Selected-aperture imaging of walkaway VSP reverse time migration

Ke Xuan, Shi Ying*
School of Earth Sciences, Northeast Petroleum University

Summary

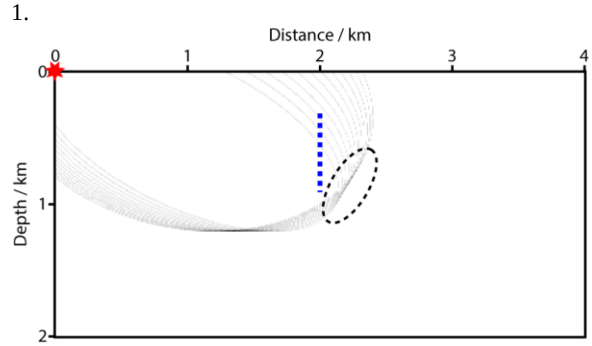
VSP seismic data often exhibits higher signal-to-noise ratio than the surface observed data, which has the potential to provide a high-quality subsurface image around the well. The uniqueness of the observation system results in uneven folds, which lead to some special noises, such as the obvious migration smiles. Based on the assumption of horizontal layers, we propose a selected-aperture scheme, which could suppress the migration smiles noise effectively.
The filed data demonstrate that the effectiveness of the scheme we proposed in this paper.

Introduction

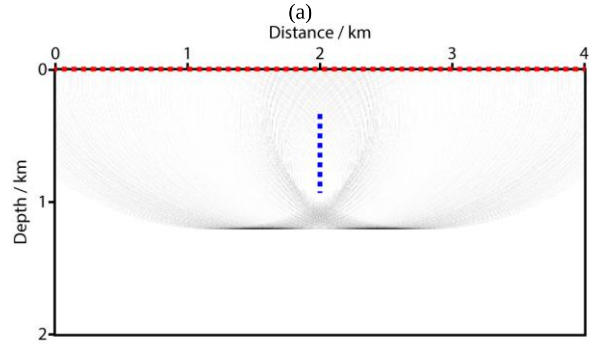
With the increasingly complex exploration targets, it is urgent to better understand the deeper subsurface geological structures for seeking the remaining oil and gas resources. Hence, it is essentially important to resort to some new technologies for carrying out high-resolution seismic exploration. Vertical Seismic Profiling (VSP), which is a significant component in reservoir geophysical techniques, plays an important role in reservoir characterization and high-quality subsurface imaging around the well. Reverse time migration (RTM), which utilizes the two-way wave equation to describe the wave field propagation, is capable of imaging various seismic events (reflection, multiple and prismatic) without dip-angle limitation and has presented great superiority over ray-based or one-way equation-based migration algorithms in handling complicated velocity models (Whitmore, 1983; Baysal et al., 1983). Therefore, it is vital significance to investigate RTM of VSP data for accurately characterizing the subsurface geologic structures (Shi and Wang, 2016).
In the VSP acquisition survey, the receiver is usually deployed in the subsurface, which will lead to the narrow acquisition aperture, low and uneven CDP fold for seismic imaging. These features are presented in the migration image by the crosstalk artifact, uneven illumination and migration smiles. Lou (2009) select an appropriate migration aperture angle to attenuate migration smiles of VSP data, which has a positive effect on improving the imaging quality.
In this paper, we first visually analyze the generating mechanism of the migration smiles in the RTM result with VSP data. Then proposed a selected-aperture scheme, which could suppress the migration smiles noise effectively. At last, the field data is tested by our procedure and satisfactory results are obtained.

Theory

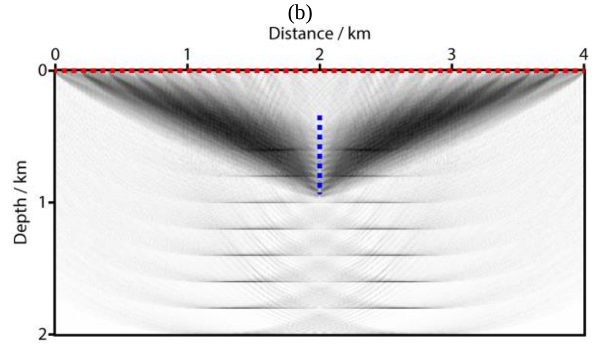
In order to facilitate us to analyze the migration smiles noise of RTM result in VSP observation system, we take the layers are all horizontal as the basic assumption. We simulate the RTM result ignoring the influence of the wavelet. The results of theoretical analysis are shown as Fig. 1.



(a)



(b)



(c)

Figure 1: Reverse time migration imaging simulation diagram of walkaway VSP observation system

10.1190/REGE2018-19.1

Fig. 1a: Suppose a horizontal layer exists at 1.2km underground, the source locates at the 0km on the ground, the well locates at the 2km on the horizontal direction, 40 receivers are set in the well between 0.6km and 1.0km depth. We could found that there is a obvious fault imaging beside the well, this because the uneven distribution of migration smiles, which leads that the migration smiles could not be suppressed by stack. On the contrary, in the specific area besides the well, the coherent fault imaging is formed.

Fig. 1b: Sources are set between 0.0-4.0km on the surface, the other parameters are the same as Fig. 1a. Based on the results of the simulated migration, we can find that: 1. Below the wellbore, the fold is lower, thus we can judge that in the VSP observation system, the image below the wellbore is not as reliable as we think.

Fig. 1c: The observation system is the same as Fig. 2, by introducing more layers to simulate the result of migration. We can more intuitively identify some of the characteristics of the VSP observation system's imaging results:

1. The effective imaging range of the VSP observation system should be identified as a specific area near the well, rather than the nearer the wellbore, the better the imaging effect;
2. The particularity of the observation system has resulted in the uneven distribution of the migration smiles in space, which is the main cause of the migration smiles and the fault imaging near the well, it is necessary to use some methods to eliminate these disturbances;
3. The uneven fold brings the uneven illumination energy, so it is necessary to make illumination compensation for the final migration result.

The purpose of this article is to make a accurate description with reverse time migration method of VSP data. Because of the use of GPU acceleration algorithm, so we can temporarily ignore the aspect of computational volume. Therefore, we proposed a method to estimation of the observation scope of VSP observation system and perform the RTM algorithm for each trace data respectively.

Based on the assumption that the reflection interface is horizontal, with the law of reflection and the coordinates of source and receivers, we could estimate the approximate range of imaging. As shown in Fig. 2, we can draw the following relation:

$$b = \frac{L * h2}{h1 + h2} \tag{1}$$

Where and are the distance from the reflection point to the source and the receiver in horizontal direction respectively. Then we could get the approximate reflection position, which we defined as the theoretical imaging area.

For given two sources and one receiver, the computed range is shown in Fig. 3. In order to get a more reasonable migration result, we need to extend the imaging scope in the horizontal direction from the imaging point calculated by equation 3, which is shown in Fig. 3.

The positions on horizontal direction of sources and receivers have a greater proportion to the influence factors of the imaging area. In VSP observation system, receivers are arranged vertically, therefore, in order to save the computation, the imaging area can be estimated according to the positions of the most shallow receiver and the source, then the imaging result can be obtained by using the common shot gather, by which could also get a good migration profile.

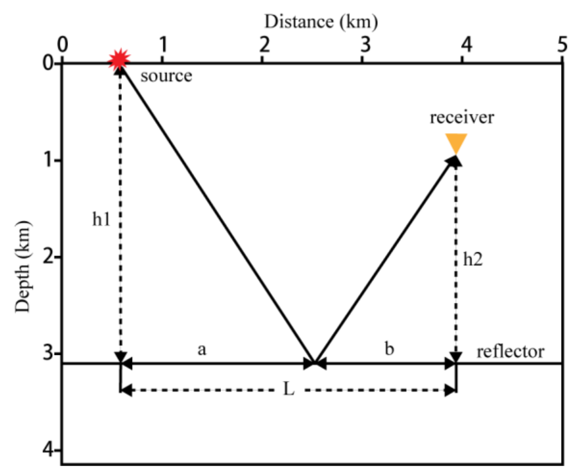


Figure 2. Sketch of observation range of VSP observation system

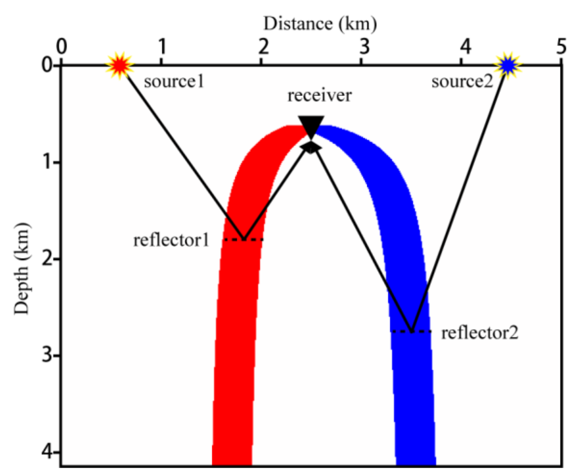


Figure 3. Estimation of the observation scope of VSP observation system

Examples

Fig. 4 present the velocity field of the real data we tested for this article. The red dot line represents the source positions, in which there are 411 shots evenly distributed in

10.1190/REGE2018-19.1

the 8.1km to 4.92km range of the surface. The blue dot line represents the receiver positions, in which there are 40 receivers in the well between 0.6km and 1.0km depth.
Fig. 5a shows the reverse time migration result without any processing and Fig. 5b shows the reverse time migration result based on the selected-aperture imaging. And we mark the same imaging range as Fig. 5b with a red dotted line on Fig. 5a. The migration result with common shot gather, the principle which is mentioned above, is shown in Fig. 5c.
After performing the reverse time migration algorithm for every single trace data, and only save the imaging results in the range of the advance calculation. Then, we stack the migration results of all traces and obtain a profile with more continuous events, which effectively avoids the bad interference of the migration smiles. The migration smiles are suppressed obviously and the stratigraphic information is more clear and realistic. The migration with common shot gather could avoid the big computation and obtain the a satisfactory result.

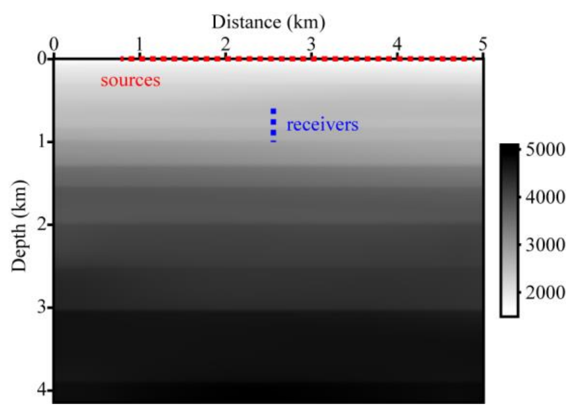
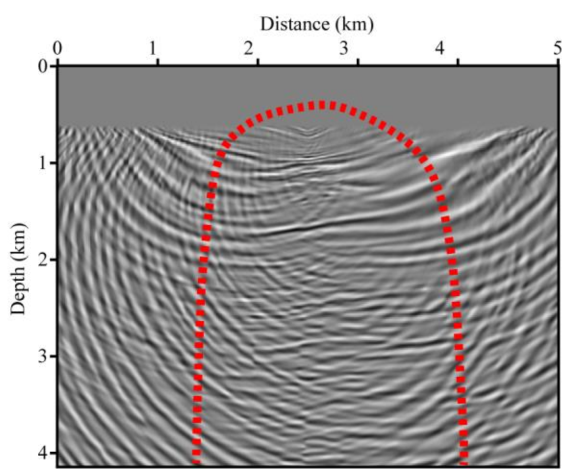
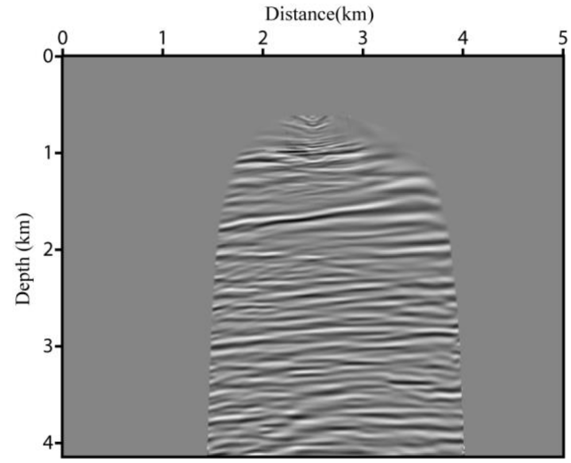


Figure 4. Velocity field of real data



(a)



(b)

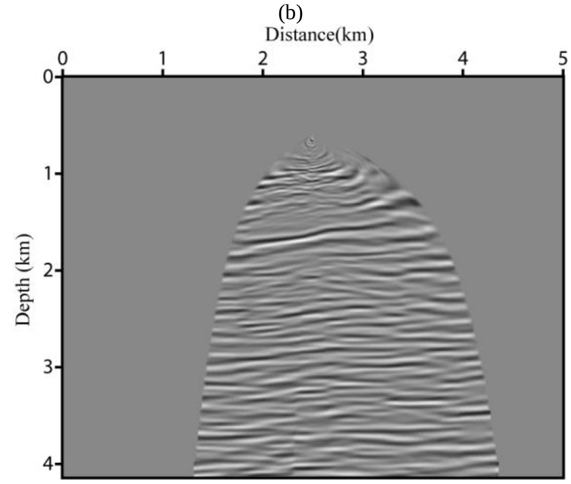


Figure 5. Results of reverse time migration of VSP data.

(a) Result of reverse time migration; (b) Result of reverse time migration after selected-aperture; (c) Result of reverse time migration after selected-aperture with common shot gather.

Conclusions

1. The selection of the imaging aperture is indispensable in the reverse time migration method of VSP data, which could help suppress the migration smiles.
2. We should realize that the fold is low just below the well on the vertical direction. Therefore, the imaging in this area is not as reliable as we think.
3. More comprehensive methods of imaging aperture selection may be effective means to improve the RTM result of VSP data, and the selection method should not be limited in space domain.

10.1190/REGE2018-19.1

Acknowledgments

Thanks for the Project of National Natural Science Foundation of China (Grant Nos. 41574117 and 41474118), Heilongjiang Province Natural Science Fund for Distinguished Young Scholar (Grant No. JC2016006), Northeast Petroleum University Excellent Scientific Talent Fund (Grant No. GLJHB201601).

REFERENCES:

Baysal, E., Kosloff D., and Sherwood J., 1983. Reverse time migration. Geophysics, 48, 1514–1524, doi: 10.1190/1.1441434.

Lou M, D. Cheng, and F. Doherty, 2009, Suppressing VSP migration artifacts and noise by selected-aperture migration and damped-least square smoothing. 79th Annual International Meeting, SEG, Expanded Abstracts, 4144-4148.

Shi, Y., and Wang Y., 2016. Reverse time migration of 3D vertical seismic profile data. Geophysics, 81, S31-S38, doi:10.1190/geo2015-0277.1.

Whitmore, N. D., 1983, Iterative depth migration by backward time propagation: 53rd Annual International Meeting, SEG, Expanded Abstracts, 827–830.