Kirchhoff Prestack Time Migration with Angle Domain Common Image Gathers

Summary

This poster shows one method to construct angle gathers during prestack Kirchhoff time migration and an other method to convert migrated offset gathers to angle gathers. The first method extracts angle gathers at each image point through gradients of travel time from the source and the receiver to the reflector. The second method calculates the angle at each image point with a certain offset for a given background velocity and a local dip, thus creating angle gathers.

Introduction

Common image gathers (CIGs) produced from Kirchhoff time migration are conventionally in the offset domain. Offset CIGs are commonly used for migration velocity analysis and AVO studies. However, recent works show that more benefits can be obtained from seismic data by processing in angle CIGs. Basic concepts of angle CIGs and techniques of creating angle CIGs can be seen from Fomel and Prucha (1999) as well as Mahmoudian and Margrave (2009). The purpose of this poster is to show two methods of providing angle CIGs from prestack Kirchhoff time migration. One calculates the reflection angle in terms of travel time and velocity (both RMS and interval) during migration and the other converts offset CIGs to angle CIGs with a provided velocity field and a dip field.

Theory

1. Angle calculation in prestack Kirchhoff time migration

Producing angle gathers from prestack Kirchhoff time migration is simply to calculate the angle between source and receiver rays. Although Kirchhoff time migration is a constant velocity migration procedure at each image point, the ray is actually curved in the depth domain in the case that velocities vertically above this image point are not constant. The following figure shows that the opening angle is the angle between gradients of the travel time from the source and the receiver to the image point.

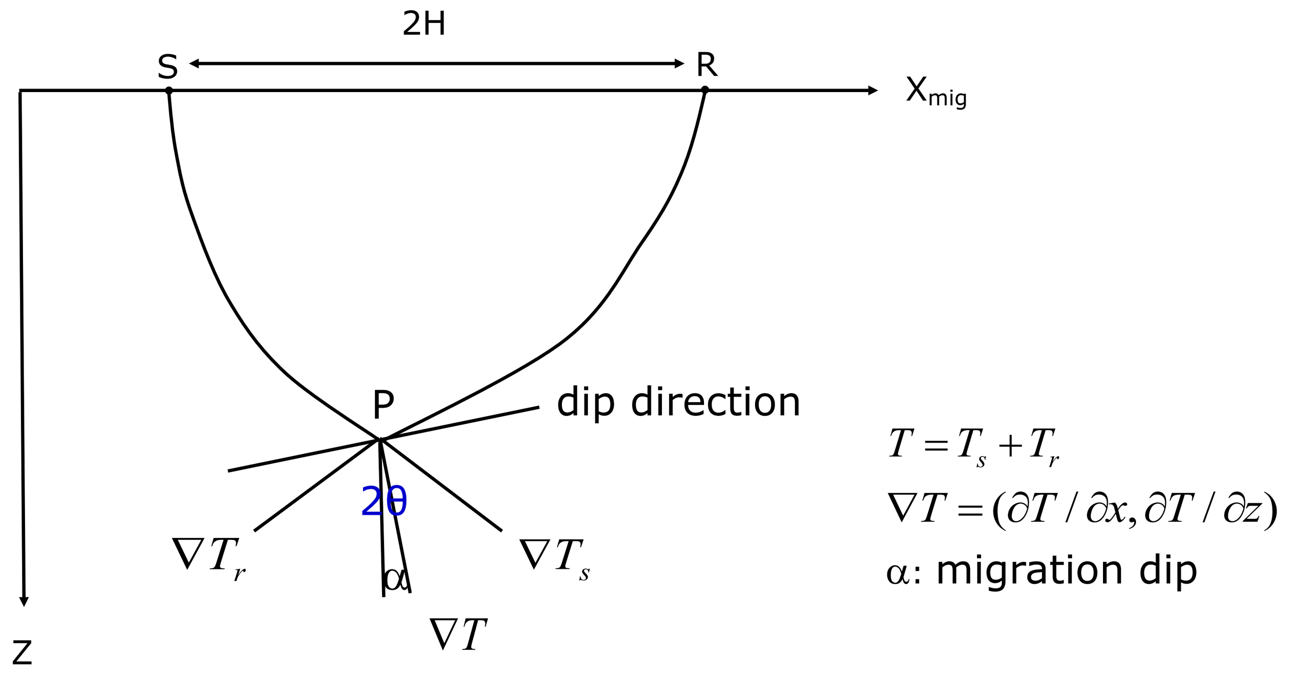

Figure 1: Angle in Kirchhoff migration. *2θ* is the opening angle between the source and receiver rays, and α is the dip angle (an angle between the vertical axis and the gradient of total travel time ∇T).

From the time to depth conversion $dz = \frac{1}{2} v_{\text{int}} d\tau$ one can see that

$$\nabla T_s = \left(\frac{\partial T_s}{\partial x}, \frac{\partial T_s}{\partial \tau}\frac{2}{v_{\text{int}}}\right) \quad \text{and} \quad \nabla T_r = \left(\frac{\partial T_r}{\partial x}, \frac{\partial T_r}{\partial \tau}\frac{2}{v_{\text{int}}}\right),$$

Where τ is the two-way vertical travel time and v_{int} is the interval velocity at the image point P. The reflection angle can then be obtained from the following equation

$$\cos(2\theta) = \frac{\nabla T_s \bullet \nabla T_r}{|\nabla T_s| |\nabla T_r|} \quad . \tag{1}$$

The above equation is valid for both isotropic and anisotropic medium. Calculating the travel time gradient takes time and thus migration for angle CIGs will be more resource intensive than for offset CIGs.

2. Conversion from offset CIGs to angle CIGs

Since the dip direction is perpendicular to the direction ∇T, one can see

$$\frac{\partial T / \partial x}{\partial T / \partial z} = -\tan\alpha. \tag{2}$$

Let $x - \xi$ be the horizontal distance between the source-receiver midpoint x and the reflection point ξ, and h be the half of the source-receive offset. The travel time T is expressed in terms of $x - \xi$, h, τ and RMS velocity v_{rms} at the point P. As an example of the isotropic background medium, T is formulated through

$$T = T_s + T_r = \sqrt{\frac{\tau^2}{4} + \frac{[(x-\xi)-h]^2}{v_{rms}^2}} + \sqrt{\frac{\tau^2}{4} + \frac{[(x-\xi)+h]^2}{v_{rms}^2}} \quad . \tag{3}$$

Solving the equation (2) by Newton iteration for $x - \xi$, one can calculate travel time T_s as well as T_r and can furthermore obtain $\cos(2\theta)$ from the equation (1). Therefore, for a position (time, offset) in an offset gather at a horizontal position, and for a given associated dip, the opening angle can be calculated.

Real Data Examples

Migrated angle CIGs as well as offset CIGs and angle CIGs converted from offset CIGs with a few selected CDP locations in a 2D dataset are shown in the following examples. Angle CIGs in Figure 4 are standard output directly from migration. Angle CIGs in Figure 5 are quite similar to the one in Figure 4 except for sparsely distributed amplitudes in the shallow area. The reason for this is because the original offset CIGs in Figure 3 do not have enough information in the shallow area. To overcome this problem, the offset interval is decreased to 4 meters (see Figure 3) so that the converted angle CIGs in Figure 6 are almost the same as in Figure 4 and are thus more accurate than the one in Figure 5.

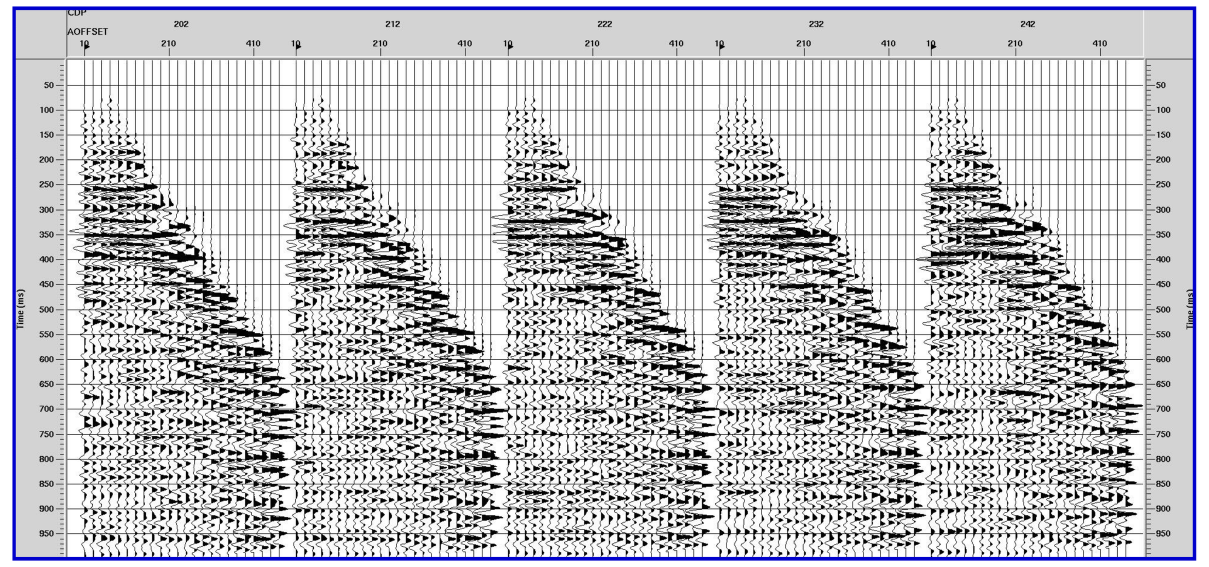

Figure 2. Offset CIGs with 24 offset bins and an offset interval of 20m.

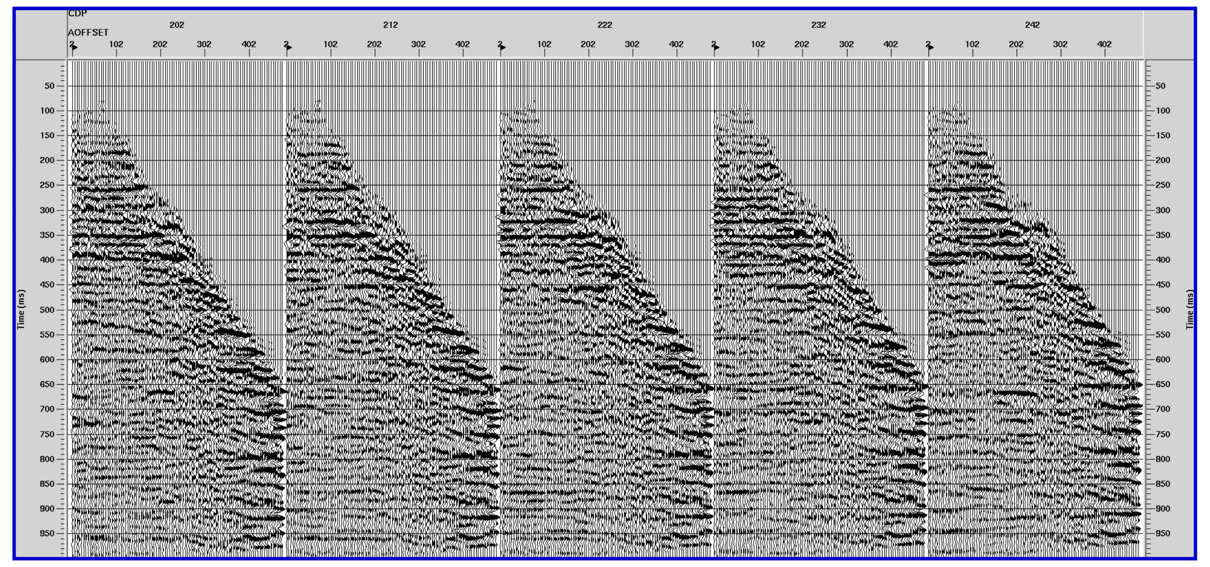

Figure 3. Offset CIGs with 96 offset bins and an offset interval of 4m.

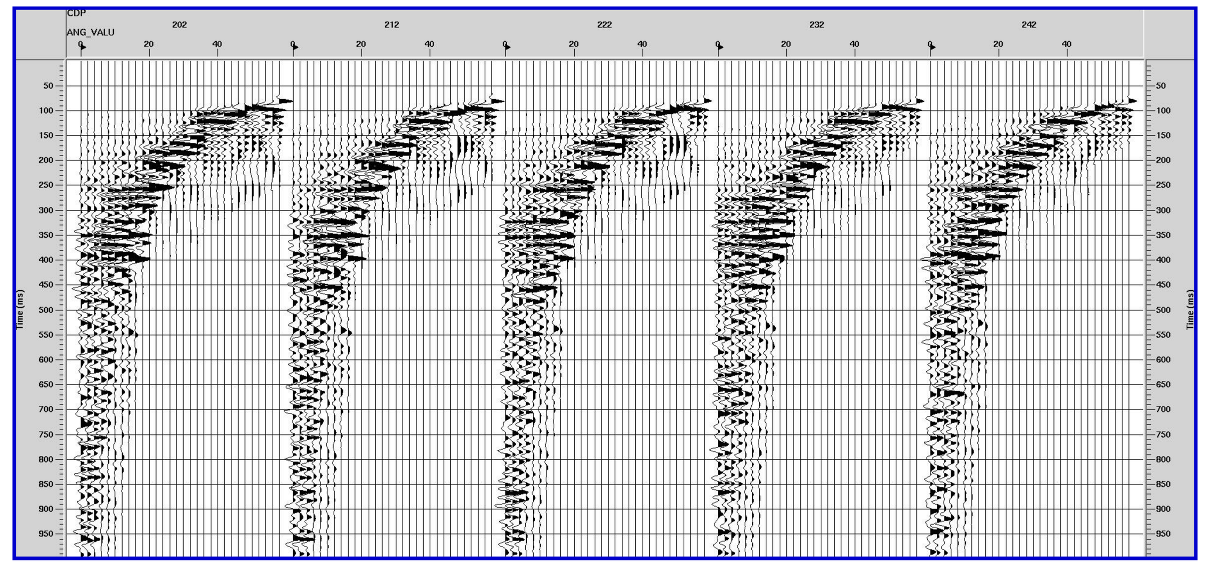

Figure 4. Angle CIGs directly from migration with 30 angle bins and an angle interval of 2 degrees.

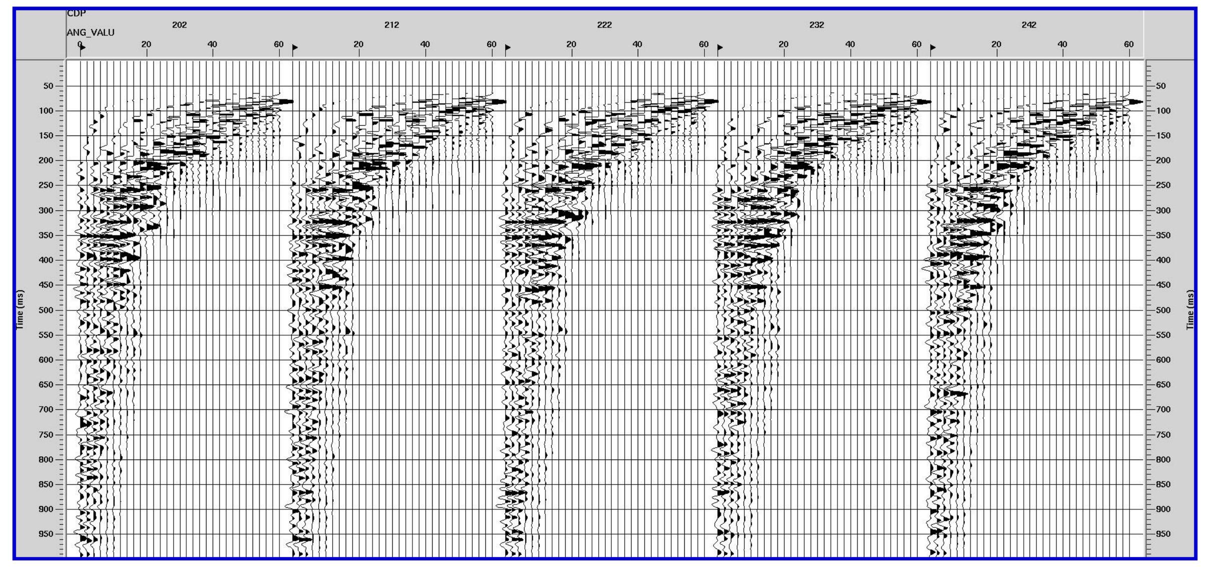

Figure 5. Angle CIGs converted from offset CIGs in Figure 2 with 30 bins and an interval of 2 degrees.

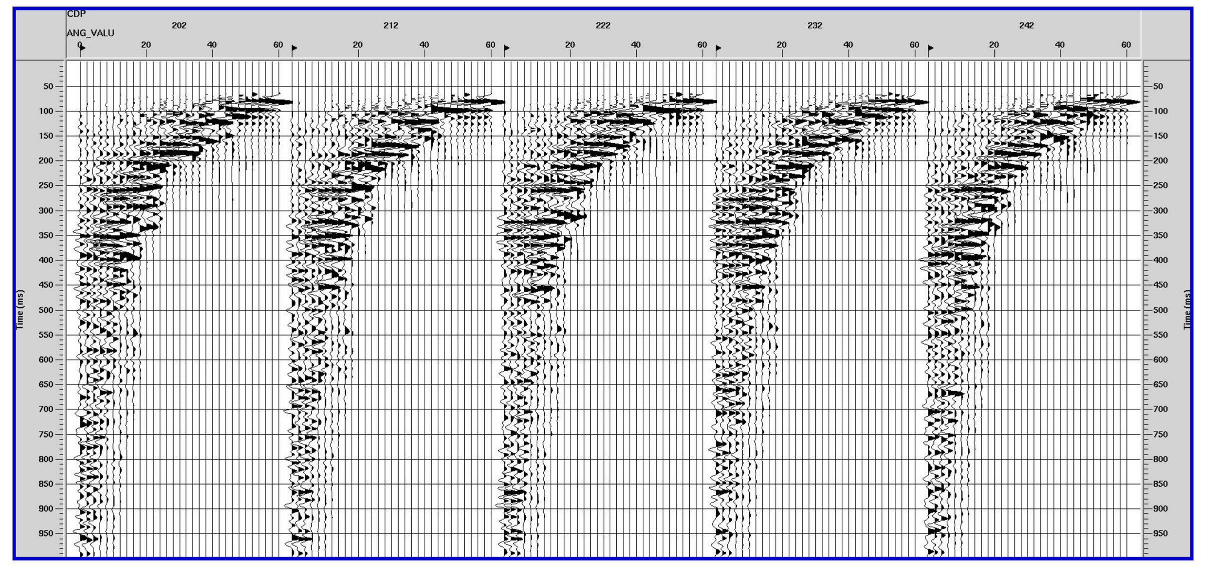

Figure 6. Angle CIGs converted from offset CIGs in Figure 3 with 30 bins and an interval of 2 degrees.

Conclusion

Two methods for obtaining angle CIGs from Kirchhoff time migration are shown. Both methods are to calculate the angle between gradients of the travel time from source location to the image point and the image point to the receiver location. One method easily does it during migration. For migrated offset CIGs, the other method solves an equation about gradients of travel time and the dip angle for the distance between source-receiver midpoint and the horizontal location of the image point, and then calculates the gradients of travel time to obtain an incident angle. Thus offset CIGs can be converted to angle CIGs as long as the migration velocity and dip fields from the stack data are provided.

References

Fomel S. and Marie P., 1999, Angle-gather time migration, SEP report 100, 141-151.

Mahmoudian F. and Margrave G. F., 2009, A review of angle domain common image gathers, CREWES Report 21.

Presented by:
Dr. Jianhua Pan*, Rob Tilson, Gerry Schlossser and Elvis Floreani.

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