CANADIAN JOURNAL OF EXPLORATION GEOPHYSICS
VOL. 32, NO. 2 (DECEMBER 1996), P. 139-142

SHEAR-WAVE INTERVAL VELOCITY FROM P-S STACKING VELOCITIES

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ABSTRACT

The stacking velocity for P-S = > for P-S/converted waves is used to calculate a Dix interval velocity for shear waves. In synthetic examples, we find that the calculated long-wavelength shear velocity agrees well with log values. We also find that the estimated stacking velocities (and thus interval velocities) are strongly dependent on the offset range used. Small offset ranges correspond better to the assumption that stacking velocity is equal to the RMS velocity – thus allowing Dix analysis. Application to a field data set over the Blackfoot pool in Southern Alberta shows reasonable agreement with an S-wave log in the area.

INTRODUCTION

Estimation of the P-wave interval velocity from the stacking velocity is a common procedure in processing P-P data. We assume that the stacking velocity, calculated from the coherency of hyperbolic events across a gather, is equal to the RMS velocity. From the RMS velocity, we compute the Dix interval velocity. The interval velocity can be used in further processes such as migration and inversion. The S-wave interval velocity is also of interest for rock property analysis and three-component seismic processing. So, we ask, can a procedure, similar to conventional Dix velocity analysis, be developed for estimating shear velocity from converted-wave (P-S) =) converted-wave (P-S) stacking velocities?

We can find the converted-wave stacking velocity using a variety of methods, including standard velocity analysis (hyperbolic scanning). Once we have this stacking velocity, we again assume it is equal to the RMS velocity and compute S-wave interval velocities from it. This is done using the standard Dix interval velocity calculation as follows.

DIX INTERVAL VELOCITIES

Suppose that we have a layered medium (with layers i=1, N) having P-wave and S-wave interval velocities (α_i, β_i). Each layer has a set of transit times: t_i^p for one-way P-waves and t_i^s for one-way S-waves (Figure 1).

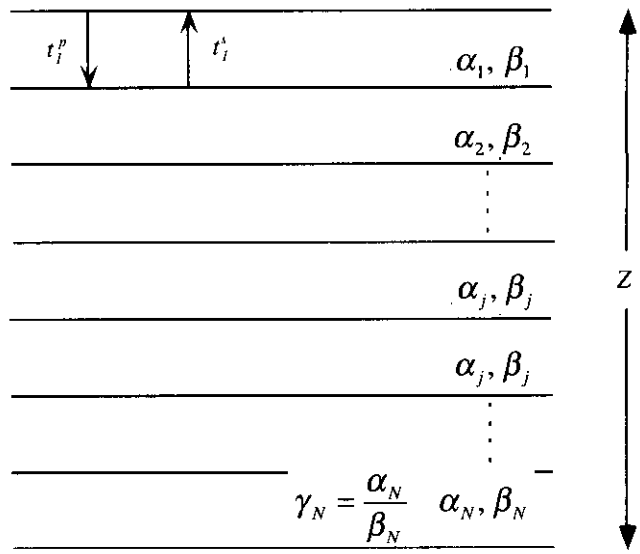

Fig. 1. Plane-layer elastic medium with N layers.

The converted-wave RMS velocity is given by Tessmer and Behle (1988):

$$V_k^2 = \frac{\sum_{i=1}^{k} \alpha_i \beta_i t_i}{T_k}, \text{ where } t_i = t_i^p + t_i^s, \text{ and}$$
$$T_k = \sum_{i=1}^{k} t_i . \tag{1}$$

Following standard procedures for computing the Dix interval velocity (e.g., Dix, 1955; Sheriff and Geldart, 1983), we have:

$$V_k^2 T_k - V_j^2 T_j = \sum_{i=1}^{k} \alpha_i \beta_i t_i - \sum_{i=1}^{j} \alpha_i \beta_i t_i . \tag{2}$$

Manuscript received by the Editor October 15, 1996; revised manuscript received November 12, 1996.
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If $k = j + 1$, then

$$V_{j+1}^2 T_{j+1} - V_j^2 T_j = \alpha_{j+1}\beta_{j+1}\left(T_{j+1} - T_j\right) \tag{3}$$

and

$$\alpha_{j+1}\beta_{j+1} = \frac{V_{j+1}^2 T_{j+1} - V_j^2 T_j}{T_{j+1} - T_j} \tag{4}$$

$$\beta_{j+1} = \frac{V_{j+1}^2 T_{j+1} - V_j^2 T_j}{\alpha_{j+1}(T_{j+1} - T_j)} \, . \tag{5}$$

So knowing the converted-wave traveltimes bounding the interval of interest, the converted-wave stacking velocities, plus the P-wave interval velocity allows computation of the S-wave interval velocity. Direct computation of β_j+1, in this manner though, requires correlation of P-P and P-S events to find the associated P-wave velocity (α_{j+1}). On the other hand, from the P-S data alone, we could find the interval velocity product ($\alpha_{j+1}\ \beta_{j+1}$) or assume a general relationship between α and β to find the interval shear velocity. In this paper, we find the S-wave interval velocity assuming a linear relationship between α and β.

Synthetic Example

A numerical experiment was conducted to test the new Dix interval velocity equation. P-sonic and density logs were obtained from the Blackfoot pool in Southern Alberta (Figure 2). Some of the regional markers annotated are (BR - Belly River, MR - Milk River, 2WS - 2nd White Speckled Shale, Viking, Coal 1, Mississippian). An S-wave velocity log was derived from the P-sonic using a depth-varying γ value, where γ is the ratio of P-wave velocity to S-wave velocity (Figure 3). The P-wave, S-wave and density logs were used to generate a synthetic P-S gather using the

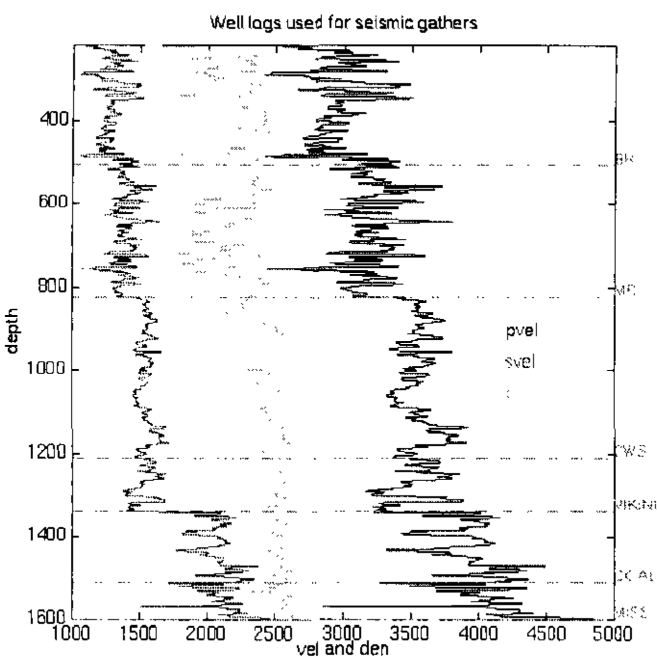

Fig. 2. Logs used to generate the P-S gather of Figure 4. The S-wave velocity (left) was derived from the P-wave velocity (right) using a depth varying γ (Figure 3).

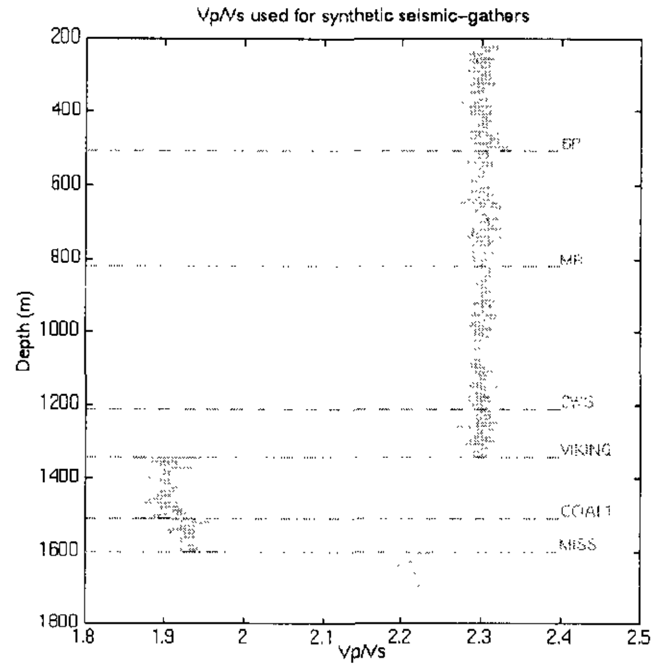

Fig. 3. Depth varying γ (Vp/Vs) used in estimation of S-wave velocity.

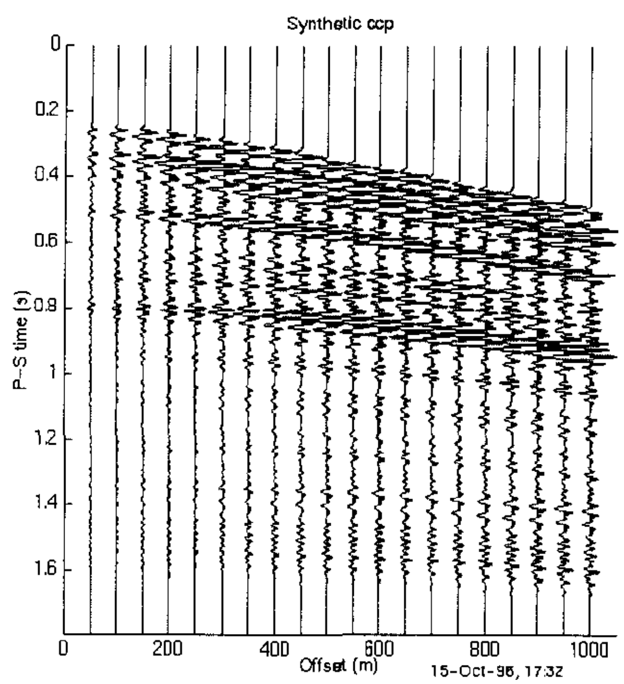

Fig. 4. Synthetic seismic data from the SYNTH, (P-S component). Offsets 0 - 1000 m are shown here. The range of offsets used in velocity analysis (Figure 5) extended from 0 m to 2500 m.

SYNTH algorithm (Lawton and Howell, 1992). The resulting gather is shown in Figure 4. A stacking velocity, picked according to maximum semblance across a hyperbolic moveout, was obtained from the P-S gather (Figure 5).

We tested a number of stretch mutes but found a small number best flattened the near-offset data. Thus, we used a rather severe mute, corresponding to 10% NMO stretch or offset/depth values of about 1.0. The NMO-corrected gather is also shown in Figure 5. We note that the correction is good to offset/depth values of about 1.0. Beyond that, the gathers are over-corrected. This is a result of the inadequacy of the hyperbolic moveout correction for P-S waves. A shifted hyperbolic analysis is more accurate (Slotboom et al., 1990) and is being implemented. To avoid correlation of P-P and P-S data, we assume that $\alpha = \gamma\,\beta$. This allows a direct, but approximate, calculation of β from P-S data alone. Thus,

$$\beta_{j+1} = \left(\frac{V_{j+1}^2 T_{j+1} - V_j^2 T_j}{\gamma(T_{j+1} - T_j)}\right)^{\frac{1}{2}}, \text{ where } \gamma = \alpha/\beta. \qquad (6)$$

The estimated β is compared to the true S-wave velocities in Figure 6. We find a reasonably good correlation, in a low-frequency sense, between the well log and the Dix estimate. With $\gamma = 2.3$ and using only small offset data, the general log character is recovered. Using larger offsets biases the stacking velocity to larger values to compensate for the non-hyperbolic moveout. This causes the corresponding interval velocities to be too large.

Blackfoot Field Data

A comprehensive set of seismic experiments were conducted over the Blackfoot oil field in Southern Alberta

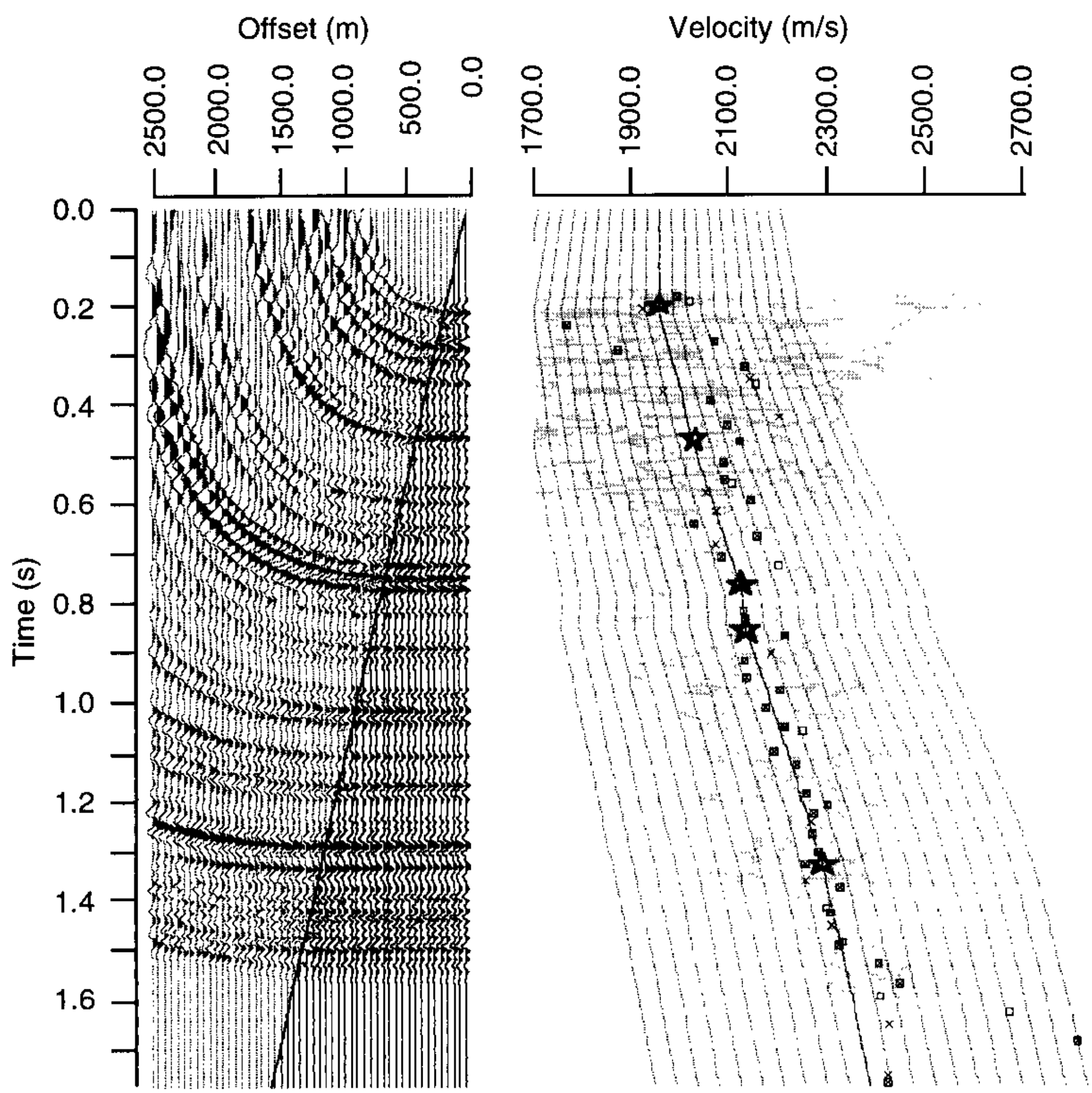

Fig. 5. Semblance velocity analysis of the P-S gather. The gather is shown with the stacking velocity applied (left). The stacking function is marked by stars (right). Note the offset mute required to obtain event flattening (stretch mute = 10%) at near offsets. AGC has been applied to enhance the amplitude of the near offsets to further improve semblance.

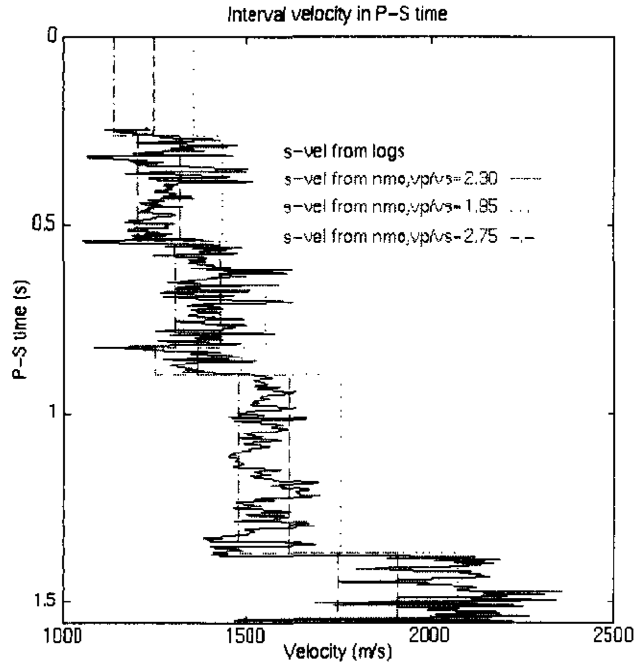

Fig. 6. Comparison of Dix estimates from the velocity analysis of Figure 5 to the S-wave well log. The effect of changing γ (from 1.09 to 2.75) is shown in the plot.

(Stewart et al., 1996). We took the stacking velocities from the 2 Hz P-S section at shotpoint 155 (CCP 100) on the 2-D seismic line. These stacking velocities (Figure 7) were picked independently by a contractor processing the data. They used offsets exceeding 1.0 offset/depth values. Thus we expect the stacking velocities to be raised to higher values. These velocities are then used alone to calculate the interval velocities (with $\gamma = 3.25$ as shown in Figure 7). The resultant interval velocities are compared to an S-wave log from the area. The Dix interval velocity for S-waves reproduces much of the character of the S-wave log (Figure 2) acquired in the area.

Conclusions

This paper presents a technique to compute approximate S-wave interval velocities. The stacking velocity for converted waves is assumed to be equal to the RMS velocity which is, in turn, used to calculate a Dix interval velocity for S-waves. This assumption breaks down at offsets larger than the depth of the event due to the hyperbolic moveout assumption. In synthetic and field examples however, we find that the estimated interval velocity for S-waves agrees reasonably well with log values. This procedure is useful as an independent or complementary estimator of S-wave interval velocity.

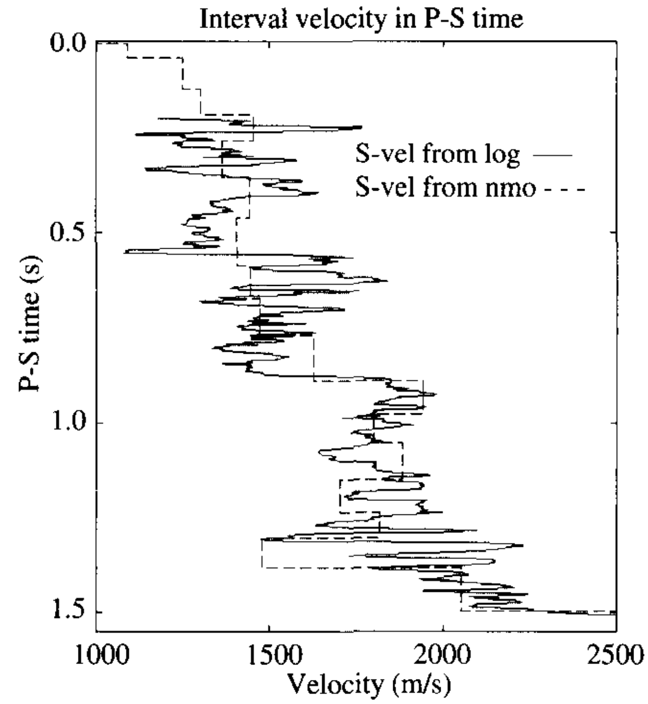

Fig. 7. a) Stacking velocity from the Blackfoot 2D - 3C. Comparison of the Dix estimate to an S-wave log from the area. The γ estimate is high ($\gamma = 3.25$) due to picking the stacking velocities (a) based on large-offset NMO semblance.

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