Angle domain common imaging point gathers during Kirchhoff PSTM

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Summary

In this paper we present the improved algorithm for angle domain common imaging point gathers during pre-stack Kirchhoff time migration. The algorithm can calculate relatively true incident angle under three-dimensional circumstance, while the traditional ray-parameter method could not handle the incident angle for the dipping events. Compared with straight-ray Kirchhhoff angle domain gathers method proposed in recent years, our method is able to extract wide-angle. Increased angular illumination is beneficial for AVA inversion. The results of synthetic model data have verified that : for V(z) (layered) media, the traveltime calculation adopt bending ray, which is much more accurate than straight ray for large angle. Using the method, the wide angles of angle domain common imaging point gather are flat. For laterally varied velocity medium, we apply the asymmetry ray to calculate the travel time. The asymmetry travel time method is able to deal with the media with laterally varied velocity, while the conventional Kirchhoff migration fails to solve the problem.

Introduction

In recent years, pre-stack time migration has been considered as the conventional process in oil industry. The Kirchhoff pre-stack time migration plays a dominant pole in practice for its high efficiency of computation as well as strong adaptability for the geometry. However, conventional Kirchhoff time migration, theoretically based on the laterally homogeneous layered model, fails to handle laterally varied velocity media. To overcome the problem, Liu Hong (2007) proposed new expressions for calculating travel time in laterally varied velocity media. Due to the odd terms added in the expressions (asymmetry travel time), it is able to solve the laterally velocity varied problem. The new algorithm extends the structure-preserved idea introduced originally by Feng Kang and makes use of pseudo differential operator and symbol theory.

Common angle gathers (CAG) are the basic data for AVO inversion. Conventional CAG method (Walden 1991) derived from ray parametric equations or straight ray approximation, transforms offset to angle domain. Moreover, the input data should be CMP gathers after NMO or common imaging point gathers after pre-stack time migration. Thereby the kind of method fails to gain accurate incidence angle on dipping events. Based on straight ray approximation, Zheng (2006)、Perez (2007) proposed imaging method of Kirchhoff pre-stack time migration within angle domain and applied it to high resolution imaging as well as AVA analysis for cracks. In reservoir characterization, wide angle seismic data give valuable information for analyzing lithology and fluids nature. For example, AVO/AVA studies need incidence angle larger than 40 degrees for inverting density. Wide angle data may also provide significant improvements to the structural image by additional target illumination. However the method based on straight ray could not meets the need. Wang (2008) presented one imaging method of table-driven Kirchhoff PSTM within angle-domain. Unlike conventional travel time expressions, the method to calculate travel time adopts two point ray tracing in laterally homogeneous media. Especially for V(z) medium, the algorithm, without any approximation, is the most accurate than any others, and the range of incident angle it obtains is wider.

In this paper we propose the modified algorithm for incidence angle during Kirchhoff pre-stack time migration. For taking ray-bending effect into account, the algorithm is able to gain greater angle than straight ray approximation without using computationally expensive ray tracing. For vertically varied velocity media, we analyze the imaging quality using straight ray, bending ray and asymmetry ray pre-stack time migration and respective angle domain common imaging point gathers. The asymmetry ray Kirchhoff PSTM is able to deal with laterally varied velocity media. Not only the imaging quality but also CAG produced through our method have been greatly improved, however, the cost of computation rises by about 5%.

Theoretical Aspect

In accordance with the relationship between travel time and offset in homogeneous medium and function approximation theory, Tarner and Koehler (1969) proposed the expression giving travel time t in terms of offset x in laterally homogeneous media. As we know, the expressions have been widely applied in oil industry. The relation is given by:

$$t^2(x) = t_0^2 + c_2x^2 + c_4x^4 + c_6x^6 + .. \quad (1)$$

In practice, we keep x^2 term when implementing migration with straight ray, and to x^6 term with bending ray. For V(z) media, using bending ray could calculate much more accurate travel time than straight ray, especially for long offset (wide angle).

The asymmetry theory (Liu 2007) for travel time takes the changes of laterally varied velocity into account and thereby adds odd term of offset x into traveltime expressions. The coefficients of odd terms are related with derivatives of laterally varied velocity:

$$t^2(x) = t_0^2 + \sum_{i=2}^{m}\sum_{j=2}^{i} c_{j,i-j} x^j y^{i-j}$$
$$= t_0^2 + c_{2,0}(x^2+y^2) + (c_{3,0}x^3 + c_{2,1}x^2 y + \quad (2)$$
$$c_{1,2}xy^2 + c_{0,3}y^3) + (c_{4,0}x^4 + c_{3,1}x^3 y + c_{2,2}x^2 y^2$$
$$c_{1,3}xy^3 + c_{0,4}y^4) + ...$$

Zheng (2006)、Perez (2007) obtains common incidence angle gathers using the straight ray approximation during PSTM. The simple geometric expression is shown in figure 1.

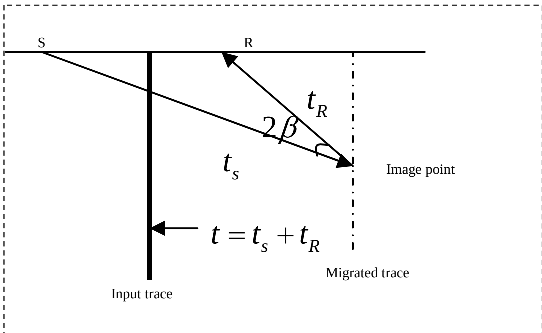

Figure 1. Straight ray, geometric expressions for incident angle

In 3D model, the incident angle β is calculated with vector relationship:: $2\beta = \cos^{-1}\left(\frac{t_{si} \bullet t_{gi}}{t_{si} t_{gi}}\right)$,

Where $t_{si} = \left(\frac{x_i - x_s}{V}, \frac{y_i - y_s}{V}, \frac{t_i}{2}\right)$,

$$t_{gi} = \left(\frac{x_i - x_g}{V}, \frac{y_i - y_g}{V}, \frac{t_i}{2}\right)$$

The paper takes ray-bending effect into account. Walden (1991) gives the incidence angle estimation: $\sin\theta = \frac{v_{\text{int}} x}{V_s^2 t}$. The formula based on laterally homogeneous media assumption, gives the relationship between offset and angle domain just for CMP data, and fails to deal with the mapped when the reflector is not flat. To overcome this problem, we firstly extend this method and thus obtain the more accurate expressions for offset and angle transformation:

$$\sin\theta = \left(\frac{c_2}{t}x + \frac{2c_3}{t}x^3 + \frac{3c_4}{t}x^5\right) * v_{\text{int}} \quad (3)$$

where v_{int} is interval velocity. In 3D model, we then need to compute the respective traveltime from source to image point, as well as from receiver to image point and respective vector of bending ray at image point. Then we could calculate the incident angle relative to the normal of reflector, instead of t axis, with vector laws. Figure 2 shows the geometric expressions in 3D.

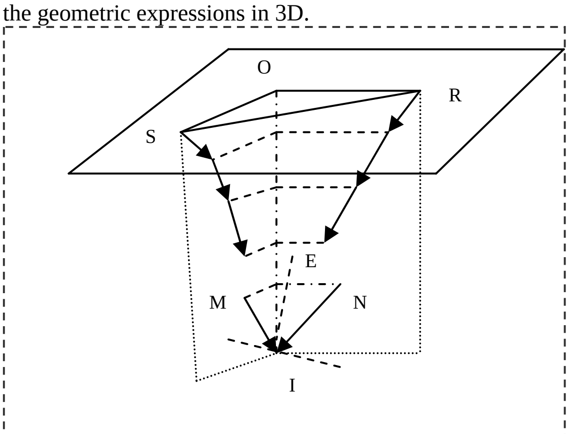

Figure 2. Bending ray, geometric expressions for incident angle

Model test

In order to verify the theory proposed in the paper, we use the same model presented by Wang Nan(2008) for reference. The model contains six reflectors with vertically varied velocity which satisfies the formula: v=2000+z. There are total 80 shots in the modeling with shot interval 40m.The offset varies from 0-4000m and the receiver interval is 20m. The time sampling interval is 2ms and the recorded length is 2s. Figure 3(a) shows the velocity model, (b) is the section with straight ray PSTM, (c) bending ray, and (d) asymmetry ray. We select 4 different locations: 0m, 1000m, 2000m, 3000m to check the quality of angle domain common imaging point gathers. The angle range obtained by straight ray (Figure 4) is smaller than that obtained by bending ray (Figure 5). Especially the traveltime at wide angle (straight ray) is not accurate (the events fails to be aligned) as that gained by bending ray. Therefore the angle range the new method produced meets the demand for wide angle in AVA inversion, even it is nearly as large as what Wan N(2008) gets. Furthermore, the amplitude-preserved character based on the method would be much more accurate than straight ray.

Furthermore, in order to verify the ability of asymmetry travletime to deal with laterally varied velocity, we modify the velocity model to make it satisfy new formula: v=2000+x. The velocity laterally varies by 100% without vertically varying. Figure 6 (a),(b),(c) and (d) show the velocity model, migrated section by straight ray, migrated section by bending ray, migrated section by asymmetry ray. From figure 6, the focus ability of asymmetry ray (d) is the best in contrast with straight ray (b) as well as bending ray (c).Compared with angle domain common angle point gathers gained with bending ray, the asymmetry ray is much more accurate and the events are much flatter(Fig.8). However, the conventional bending ray, with stronger ability in imaging than straight ray, fails to handle laterally varied velocity (Fig.7).

Conclusions

Based on previous studies, this paper proposes algorithm improving imaging of pre-stack time migration within angle domain. The results of model test illustrate that our algorithm is able to obtain much wider angle scope than the conventional algorithm. Even though the conventional acquisition length, the incident angle of target zone can reach as great as 40 degree, which is beneficial for AVA/AVO inversion and reservoir prediction. Asymmetry traveltime, as a kind of new theory, can deal with laterally varied velocity media in theory. Accordingly, for laterally varied velocity media, our method does better not only in imaging but also in angle domain common imaging point gathers. The field data test has demonstrated the advantage of the method.

The relatively amplitude-preserved character of common angle gathers is essential for parameter inversion. Consequently, it is very important to research the amplitude-preserved factor based on asymmetry ray. The accuracy of migration velocity and traveltime affects whether the CAG are aligned or not. In contrast with straight ray, the method to extract CAG presented in the paper adds interval velocity term which is calculated by Dix formula. If the migration velocities discontinue, the CAG would not be so robust for Dix's flaw. Thus it is also in need of more attention to obtain the smooth interval velocity.

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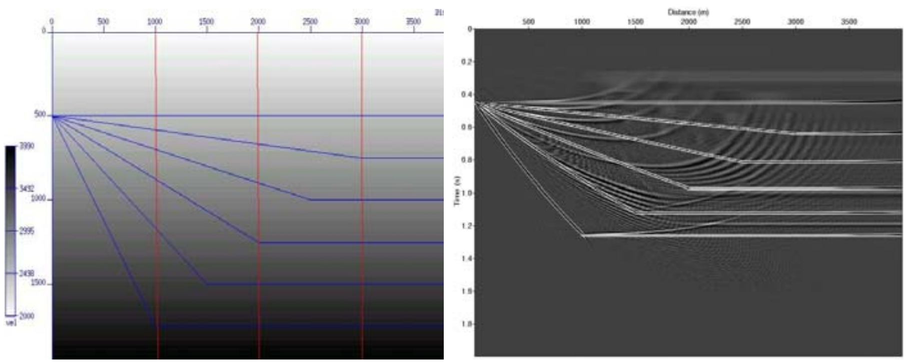
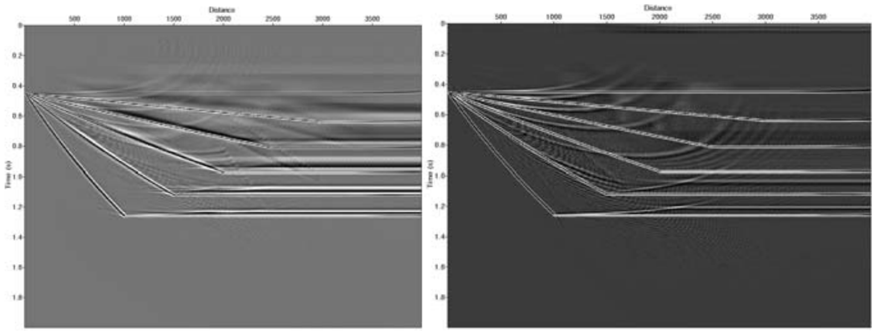


(a) (b)



(c) (d)

Figure 3 (a) vertically varied velocity model; (b) Migrated section by ray1; (c) migrated section by bending ray; (d) migrated section by asymmetry ray

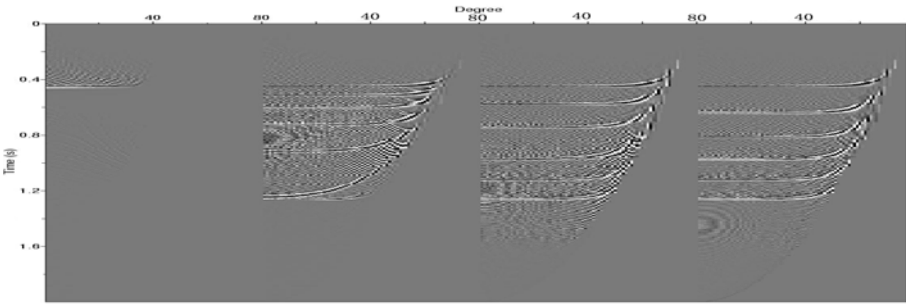


Figure 4 Angle domain common imaging gathers(Figure 3(a)) calculated by straight ray

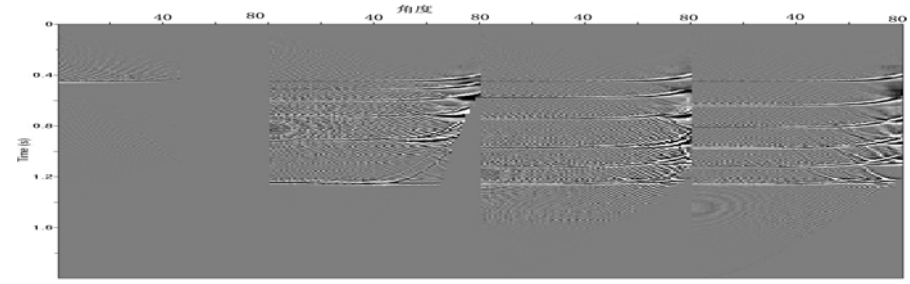
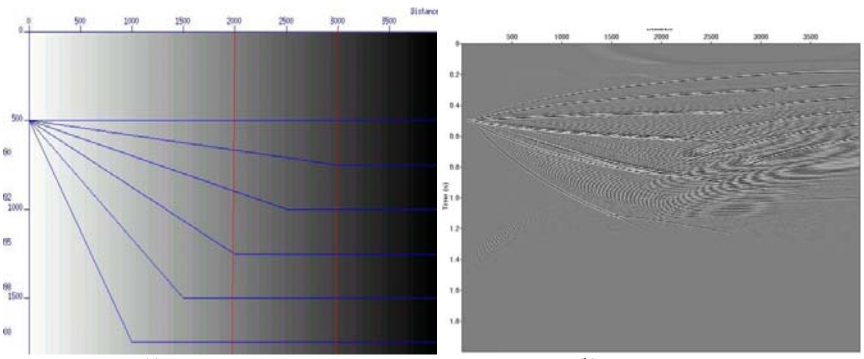
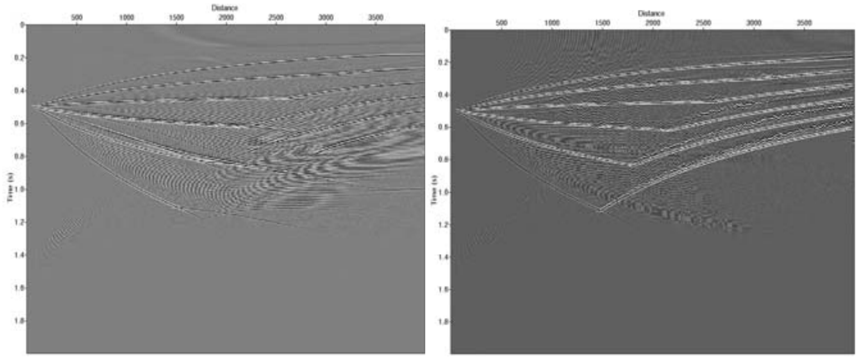


Figure 5 Angle domain common imaging gathers(Figure 3(a)) calculated by bending ray



(a) (b)



(c) (d)

Figure 6. (a) laterally varied velocity model; (b) Migrated section by straight ray; (c) migrated section by bending ray; (d) migrated section by asymmetry ray.

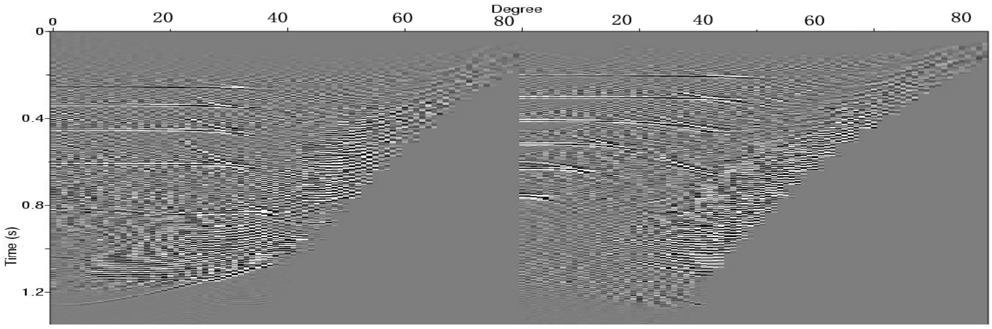


Figure 7 Angle domain common imaging gathers(Figure 6(a)) calculated by bending ray

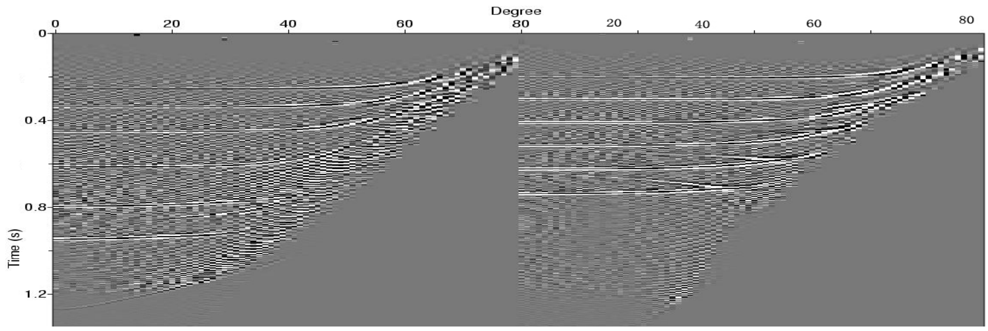


Figure 8 Angle domain common imaging gathers(Figure 6(a)) calculated by asymmetry ray

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