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Dip-dependent residual moveout

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ABSTRACT

Residual moveout is an effective tool for interval velocity analysis for depth migration. However, the conventional residual moveout method assumes that the reflectors in the subsurface are all flat, and thus estimates curvature parameters for velocity analysis that are inaccurate for steeply dipping reflectors. In this paper, we develop a dip-dependent residual moveout method, which is performed in the Fourier domain and handles dip effects.

INTRODUCTION

Prestack depth migration produces superior images of complex structures and has become practical with the continued improvement of computer performance. However, the method is sensitive to errors in the velocity model and requires a good velocity model from velocity analysis.

Velocity analysis, whether ray-based (Clapp, 2001) or wave-equation-based (Sava and Biondi, 2003), requires estimation of the curvature parameters of common image gathers (CIGs). Residual moveout and residual migration (Sava, 2003) are two leading methods for estimating the curvature parameters. Residual migration, the more accurate of the two methods, constrains only global velocity changes. However, residual moveout, although assuming stationary rays, estimates the curvature parameters of CIGs affected by local velocity changes.

For 2-D problems, Biondi and Symes (2003) show that the image point should be on a line that passes through the crossing point between source and receiver rays and is normal to the reflector. When the migration velocity is not the true velocity, the migrated image points move in the direction normal to the reflector at the reflection point. However, conventional residual moveout methods assume that the image point moves only vertically. For steeply dipping reflectors, the normal direction deviates from vertical, approaching horizontal for nearly vertical reflectors. Thus, the vertical moveout assumption in the conventional residual moveout methods may lead to significant errors in the estimation of the curvature parameters for velocity analysis.

In this paper, we suggest a new way to perform residual moveout, which we call dip-dependent residual moveout. The key idea is to perform phase shifts in the Fourier domain instead of image-point shifts in the space domain. In the Fourier domain, dip information

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can be obtained easily, so that the new method can account for dip effects and result in more accurate curvature parameters.

ANGLE-DOMAIN CIGS

Most current migration velocity analysis methods (Sava and Biondi, 2003; Clapp, 2001) are based on the curvature information from Angle-Domain CIGs(ADCIGs), which are created from the migration cube (Sava and Fomel, 2003). When the migration velocity is the true velocity, the ADCIG at a reflection point is a flat line. When the migration velocity is inaccurate, the curvature parameters estimated from ADCIGs can be back-projected and inverted for velocity updates. Biondi and Symes (2003) demonstrates that in an ADCIG cube, the image point lies on the line normal to the apparent reflector dip, passing through the point where the source ray intersects the receiver ray. Figure 1 shows the ADCIGs at reflection points of different dip angles. Under the stationary-raypath assumption, the shift of the image point along the normal direction is (Biondi and Symes, 2003)

$$\Delta \mathbf{n} = \frac{1-\rho}{1-\rho(1-\cos\alpha)} \frac{\sin^2\gamma}{\cos^2\alpha - \sin^2\gamma} z_0 \mathbf{n}, \tag{1}$$

where ρ is the constant scaling factor of the slowness, α is dip angle of the reflector, γ is the opening angle, $\mathbf{n}$ is the normal direction vector of the reflection point, and z_0 is the depth at the reflection point. For flat reflectors, the shift (1) reduces to

$$\Delta \mathbf{n} = (1-\rho)\tan^2\gamma z_0 \mathbf{n}. \tag{2}$$

Equations (1) and (2) can be used to estimate the curvature parameters for velocity analysis. However, to estimate the curvature parameters caused by local velocity perturbation, we don't consider the effect of depth z_0.

RESIDUAL MOVEOUT IN THE FOURIER DOMAIN

Conventional residual moveout is usually performed in the space domain. It assumes that the reflectors are flat, and thus image points only need to move vertically to flatten the ADCIGs. However, in dip-dependent residual moveout, the image points are moved along the direction normal to the reflector to flatten the ADCIGs.

It is difficult to calculate an accurate dip map for an image in the space domain, but the dip map can be obtained easily in the Fourier domain by the following relation:

$$\tan\alpha = \frac{k_x}{k_z}, \tag{3}$$

where α is the dip angle, and k_x and k_z are the wave numbers of x and z direction, respectively. In the local versions of equation (1) and (2), the shift along the direction normal to the

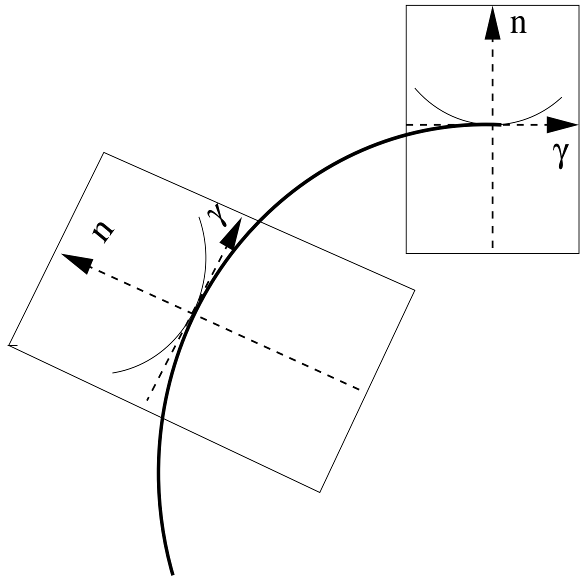

Figure 1: ADCIGs with different dip angles. **n** is the normal direction vector, and γ is the opening angle. guojian1-ball [NR]

reflectors depends only on the dip angle α and the opening angle γ. In the Fourier domain, the dip angle α is calculated by equation (3), and the opening angle γ by

$$\tan\gamma = \frac{k_h}{k_z}, \tag{4}$$

where k_h is the wave number of offset h (Sava and Fomel, 2003). Let Δn be the shift along the direction normal to the reflectors. From the geometric relation, the shift along the normal direction is equivalent to a horizontal shift $\Delta x = \sin\alpha\Delta n$ followed by a vertical shift $\Delta z = \cos\alpha\Delta n$. Figure 2 shows, for an ADCIG at a reflection point with a dip angle of α, the relation between normal direction shift Δn, horizontal shift Δx and vertical shift Δz. A shift in the space domain is equivalent to a phase shift in the Fourier domain. Let $I(x,z,h)$ be the image cube obtained by migration, and $I(k_x,k_z,k_h)$ is its Fourier transformation. Then in the space domain, the shift Δn along the direction normal to the reflector is equivalent to a phaseshift of k_x followed by a phaseshift of k_z:

$$I^{RMO}(k_x,k_z,k_h) = I(k_x,k_z,k_h)\cdot e^{ik_x\Delta x}\cdot e^{ik_z\Delta z} \tag{5}$$

in the Fourier domain.

SYNTHETIC DATA EXAMPLE

In this section, We present a 2-D synthetic example to verify the theory. The reflector of the synthetic model has a spherical shape with a radius of 500 m. Modeling and migration have been done in Biondi and Symes (2003). Figure 3 shows the images obtained with the

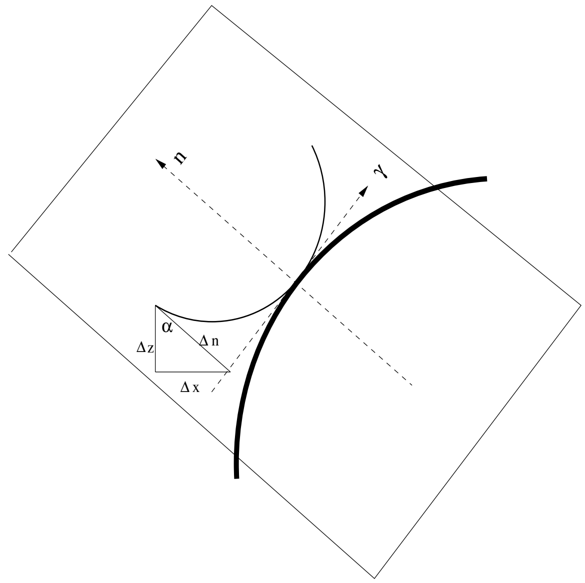

Figure 2: Geometric relation between the shift in normal direction Δn, the horizontal shift Δx and the vertical shift Δz. guojian1-geometry [NR]

true (left panel) and a too low ($\rho = 1.04$) (right panel) velocity models. Figure 4 shows the conventional residual moveout and dip-dependent residual moveout with a same velocity scale parameter. The vertical axes of these three panels are the direction normal to the reflector and the horizontal axes are the opening angle. The ADCIG is at $x = 3100$m, $z = 720$m, where the dip angle is about 45 degree. Panel (a) is the ADCIG without residual moveout. Panel (b) is the ADCIG after conventional residual moveout. Panel (c) is the ADCIG after dip-dependent residual moveout. In Figure 4, the energy out of 40 degree is the noise due to the illumination. Figure 5 shows the ADCIGs at $x = 2900$m, $z = 1000$m, where the dip angle is about 60 degree. The energy out of 20 degree is the noise due to the illumination. Comparing to 45 degree case, we find that the 60 degree case has a smaller aperture and is more affected by the noise. Since the dip-dependent residual residual moveout moves image points in the direction normal to the reflector (vertical axes in Figure 4 and Figure 5), rather than the vertical direction (z direction) as in the conventional residual moveout processing, the former method flattens the ADCIGs better.

CONCLUSION

We develop a dip-dependent residual moveout formulation and test it on a synthetic dataset with steep dips. We perform the new residual moveout method as a phase shift in the Fourier domain, and obtain more accurate curvature parameters than with traditional spatial residual moveout. Although a 2-D example is tested in this paper, the method can easily be extended to 3-D.

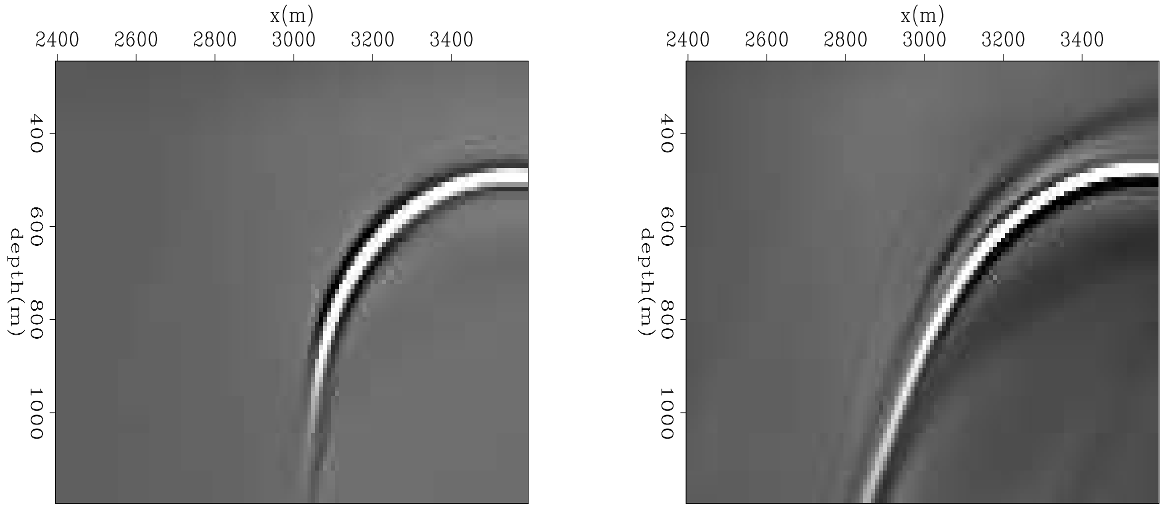

Figure 3: Migration results: Left panel is the image migrated with the correct velocity. Right panel is the image migrated with a too slow velocity. guojian1-migration [ER]

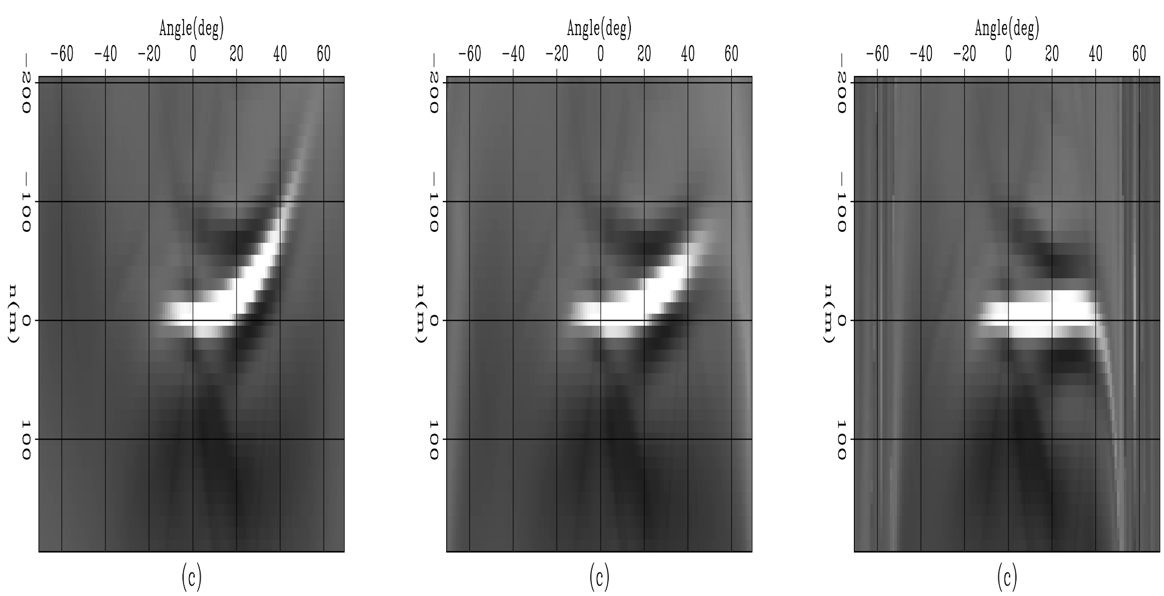

Figure 4: Compares between conventional and dip-dependent residual moveout: (a) ADCIG at $x = 3100$m, $z = 720$m without residual moveout; (b) ADCIG at $x = 3100$m, $z = 720$m after conventional residual moveout; (c) ADCIG at $x = 3100$m, $z = 720$m after dip-dependent residual moveout. The vertical axes n is the direction normal to the reflector. The dip angle at $x = 3100$m, $z = 720$m is about 45 degree. guojian1-rmo45 [ER]

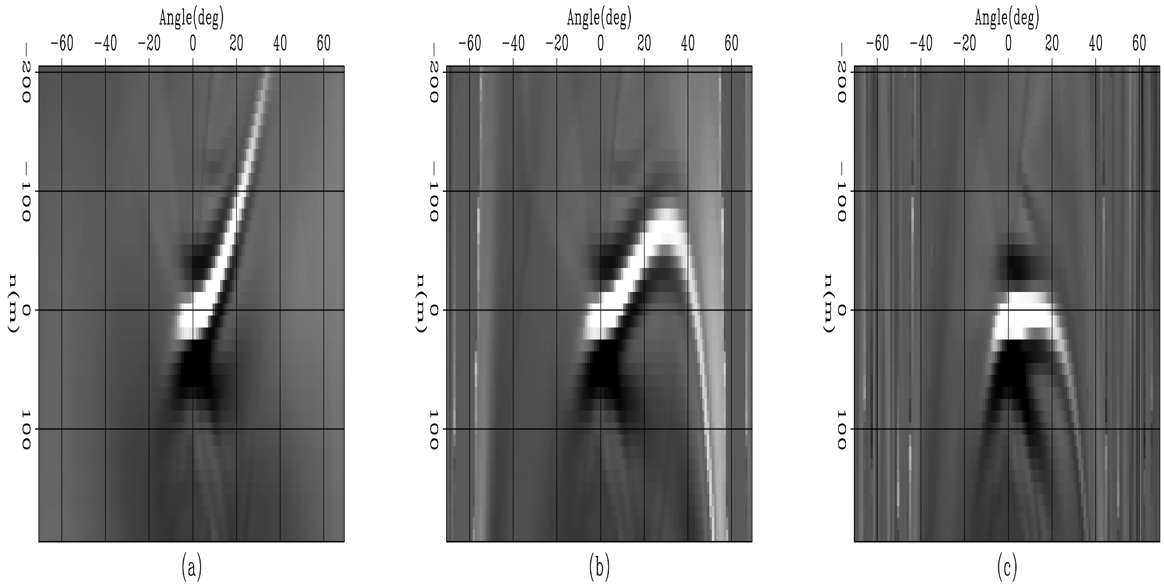

Figure 5: Compares between conventional and dip-dependent residual moveout: (a) ADCIG at $x = 2900$m, $z = 1000$m without residual moveout; (b) ADCIG at $x = 2900$m, $z = 1000$ m after conventional residual moveout; (c) ADCIG at $x = 2900$m, $z = 1000$ m after dip-dependent residual moveout. The vertical axes n is the direction normal to the reflector. The dip angle at $x = 2900$m, $z = 1000$m is about 60 degree. guojian1-rmo60 [ER]

REFERENCES

Biondi, B., and Symes, W., 2003, Angle-domain common-image gathers for migration velocity analysis by wavefield-continuation imaging: SEP–**113**, 177–210.

Clapp, R. G., 2001, Geologically constrained migration velocity analysis: Ph.D. thesis, Stanford University.

Sava, P., and Biondi, B., 2003, Wave-equation migration velocity analysis by inversion of differential image perturbations: SEP–**113**, 299–312.

Sava, P., and Fomel, S., 2003, Angle-domain common-image gathers by wavefield continuation methods: Geophysics, 68, 1065–1074.

Sava, P., 2003, Prestack residual migration in the frequency domain: Geophysics, 68, 634–640.