Migration velocity analysis by curvature measurement and stacking power

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Summary

In conventional seismic processing, velocity analysis is performed by using the normal moveout (NMO) equation that is based on the assumption of flat, horizontal reflectors. Prestack migration velocity analysis can be carried out by using "depth-focusing" and "smiles/frowns" criteria in the iterative and interpretive prestack depth migration procedures. In this paper we develop an analytical equation for migration velocity analysis, which consists of dip-corrected residual normal moveout (NMO), curvature measurement and stacking power. The dip-corrected residual NMO equation is derived by generalizing Al-Yahya's residual NMO equation and Lee's residual NMO and depth restretching equations. Using this dip-corrected residual NMO equation, interval velocity can be estimated accurately by searching a range of γ s (slowness ratios) until the largest semblance (or stacking power) for the value of γ that matches the curvature is obtained. This method proves to be more effective and robust than the historically used residual NMO equations when velocity analysis is performed with dip angles from 0 to 30 degrees.

Introduction

It is well known that velocity accuracy has a great impact on prestack migration. The difficulties of quantifying velocity errors in migration velocity analysis have made prestack depth migration itself, especially the image of complicated structural settings in foothills, to be more challenging. Therefore, it would be more appropriate to understand that the primary goal of imaging is to determine the interval velocity field that positions the reflectors both at their correct lateral and vertical locations (Gray, 1997).

Residual normal moveout (or smiles/frowns) in the post-migrated common image gathers (or migrated common depth point (CDP) gathers or common reflection point (CRP) gathers) results from velocity errors. As part of prestack depth migration, residual velocity analysis can be employed to quantify velocity errors and update the velocity model. Al-Yahya (1989) discussed residual velocity analysis by iterative profile migration. He measured the velocity errors by estimating the curvature of residual moveout. Lee and Zhang (1992) generalized Al-Yahya's residual NMO equation and proposed another residual NMO equation and depth restretching equation. Lee and Zhang's approach considered the dip effect on the residual moveout. However, their method was restricted by the assumptions of small dip angle and small offset compared to the migrated depth.

In this paper, we integrate methods of Al-Yahya, Lee and Zhang and develop an analytical equation for migration velocity analysis. This approach consists of building the dip-corrected residual normal moveout (NMO) equation, measuring a set of curvatures (γ s or slowness ratios) and computing the semblance (or

stacking power) to search the value of γ that matches the residual moveout of common image gathers in the post-migrated data sets. The experimental results prove this method to be effective and accurate in estimating interval velocities with dip angles of 0~30 degrees. Unlike the assumptions made by Lee and Zhang (1992), our method has no restrictions of small offset and small dip.

The principle of residual moveout migration velocity analysis

Reliable prestack depth migration requires an accurate input velocity model. Inaccurate velocity estimates will cause moveout artifacts (or residual moveout), such as smiles and frowns, to appear on depth-migrated common image gathers (Zhu et al., 1998). The residual moveout equation from Al-Yahya (1989) works pretty well for a horizontal reflector since the moveout trajectories in that equation are symmetric at the CMP location, which is also the CRP or CDP location. However, the reflector geometry of the subsurface is not always horizontal. In some complicated structural areas, such as the Canadian Foothills, the shallow clastic formations are generally steeply dipping beds; therefore, building a residual moveout equation suitable for any reflector geometry is of great significance.

Figure 1 shows common-reflection point geometry for non-horizontal reflectors. As we can see that a_0 is the separation of the common reflection point (CRP) from the common midpoint (CMP), which depends on the dip angle θ and the reflector depth z. With the assumptions of straight rays, small dip and small offset compared to depth, Lee and Zhang (1992) derived another residual NMO and depth restretching equations.

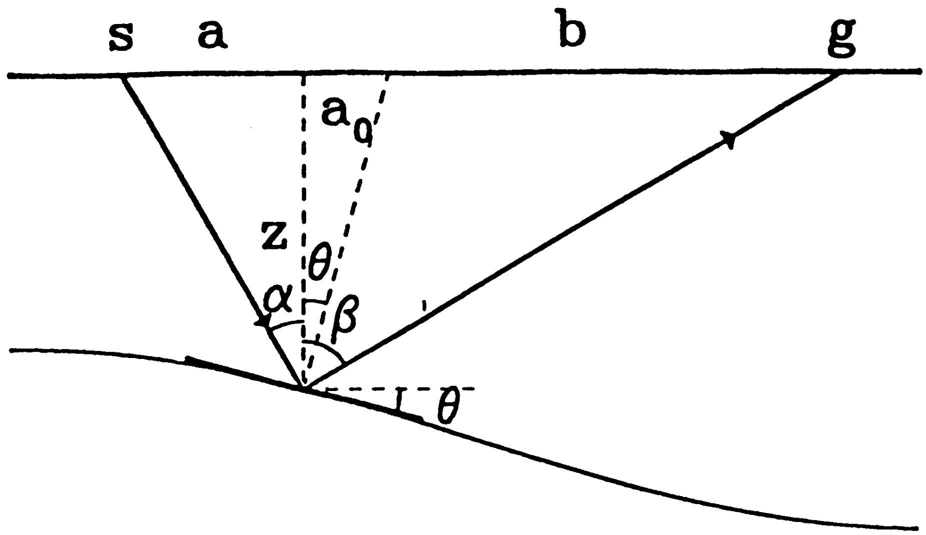


Figure 1. Common reflection point geometry for a nonhorizontal reflector. CRP is separated from CMP by distance a_0 .,
Lee and Zhang (1992),

By integrating the historically used equations from Al-Yahya (1989), Lee and Zhang (1992), we derive a dip-corrected residual normal moveout equation as:

$$\tau_m = \sqrt{\tau_0{}^2 + (\gamma^2 - 1)(a - a_0)^2 w^2{}_m} \quad (1)$$

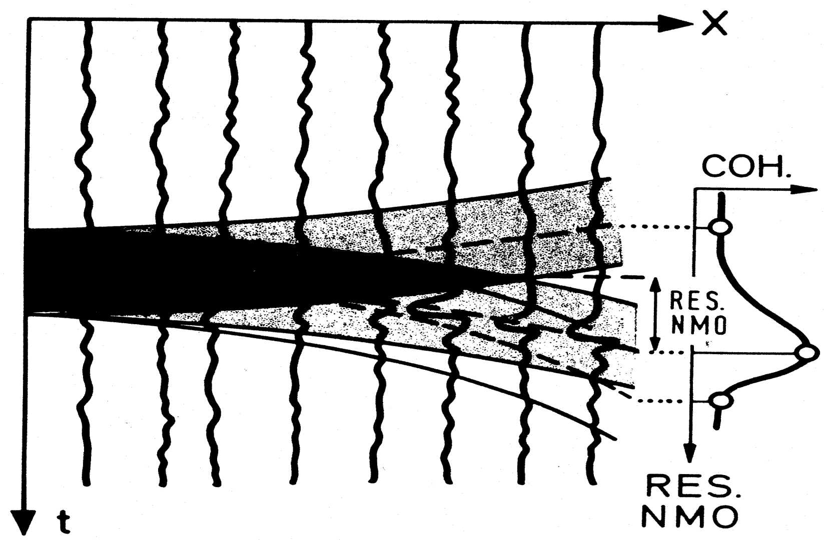
$$\tau_0 = \max(\tau_m) \quad \text{if } \gamma < 1 \quad (2)$$

$$\tau_0 = \min(\tau_m) \quad \text{if } \gamma > 1 \quad (3)$$

$$a_0 = z \tan\theta \quad (4)$$

$$\gamma = \frac{w}{w_m} \quad \text{or} \quad (\gamma = \frac{v_m}{v}) \quad (5)$$

Where τ_m is the migrated time converted by the migrated depth z_m. The goal of the method presented here is to drive all images in the post-migrated CIGs toward $\gamma = 1$, namely, $w_m = w$ (or $v_m = v$) at all depths. This goal is achieved by changing the interval-slowness (or interval-velocity) model, measuring γ s, and calculating semblance until an appropriate γ which matches the moveout is found. Figure 2 illustrates a coherence search along the moveout trajectories of (1) using semblance or any other coherency measure. If the data set in a post-migrated CIG is $p(\tau_m, x)$, then searching for curvature produces the semblance panel $g(\tau, \gamma)$.



$$g(\tau,\gamma)=\frac{\left[\sum_{x} p\left(\tau_m=\sqrt{\tau_0{}^2+(\gamma^2-1)(a-a_0)^2 w_m{}^2},x\right)\right]^2}{\sum_{x}\left[p\left(\tau_m=\sqrt{\tau_0{}^2+(\gamma^2-1)(a-a_0)^2 w_m{}^2},x\right)\right]^2} \qquad (6)$$

Figure 2. Migrated common image gather trace; coherency search along residual NMO curves at a given travel time t_0.

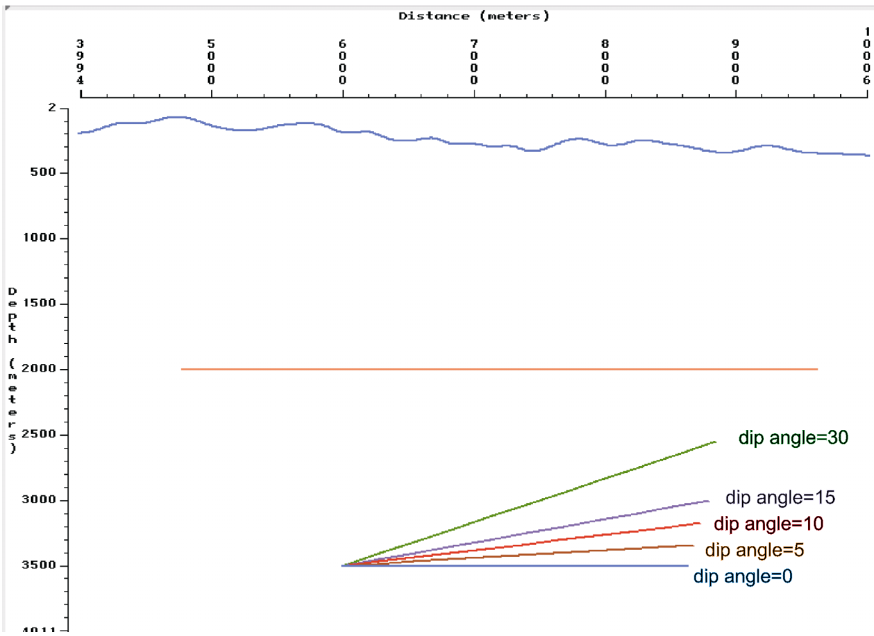
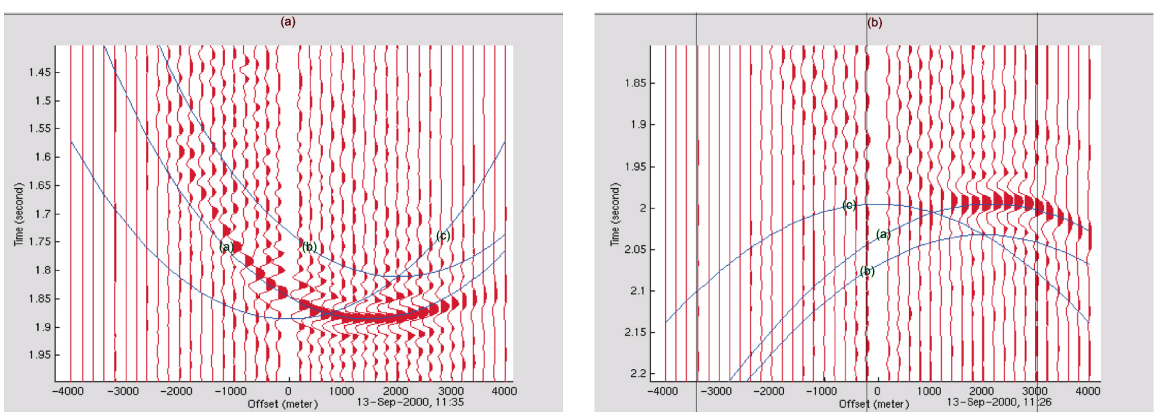


Figure 3. The geologic model for the synthetic example.

Velocity analysis results: a model example

A synthetic data set is generated using the geologic model shown in Figure 3, which has a flat reflector at depth of 2000 m and a dipping reflector at depth of 3500 m. To test the effectiveness and robustness of dip-corrected residual NMO equation in velocity estimation, we make a set of experimental datasets by changing the dip angles from 0 to 30 degrees. The synthetic data are prestack migrated with velocity models in which migration velocities are 10 percent higher and 10 percent lower than the correct values.

Figure 4 shows the velocity analysis comparison of Layer 2 with the dip angle of 30 º. Curve (a) (from equation (1)) in the top panels undoubtedly provides the best fit to the residual moveout compared with curve (b) and curve(c) (from equations of Al-Yahya, Lee and Zhang, respectively). This fact demonstrates that the new derived dip-corrected residual NMO equation is effective and robust when the reflectors become steeply dipping. The accuracy of velocity estimations in the two bottom panels is kept in the allowable range. The estimated value is 4000 m/s in the lower velocity case and is 3920 m/s in the higher velocity case with the velocity errors around -1.01%~1.01%.



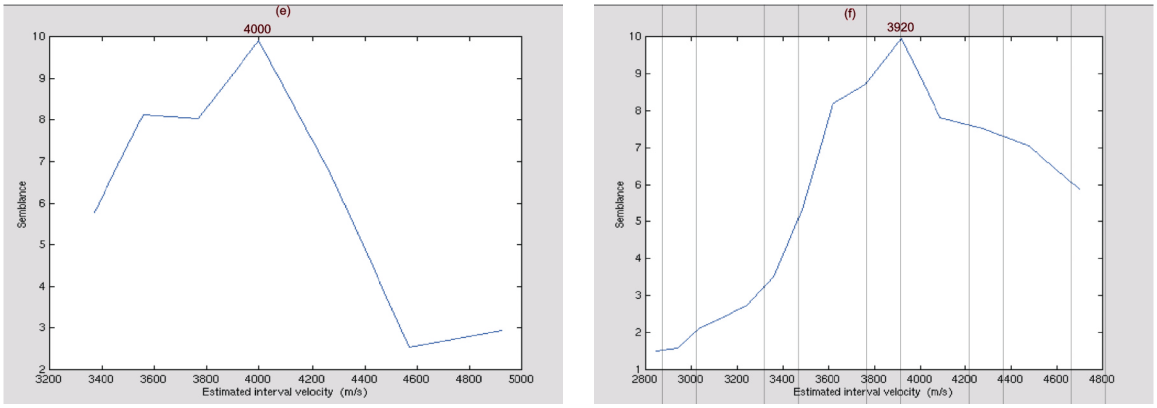


Figure 4. Migration velocity analysis with the dip angle of Layer 2 at 30 º.

Conclusions

The dip-corrected residual normal moveout equation (1) is derived by integrating the residual NMO equations from Al-Yahya (1989), Lee and Zhang (1992). The velocity estimations on a set of experiments demonstrate that this new residual NMO equation is much more effective and more robust than the previously used equations when applied to steeply dipping reflectors. The interval velocity estimation is constrained by two factors; one is the best fit of the trajectories to the residual moveout and the other is the maximum semblance calculation. No assumptions regarding the offset range and the dip angle are required in this method.

References

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