Acquisition and Processing of Large-Offset Seismic Data: A Case Study from Northwest China

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Summary

PetroChina conducted a multichannel large-offset 2-D seismic survey in the Yumen Oil Field, Northwest China, in September, 2004. The objective is to delineate the complex, imbricate structure associated with the Yumen reservoir beneath the high-velocity Kulong Shan allocthonous rocks so as to accurately position production wells in the future. The data were acquired using a common-spread recording geometry whereby the receiver spread was fixed for all shots. A total of 1,401 receiver groups was placed along a 28,000-m line traverse in the SSW-NNE dominant structural dip direction at a 20-m interval. A total of 211 shots was fired at a 200-m interval along the line traverse, beginning at a location outside the spread and 7 km away from the first receiver group in the SSW end of the line. The distance between the first and last shot locations is 42,000 m.

We analyzed the Yumen large-offset data for earth modeling and imaging in depth. By a nonlinear first-arrival traveltime tomography, a velocity-depth model was estimated for the near-surface. Then, a subsurface velocity-depth model was estimated based on rms velocities derived from prestack time migration of shot gathers combined with half-space velocity analysis to improve the accuracy of velocity estimation below the complex overburden structure associated wth the high-velocity Kulong Shan rocks. An attempt also was made to model not just the near-surface but also the subsurface by the application of nonlinear traveltime tomography to first-arrival times picked from all offsets. Finally, prestack depth migration of shot gathers from a floating datum that is a close representation of the topography was performed to generate the subsurface image in depth.

Introduction

Irregular topography associated with a rugged terrain, complexity of the near-surface that includes high-velocity layers and outcrops with significant lateral velocity variations, complexity of the overburden caused by allocthonous rocks, and the complexity of the target imbricate structures themselves, all pose challenges to exploration in thrust belts. The shot-domain analysis of the data from the large-offset Yumen seismic survey based on common-spread recording geometry, on the other hand, has successfully delineated the Yumen structure.

Wide-angle reflections observed at large offsets have been known to early researchers in exploration seismology (Richards, 1960). Recently, benefits of wide-angle reflections for exploration in thrust belts have been demonstrated by Colombo (2005). A highly instructive publication on the subject, this paper also discusses important aspects of acquisition and processing of large-offset seismic data. Here, we shall review aspects of signal processing of large-offset sesimic data and present a strategy for earth modeling and imaging in depth of the Yumen structure beneath the high-velocity rocks of Kulong Shan in Northwest China.

The Yumen large-offset line traverse is in the SSW-NNE dominant structural dip direction. The southern half of the line is over the Kulong Shan (Mountains) range and the northern half is in Gobi Tan (Desert). The elevations along the line vary between 3,500-2,000 m from south to north.

In the common-spread recording geometry, the receiver spread is fixed for all shots (Figure 1). Of the 211 shot records acquired, we decided to use 141 shot gathers that are within the receiver spread in the final analysis. The maximum offset associated with these shot gathers is the same as the receiver spread length (28,000 m).

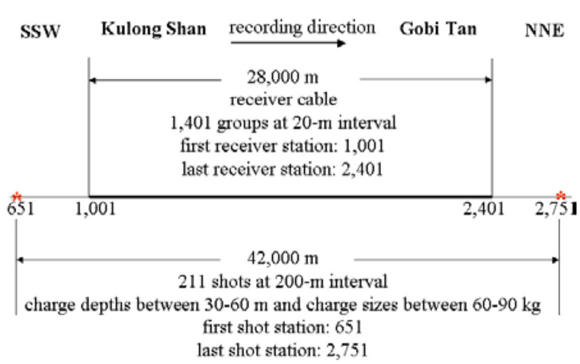

Figure 1. Common-spread recording geometry for the large-offset Yumen Line.

Figure 2 shows a field record from the large-offset Yumen Survey. Note the wide-angle reflections at large offsets and the predominance of the surface waves (ground-roll) at near offsets. Also, note the distinctively recognizable refraction events and associated multiples. Many of the shot records contain coherent noise caused by primarily man-made sources, such as moving vehicles and production drilling, while some records contain coherent noise caused by wind.

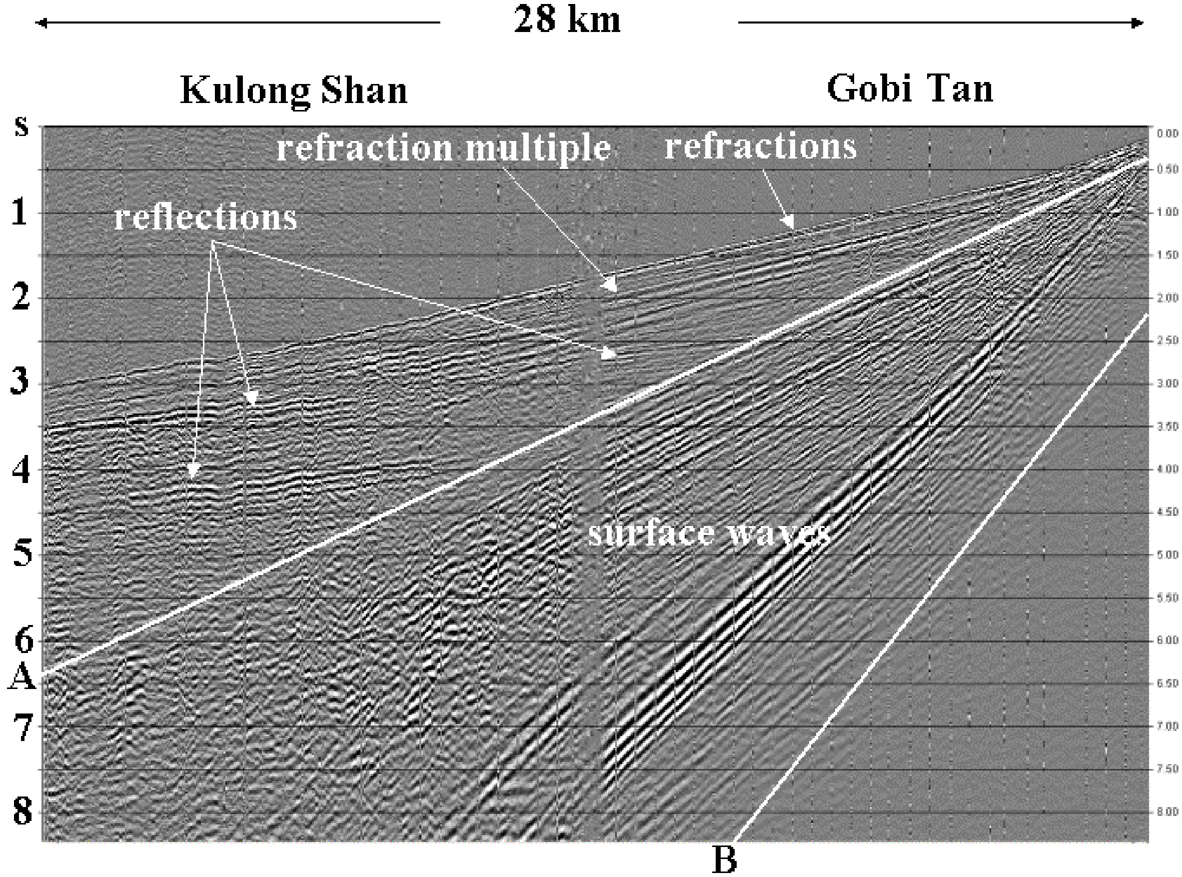

Figure 1. A field record from the large-offset Yumen seismic survey with receiver spread length of 28 km. The shot location for this record is to the right and outside of the spread. Note the wide-angle reflections at large offsets and the predominance of the ground-roll energy at near offsets. Also, note the distinctively recognizable refraction events and associated multiples.

Data Analysis

Near-Surface Modeling. Starting with the field records, we picked first-arrival times and edited traces. The average reciprocal error associated with the picked times for most of the shots is around 10 ms. By using a nonlinear traveltime tomography (Zhang and Toksoz, 1998), we estimated a near-surface velocity-depth model that exhibits lateral and vertical velocity variations (Figure 3). The nonlinear tomography solution is based on not just the first arrival times but also changes in traveltime gradient. As such, within the near-surface, we were able to resolve strong lateral velocity variations.

From the near-surface model, we picked a floating datum that is a smoothed form of the topography along the line and the intermediate datum that defines the interface between the near-surface and the subsurface (Figure 3). Also, we defined a replacement velocity taken as the lateral average of the velocities along the intermediate datum. Finally, using all the relevant information about the near-surface velocity-depth model, we computed the shot and receiver statics. We also calculated shot and receiver residual statics based on the first-arrival times.

Prestack Signal Processing. From the average amplitude spectra of selected shot records, we observed that the reflection signal at large offsets is within a bandwidth of 6-36 Hz. We applied a signal processing sequence to the shot records that include (a) inside mute to eliminate the surface waves with large amplitudes, (b) outside mute to remove ambient noise before the first arrivals, and (c) deconvolution to broaden and flatten the spectrum within the signal passband (6-36 Hz). Finally, we applied the

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near-surface corrections and placed all the shots and receivers to the floating datum.

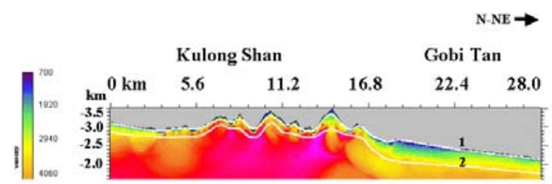

Figure 3. The near-surface model estimated from the first-arrival times. The curves labeled 1 and 2 represent the floating datum and the intermediate datum, respectively. Note that the near-surface velocities are higher in the Kulong Shan half of the model compared to the Gobi Tan sediments.

Subsurface Modeling and Imaging in Depth. We performed prestack time migration of shot gathers from the floating datum using a range of constant velocities and created an rms velocity cube (Shurtleff, 1984; Yilmaz, 2001). We then interpreted the velocity cube to derive an rms velocity field associated with events in their migrated positions (Figure 4). The rms velocity field is structurally consistent --- note the fault zone that separates the Kulong Shan high-velocity rocks from the Gobi Tan sediments.

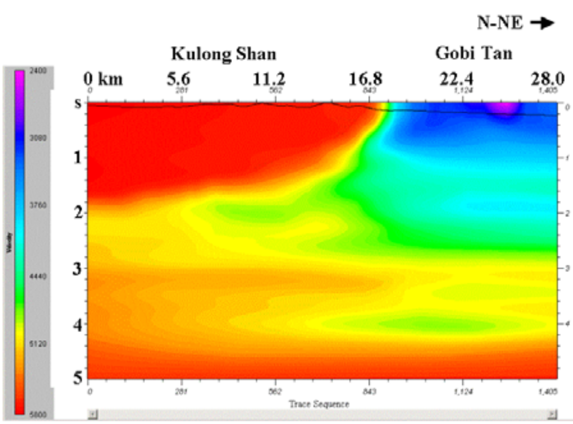

Figure 4. The rms velocity field derived from the interpretation of the velocity cube, which itself was created by prestack time migration of shot gathers using a range of constant velocities.

To construct an earth model in depth, first, we performed Dix conversion of the rms velocities to derive an interval velocity field. Next, we interpreted a set of depth horizons associated with layer boundaries with significant velocity contrast. We then divided each layer into a set of thin layers by creating phantom horizons so as to preserve the vertical and lateral velocity variations within each layer inferred by the interval velocity field, and applied lateral and vertical smoothing to velocities within each layer (Figure 5). Finally, we refined the velocity estimation for the layers below the complex overburden structure associated with the high-velocity Kulong Shan rocks by half-space velocity analysis (Yilmaz, 2001). This involved, first, separating the model into two regions --- the overburden that is the known part of the model and the substratum that contains layers yet to be resolved. Next, prestack depth migration was performed and a set of images was generated by using the same onverburden model but assigning a set of constant velocities to the half-space below. By interpreting the set of images, an optimum layer velocity that corresponds to the best image for the base of the layer under consideration was determined. The process then is repeated for as many layers as necessary.

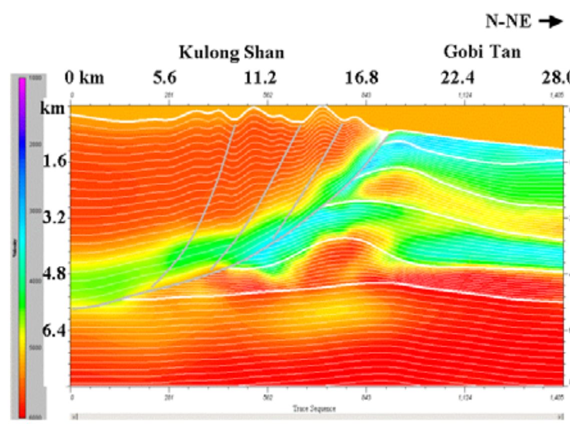

Figure 5. The velocity-depth model used for prestack depth migration of the large-offset Yumen data.

We also experimented with an alternative model building strategy. Specifically, we picked the first-arrival times from all offsets of all shots and performed nonlinear tomography to model not just the near-surface but also the subsurface. The concept of *'modeling by refraction and imaging by reflection'* is very appealing, particularly for cases with very poor reflection signal. Nevertheless, our experiments with this approach have been so far inconclusive. The main problem has been dealing with very complicated behavior of first breaks at large offsets.

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Finally, we performed depth migration of the shot gathers, individually, from the floating datum, and sorted the resulting shot images to common-receiver gathers in depth (one type of image gathers). To obtain the image (Figure 6) from prestack depth migration, we simply stacked the traces in each common-receiver gather. Prestack depth migration based on migration of shot gathers (Schultz and Sherwood, 1980; Reshef and Kosloff, 1986) was performed using the phase-shift-plus-interpolation (PSPI) algorithm (Gazdag and Squazzerro, 1984), adapted to start the imaging from a floating datum (Reshef, 1991).

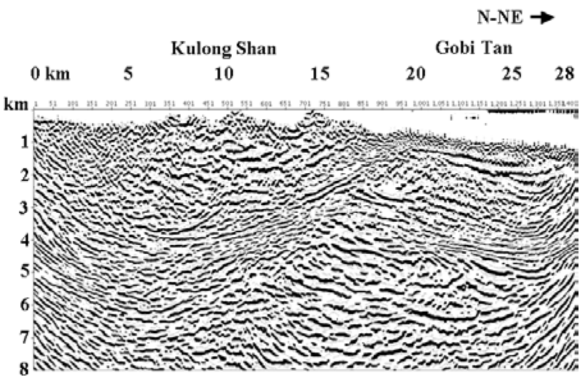

Figure 6. The earth image in depth derived from prestack depth migration of the large-offset shot gathers. The signal bandwidth is limited to 6-36 Hz.

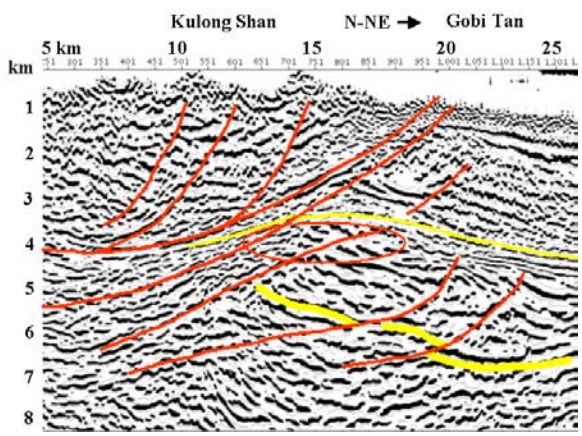

Figure 7. Interpretaiton of the depth image shown in Figure 6. The Yumen structure is denoted by the ellipse.

Conclusions

The Yumen large-offset land seismic survey has indeed made possible deriving a reliable depth image of the Yumen structure (Figure 7). The image from prestack depth migration exhibits structural features that have not been previously verified by the seismic sections derived from conventional surveys with spread lengths less than 3,000 m.

Acknowledgements

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