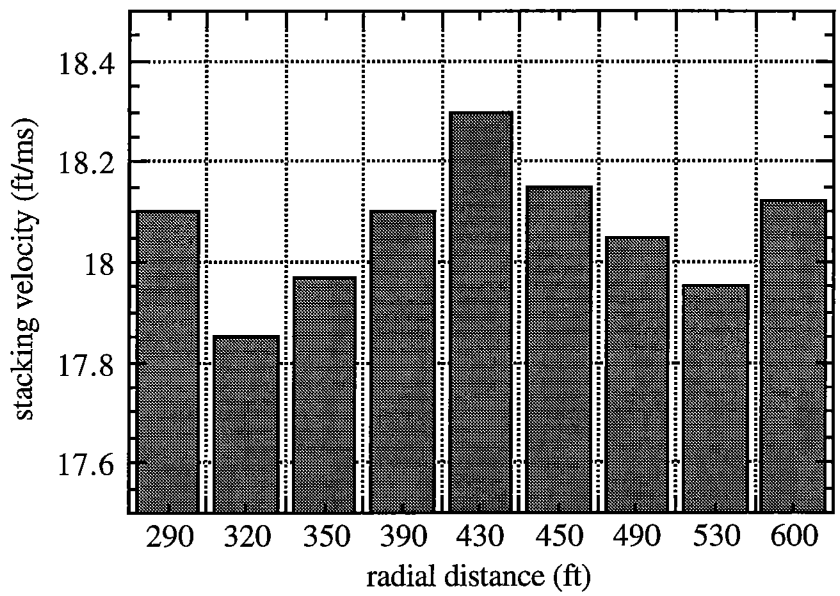

Figure 4. Stacking velocities for reflection depth 2410 feet at the source well.

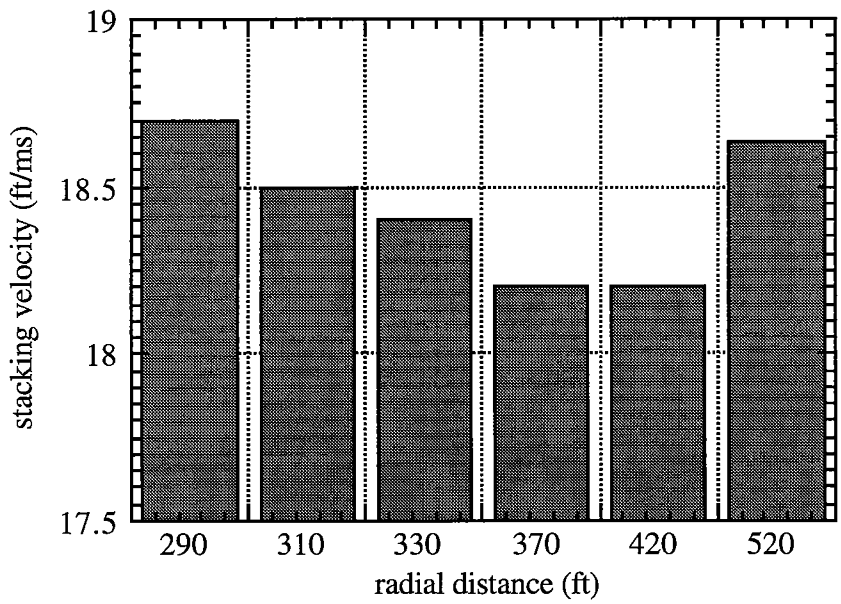

Figure 5. Stacking velocities for reflection depth 2560 feet at the source well.

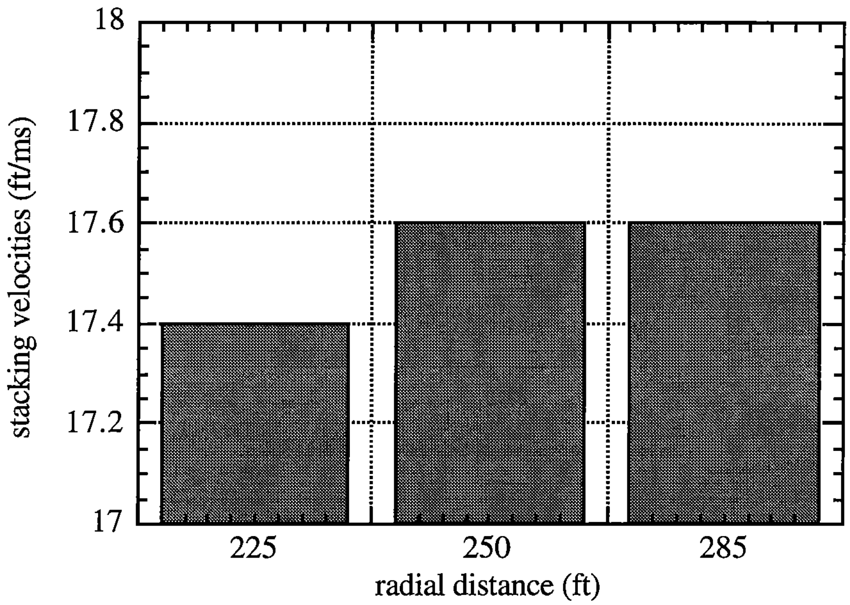

Figure 6. Stacking velocities for reflection depth 2660 feet in the middle of the survey.

INVERSION RESULTS

In figures 7, 8, and 9 we see the interval velocity inversion results from the stacking velocities for reflections points at the source well for reflection depths of 2410 feet and 2560 feet, and in the middle of the wells at 2660 feet respectively. We see an interval velocity structure from each of these inversions.

Combining the inversions - imaging

In order to combine the inversions from all reflection depths for a given reflection lateral point location, we define a bin region of 10 ft thick vertically going from the source to receiver well. Within each bin we average the interval velocities determined from all the reflection depth inversions for that depth. In figures 10, 11, and 12 we see the combined inversions for the reflection lateral locations at the source well, in the middle of the survey, and at the receiver well . We see a well defined velocity profile for each of these inversions. We see more variation and depth range for the inversion at the source and receiver wells than in the middle of the survey. The range of radial distances used in velocity analysis in the middle of the wells is much smaller than the range at the wells due to the poorer signal to noise ratio.

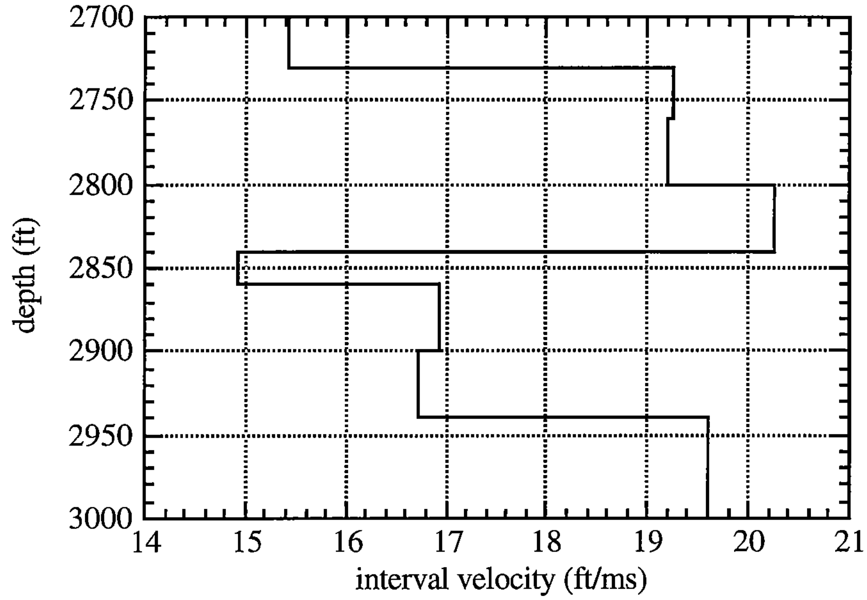

Figure 7. Interval velocities for reflection depth 2410 feet at the source well.

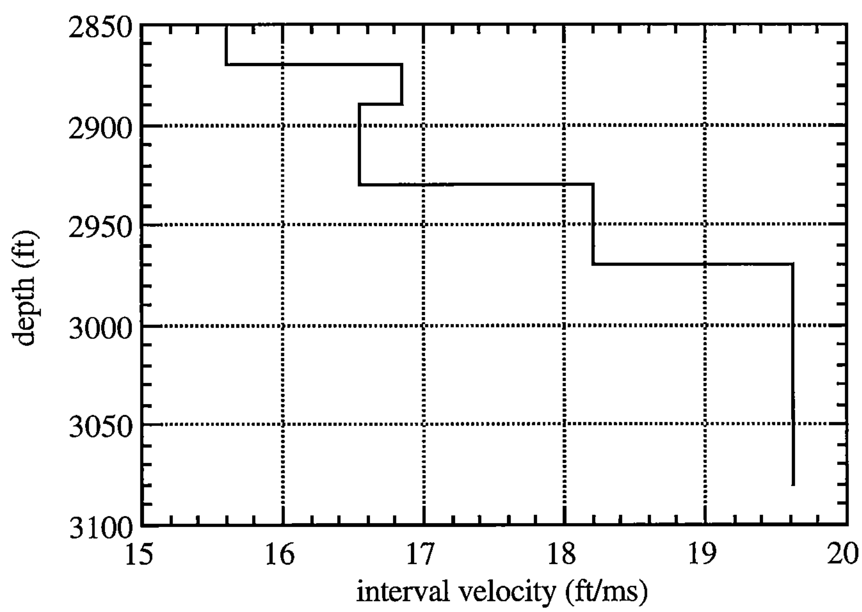

Figure 8. Interval velocities for reflection depth 2560 feet at the source well.

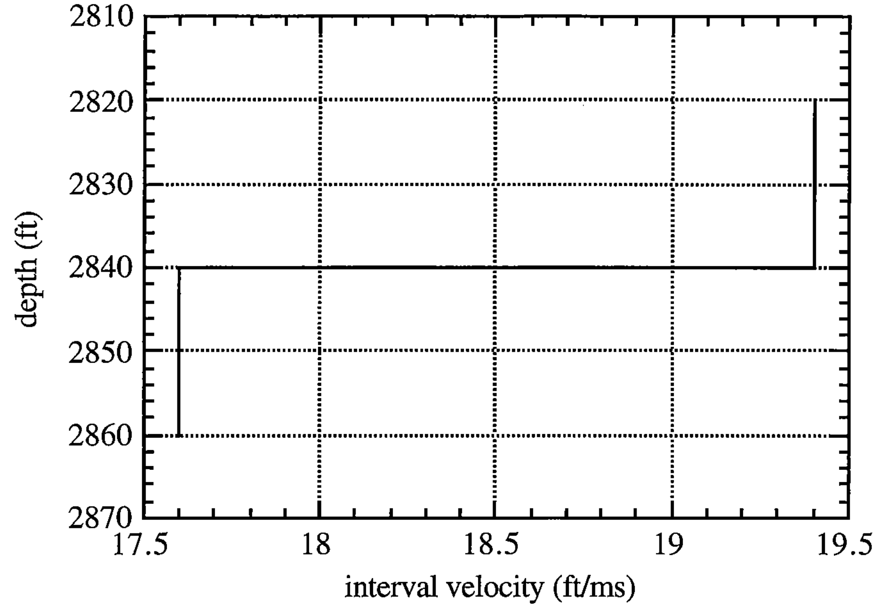

Figure 9. Interval velocities for reflection depth 2660 feet in the middle of the survey.

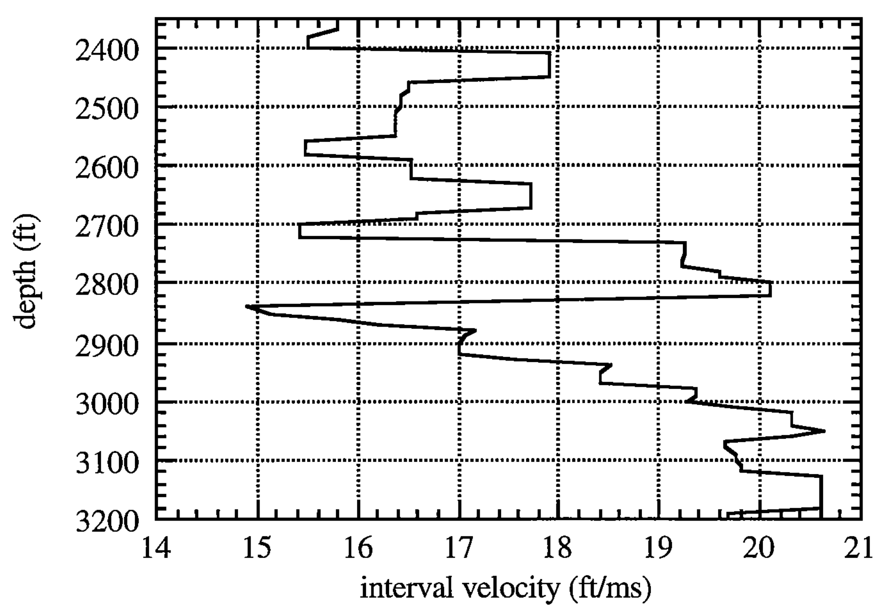

Figure 10. Final interval velocity profile from reflection points at the source well.

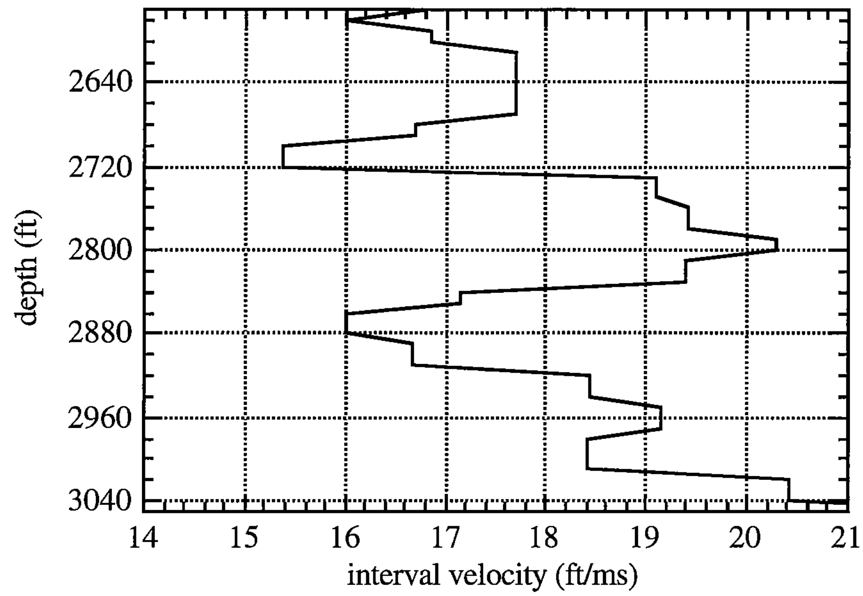

Figure 11. Final interval velocity profile from reflection points in the middle of the survey.

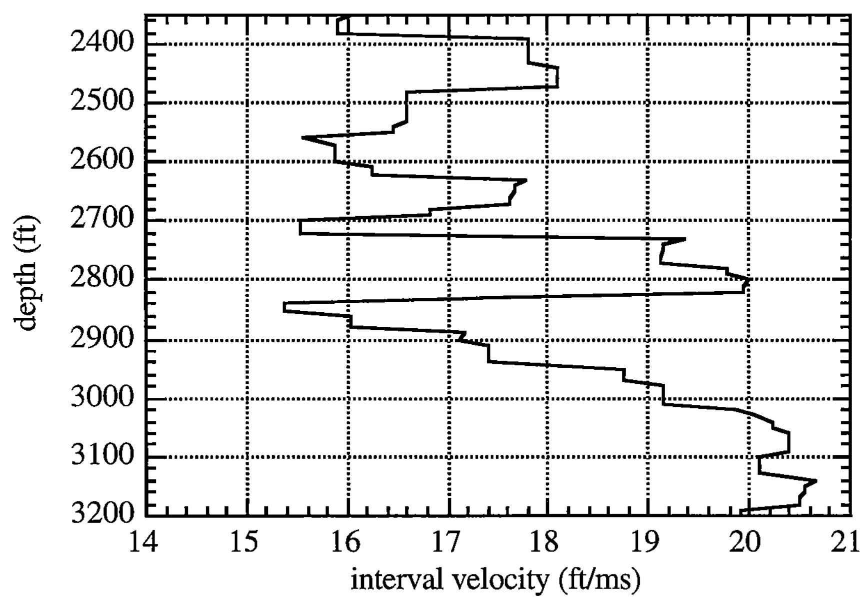

Figure 12. Final interval velocity profile from reflection points at the receiver well.

CONCLUSIONS

We have presented a method for inverting for interval velocities from stacking velocities determined from reflection velocity analysis. The interval velocity profiles are characterized by a well defined velocity structure and sharp boundaries for reflection points at both the source and receiver wells, and in the middle of the survey.

ACKNOWLEDGMENTS

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