

Quantitative analysis of the errors of the velocity field in the South edge of Tianshan and its effect on depth imaging

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Summary

We design the seismic geological model in the area of the south edge of Tianshan which includes a shallow conglomerate layer with high velocity of group Xiyue of Quaternary at the north of Yaken, and a low velocity gypsum-rock layer whose structure varies widely in a deep layer of group Jidieke of Tertiary. The shot gathers are synthesized based on the field observation system. Then stacking velocities (V_s) and a migration section are obtained and V_s is compared with the actual root-mean-square velocity (V_{rms}) of the model. The results show that V_s is smaller than the actual V_{rms} when the velocity varies laterally over the target layer. V_s can also be larger than the actual V_{rms} due to a shallow conglomerate. As a result of the synthetic effect, V_s is 8% larger than the actual V_{rms} . Moreover, the shallow high velocity conglomerate slightly affects the time image of deep layers, but the V_s of the deep layers at two ends of the conglomerate is increased, which results in the false synclines in deep layers and enlarges the height of the structure near the synclines.

Introduction

The key challenge for seismic data interpretation in the Yaken north area in the Kuche depression in the Tarim basin of northern China is increasing the accuracy of the structure maps in this area. The results of seismic data interpretation show that there are two velocity abnormalities which include a high velocity conglomerate near the surface varying laterally in thickness, and a deep low velocity gypsum-rock layer. As a result, the structural shape in the 3D seismic time section did not correspond to the actual structural shape underground. Moreover, there are large errors of interval velocity calculated by velocity analysis. The highly accurate velocity field required to convert time to depth is difficult to build. The results of prestack depth migration performed separately by three corporations differ from each other. The velocity fields built by various velocity building methods are also different. Because there are only three wells, the velocity accuracy is difficult to estimate. Therefore, it is difficult to determine which method of building the velocity field is more suitable.

Stacking velocity analysis (SVA) is principal the method for determining seismic velocity at present. Since the SVA method assumes horizontal strata, the V_{rms} obtained by SVA will contain greater errors in strata with lateral and

vertical velocity variation. Tieman (1993) proposed the approach of using scanless stacking velocity analysis which can raise the accuracy of velocity analysis in the slowly undulating structural media. But this method did not consider the time difference caused by lateral velocity variation. Millton (1989) adopted horizontal velocity analysis to obtain horizontal velocity spectra to express laterally varying velocity, yet did not analyze the effect of lateral variation velocity on vertical velocity analysis. Prestack migration velocity analysis (MVA) is another approach to determine seismic velocity (Tieman, 1995; Liu, et al, 1995; Sava et al., 2005). Uzcategui (1998) also analyzed the accuracy of velocities estimated by prestack depth migration. However, the migration velocity obtained by MVA is designed to improve the focusing power of seismic migration. In general, it does not represent the velocity of seismic wave propagation. Moreover, the main factors affecting the V_s obtained by the SVA method also influence the migration velocity.

Although the effect on seismic waves of lateral velocity variations in shallow layers can possibly be eliminated by static correction, the accuracy of velocity analysis is yet affected by laterally varying velocity. Hence, we quantitatively analyze the errors of conventional velocity analysis due to the conglomerate layer and the gypsum-rock layer and thus obtain rules which allow correction of the errors.

The model design and layout of numerical modelling

Figure.1 shows the 2D seismic geological model in line 460 across well Ku 1 built using 3D seismic data from prestack depth migration near the south edge of Tianshan. The model includes the high velocity conglomerate layer and low velocity gypsum-rock layer. The average lateral velocity gradient is 220m/s/km in the shallow layer and 60m/km in the deeper layer.

Synthetic seismograms (shown on the left in Figure 2) were computed using modeling software developed by Co. Tesseral in Canada based on the finite difference wave equation. The source is located at the free surface, and generates a Ricker wavelet with a dominant frequency of 30 Hz. The receivers are located at the free surface as well. The minimum and maximum offsets are respectively 100m and 6350m, and the receiver spacing is 50m. The sampling rate is 1 ms. We used Focus software for seismic

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processing to perform velocity analysis. Figure 2 shows a CDP super gather and the corresponding semblance which increases the accuracy of interactive Vs picking.

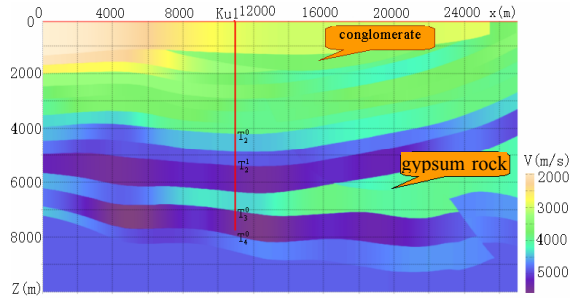


Figure 1: Model built from the seismic section across well Ku 1

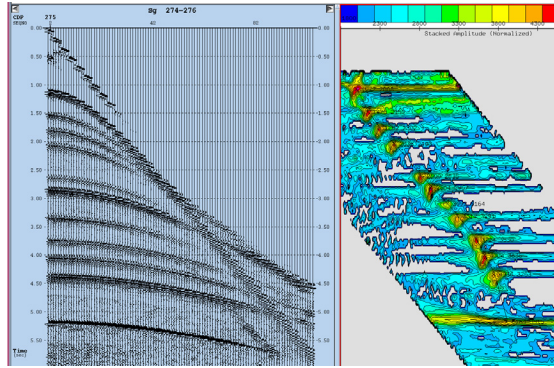


Figure 2: A CDP super gather and the corresponding semblance

The analysis of the general rules of the errors of Vs in lateral velocity variation

Lynn (1983) gives the theoretical formula of stacking slowness W_s , which is the reciprocal of Vs, and its relation to the actual slowness W in the presence of lateral velocity variation, that is

$$W_s^2 = W^2 + \frac{t_0^2 W_{xx}}{12W} \quad (1)$$

where W is also the reciprocal of the theoretical root-mean-square velocity. t_0 is echo time. W_{xx} is the second-order derivative of W . Based on Eq. 1, we know that w_s is not only related to W and t_0 at the midpoint, but is also related to W_{xx} . When W_{xx} is less than zero, w_s will be less than the W . When W_{xx} is larger than zero, w_s will larger than W .

Stacking velocity errors in a constant velocity lateral gradient

When the velocity varies laterally with constant gradient k , i.e. $v = v_0 + k(x - x_0)$, the w_{xx} will be larger than zero and will increase with k . The conventional stacking velocity will be less than the actual root-mean-square velocity and the difference will increase rapidly with k increasing.

Figure 3 shows that the isoline of errors between Vs and the actual Vrms when t_0 on the target layer varies from 1s to 4.3s and the average lateral gradients in velocity over the target layer vary from 100m/s/km to 500m/s/km. When k equals 200m/s/km and t_0 equals 4.2s, the error will be less than 10%. Nevertheless, when k equals to 300m/s/km and t_0 equals to 4.2s, the error will increase to 18%. In the Yaken north area, the average lateral gradients in velocity over the target layer are about 160m/s/km, and the error over the target layer (T_3^0) is about 8%. Because the Vs over the layer is 3600m/s, the error will be 280m/s.

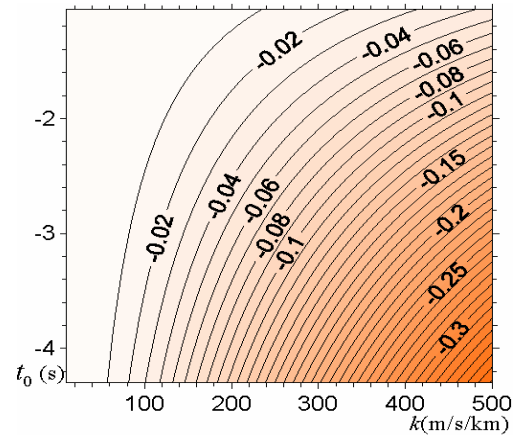


Figure 3: Isoline of errors between Vs and actual Vrms

Stacking velocity errors in rapidly varying velocity lateral gradient

In this case, Vs will be larger or smaller than the actual Vrms. The sign of the difference between them depends on the sign of the laterally varying velocity gradient on both sides of the common midpoint. The size of the difference depends on the relation of the wavelength of the velocity gradient variation to spread length (Gu, 1996). The shallow layer deposited the high velocity conglomerate with lateral variation in thickness on the right of CDP 280 (see Fig.1, $x=7000m$) and the velocity is 3700m/s. Nevertheless, the velocity on the left of CDP 280 is very low and equals 2600m/s. The conglomerate with high velocity not only increases the emergence angle at the surface of the deep reflection, but also affects the conventional static.

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Moreover, the raypath at the conglomerate layer will lengthen with spread lengthening. However, the incident raypaths pass through the low velocity layer on the other side, which makes the raypaths in the CDP gather quite asymmetric with respect to common midpoint. As a result, the error increases clearly.

Because there is a conglomerate layer, which corresponds to stacking an abnormally high velocity, the actual traveltimes in the CDP gather at the near two ends of the conglomerate layer is less than the traveltimes in the low velocity layer when the spread strides over areas with high and low velocity. The slope of the actual time distance curve in the CDP gather is less than that at the area without high velocity. Hence, the existence of the conglomerate layer made V_s larger than the actual V_{rms} . This can be evidenced in Figure 4 which shows that the errors of V_s over the layer T_3^0 vary with spread length. The n in the figure is CDP fold. The errors caused by the shallow conglomerate layer with high velocity increase as the CDP fold decreases, but decrease with increasing spread length. If the spread length is 6000m, which is used for seismic data acquisition in Yaken north area, then the error of V_s is about 16%. If V_s is about 3600m/s when t_0 is 4.2s at the target layer, the absolute error of the V_s is about 576m/s.

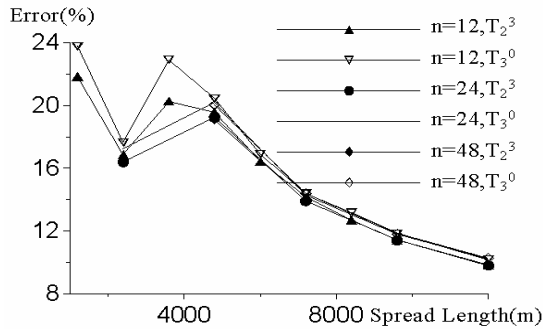


Figure 4: The error of V_s varying with spread length

The affecting of shallow conglomerate layer with high velocity on deep layer imaging

The results of the analysis of the errors of the V_s show that the lateral velocity variation over the target layer made the V_s 8% less than the actual V_{rms} , nevertheless, the existence of the shallow conglomerate layer with high velocity made the V_s 16% larger than the actual V_{rms} . Hence, the synthetic effects made the V_s 8% larger than the actual V_{rms} . If a time-depth transform is performed using the interval velocity calculated from Dix formula, the depths corresponding to the target at the near ends of shallow conglomerate layer are larger than the actual depths. Figure 5 shows the stacking time migration section corresponding to the model shown in Figure 1. We can see

that the anticline structures at the well Ku1 and the bottom of the gypsum-rock layer exist yet. Hence, the effect of the conglomerate layer on deep layers is not distinct, but the layer T_3^0 and T_4^0 at CDP280 corresponding to the end of conglomerate layer are slightly anticline.

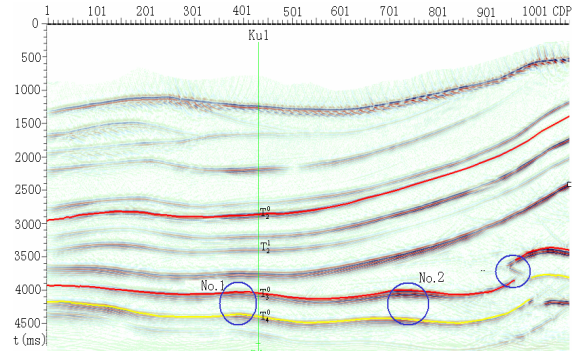


Figure 5: Stacking time migration section corresponding to model shown in Figure 1

Figure 6 shows the depth section corresponding to time section shown as Figure 5 converted using the interval velocity calculated using Dix formula. It can be seen that the anticline structures at the well Ku1 and the bottom of the gypsum-rock layer exist yet. But, there are two distinct anticlines on the layer T_3^0 and T_4^0 corresponding to two sides of well Ku1 which are near the ends of the conglomerate layer. The heights of the anticlines are about 250m, nevertheless, the heights of the anticlines corresponding to the model shown in Figure 1 and time migration section shown in Figure 5 are much smaller. It is obvious that the anticlines are false. Figure 7 shows the depth section corresponding t_0 time section shown as Figure 5 converted by using the actual interval velocity shown in Figure 1. It can be seen that the anticline structures at the well Ku1 and the bottom of the gypsum-rock layer exist yet, but there is not any distinct anticline or they are very small anticlines on the layer T_3^0 and T_4^0 . Hence, the false anticlines are brought about by the error of the velocity field which is caused by the existence of the shallow conglomerate layer with high velocity. As a result, the heights of anticline structures on the layer T_3^0 and T_4^0 corresponding to well Ku1 in the depth section shown in Figure 6 are enlarged.

In order to validate that the existence of the shallow conglomerate layer made the stacking velocity larger than the actual root mean square velocity which resulted in the false anticlines in the depth section, we eliminated the conglomerate layer in the seismic geological model. The time migration section can be obtained by applying the same modeling and processing flow as that applied in Figure 6. The features in the time migration after

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eliminated the conglomerate layer are the same as in the time migration before eliminating the conglomerate layer. Moreover, there is no distinct anticline or a very small anticline on the layer T_3^0 and T_4^0 corresponding to two sides of well Ku1 in the depth section converted by using the interval velocity calculated by Dix formula. Hence, whether or not the shallow conglomerate layer exists did not affect the deep layer time imaging. However, the errors of velocity analysis used to convert time to depth come from the effect of the shallow conglomerate layer with high velocity.

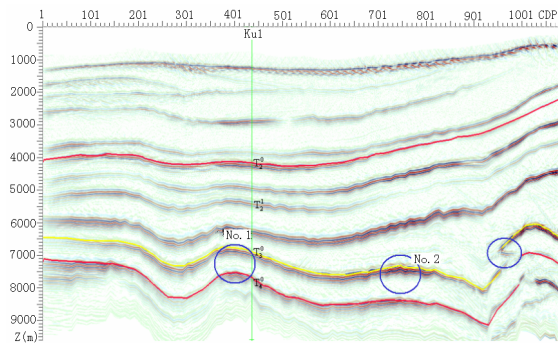


Figure 6: Depth section converted by calculated interval velocity

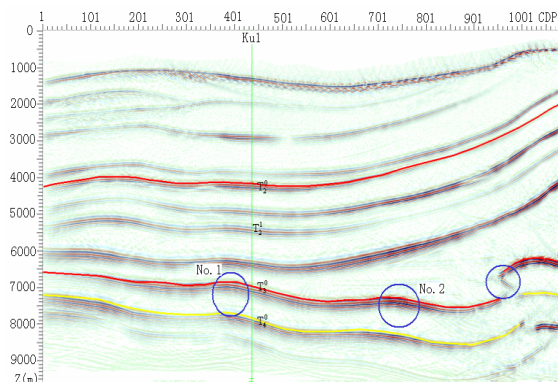


Figure 7: Depth section converted by actual interval velocity

Conclusions

The lateral velocity variation made the stacking velocity less than the actual root mean square velocity. In the Yaken north area, the average lateral velocity gradients over the target layer is about 160m/s/km, and the difference between stacking velocity and actual root mean square velocity over the layer T_3^0 is about 8%.

The existence of the shallow conglomerate layer with high velocity made the stacking velocity larger than the actual root mean square velocity. The difference between them

decreases with increasing spread length. Hence, the synthetic effects made the stacking velocity 8% larger than the actual root mean square velocity. In Yaken north area, the error of stacking velocity over the target layer will be about 16% when the spread length is 6000m.

The shallow conglomerate layer did not affect the deep layer time imaging, but it made the stacking velocity at its ends larger than the actual root mean square velocity which resulted in the false anticlines in the depth section.

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