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APPLICATION EFFECTS OF SWATH 3D GEOMETRY IN THE FOOTHILL REGIONS OF WESTERN CHINA

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ABSTRACT

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Abundant oil and gas resources have been discovered in last decade in the foothill regions of western China, which implies a great potential for oil and gas reservoir in these areas. However, the ‘double-complex’ seismo-geological features of complex near-surface and complex subsurface result in a low signal to noise ratio (SNR) of seismic data, restricting further breakthroughs in these areas. In practice, wide-line 2D and high-density 3D are widely employed techniques in the foothill regions of western China. It has been found that wide-line 2D geometry can improve the signal to noise ratio (SNR) of seismic data effectively, but the imaging accuracy is relatively lower than conventional 3D. “Two-wide One-high” is a technology that stands for wide azimuth, wide frequency bandwidth, high- density 3D seismic exploration, which could record more complete field information, fewer alias and more low frequency signals. Featured by high-density seismic acquisition, “Two-wide One-high” has achieved significant improvements in data quality, and many cases have been carried out in different regions of China in last decade. High-density 3D geometry characterized by small bin size, high fold number and wide azimuthhas significantly improved the SNR and imaging quality of seismic data in these areas, which improve success rate of exploratory drilling.

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However, investment in high-density 3D in mountain areas is still not economical since the amount is large and the risk is high. Particularly, in the downturn of oil & gas industry, technology and economy must be considered as a whole. A reasonable geometry for seismic acquisition should balance the cost and risk while obtainingdesired SNR and accuracy. In this paper, a novel acquisition geometry named the swath 3D technique has been proposed. With wide application of the proposed swath 3D seismic acquisition technology, acquisition cost and exploration risk have been reduced, meanwhile the SNR of seismic data has been effectively improved and the seismic imaging results havebeen also significantly enhanced.

KEY WORDS: foothill regions, seismic acquisition, swath 3D geometry, parameters design, trace density, SNR, imaging quality.

INTRODUCTION

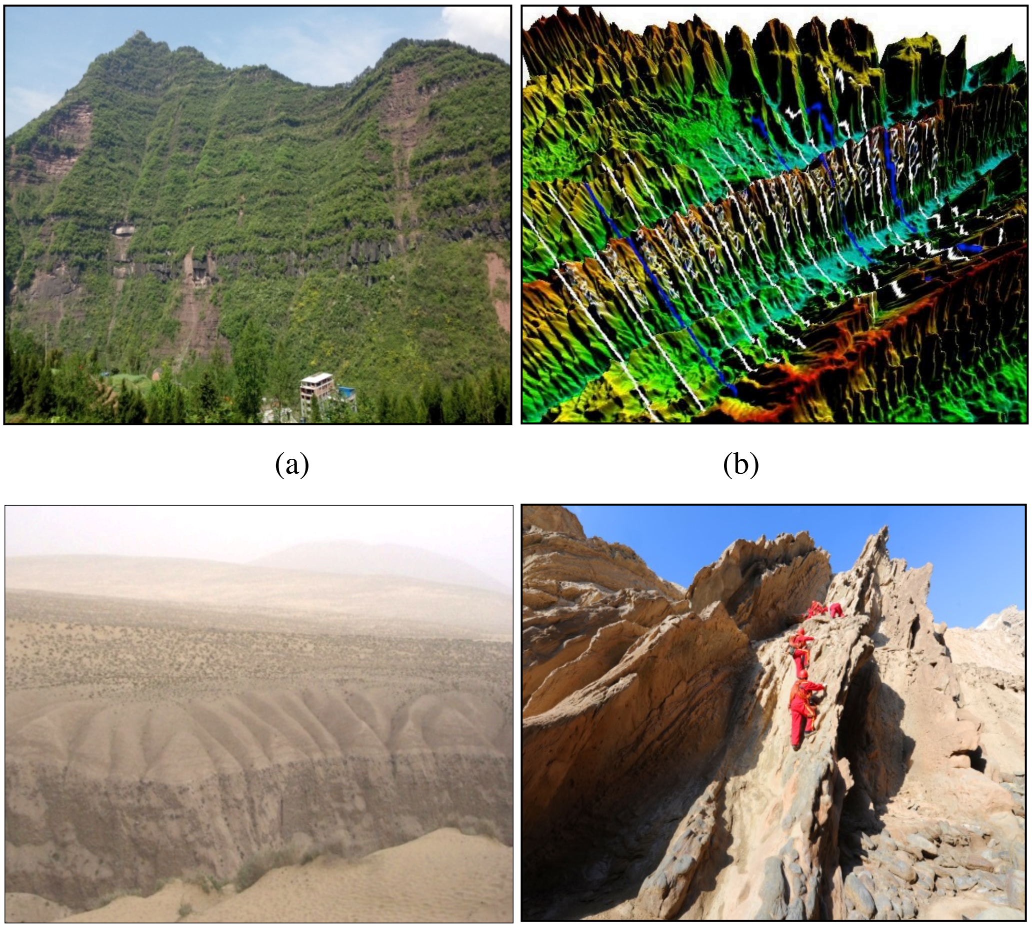
With the deepening exploration of oil and gas resources in China, the exploration targets have been shifted from simple structures of the plains and deserts areas to complex structures and lithological structures, and the exploration areas have been extended to the complex mountain areas, transition zones and to the deep-sea.

In recent years, increases of measured oil initially in place (OIIP) and gas initially in place (GIIP) in China had hit a record high (Wu et al., 2016). Major basinswith complex seismic geological features are the important zone with proven oil and gas reserves in the foreland basin and are mainly distributed in Dabashan and Longmenshan piedmont of the Sichuan Basin, Kuqa area, southwestern Tarim in the Tarim Basin, southern margin of the Junggar Basin and Western margin of the Ordos Basin in western China (Du et al., 2016). However, these areas are also the most challenging ones for geophysical exploration (Wang et al., 2014). They have been deformed drastically by the intense orogenic movements and weathering. Strong lateral velocity variation of near-surface layers result in serious problems for static correction, which causing great difficulties to build the near-surface model accurately (Luo et al., 2017) because of the development of salt structures, reverse thrust structures, strike slip faults and other geological phenomena. Thus the seismic wavefield recorded is extremely complex and the SNR is low.

Application of high-density seismic exploration in complex mountain areas in recent years has significantly improved the SNR and imaging quality of seismic data, bringing higher success rate on exploratory drilling (Wang et al., 2017; Zhang et al., 2015; Peng et al., 2006). Whereas the high cost also increases investment risk at the same time (Cordsen et al., 2015). In the trend of ‘low oil price’, technical factor and investment efficiency must be considered integrately to maintain a reasonable data quality with relative lower cost (Wang et al., 2018). In order to achieve such a goal in complex mountain areas, swath 3D seismic acquisition technique has been applied widely in the foothill regions of western China.

SEISMOGEOLOGICAL CHARACTERS OF FOOTHILL REGIONS

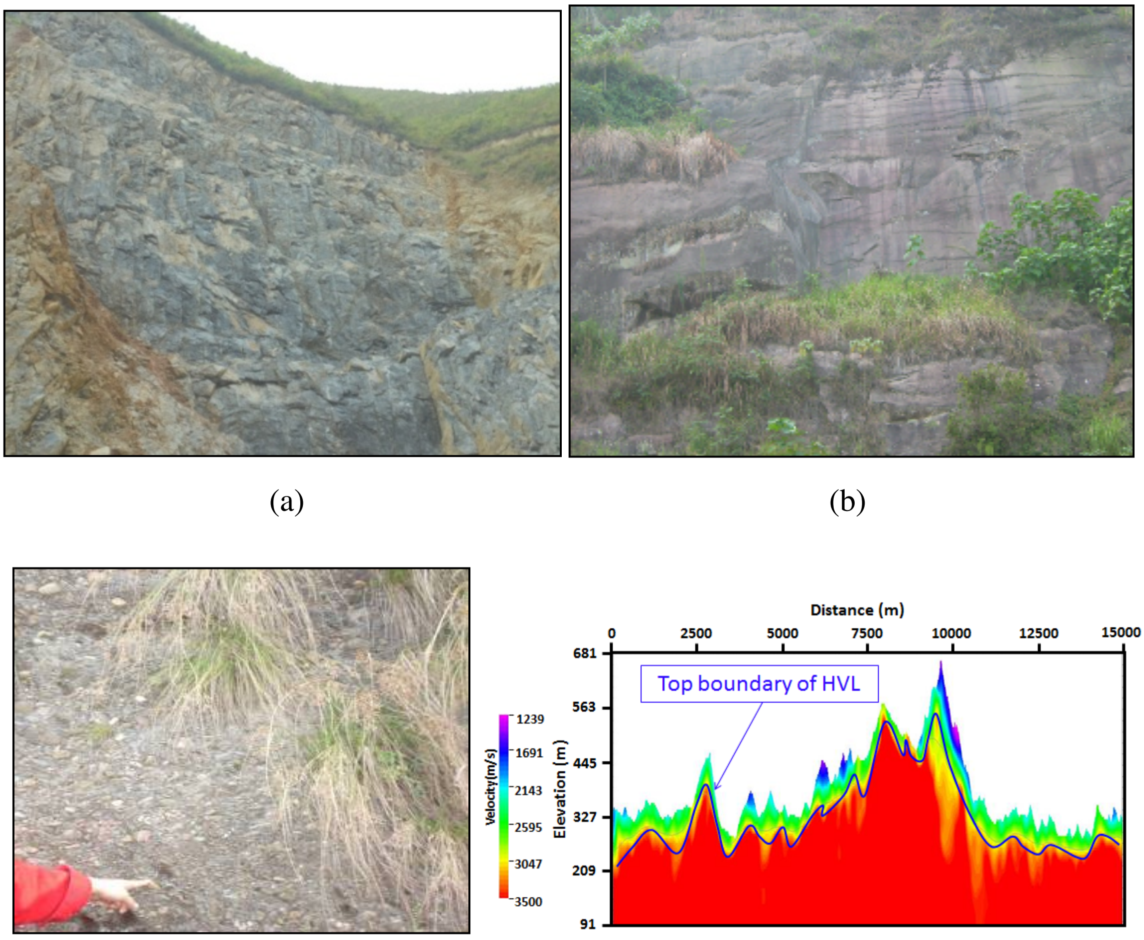
The "double-complex" seismogeological features of complex near-surface and complex subsurface in foothills regions result in an extremely low SNR of seismic data. The complexity on near-surface is mainly manifested in, on one hand, severe topography, ravines with large relative elevation differences (Fig. 1 illustrates respectively typical topography in Western Sichuan basin, Eastern Sichuan basin, Southwestern Tarim and Kuqa area in Tarim basin), and on the other hand, complex outcropping lithology with widely lateral variations. For example, there are limestone (Fig. 2a), sandstone (Fig. 2b), conglomerate (Fig. 2c) outcropped in the western Sichuan basin. Lateral velocities change rapidly according to near surface velocity model (Fig. 2d) established using tomographic inversion. The complex subsurface is mainly caused by the complicated and varied geological structures (Fig. 3) with large local strata dip, such as fractures and folds.



(a) (b)

(c) (d)

Fig. 1. Topography characters in foothill regions in (a) Western Sichuan basin, (b) Eastern Sichuan basin, (c) southwestern Tarim in Tarim basin and (d) Kuqa area in the Tarim basin.



(a) (b)

(c) (d)

Fig. 2. Typical outcropping lithology. (a) Limestone. (b) Sandstone. (c) Conglomerate. And (d) near-surface velocity model in the eastern Sichuan Basin in China.

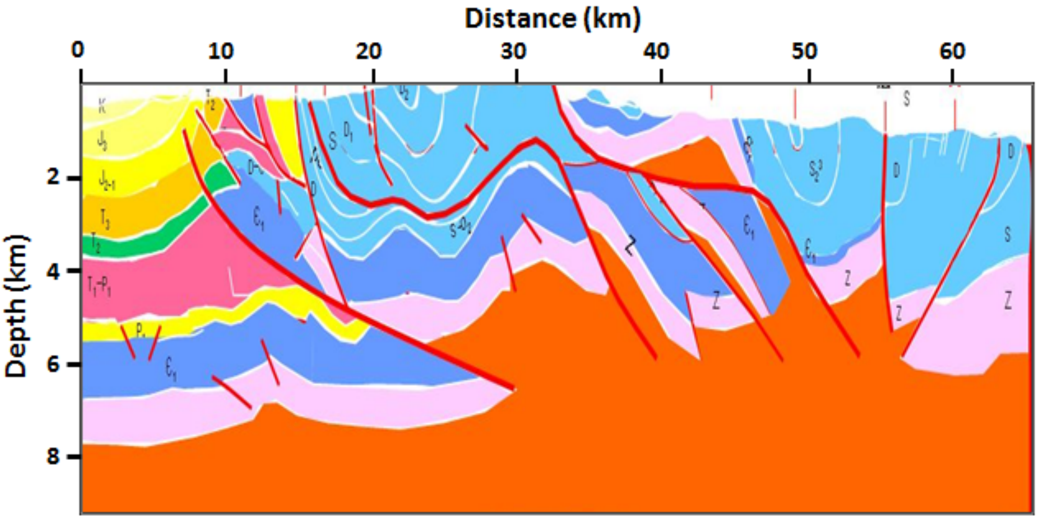
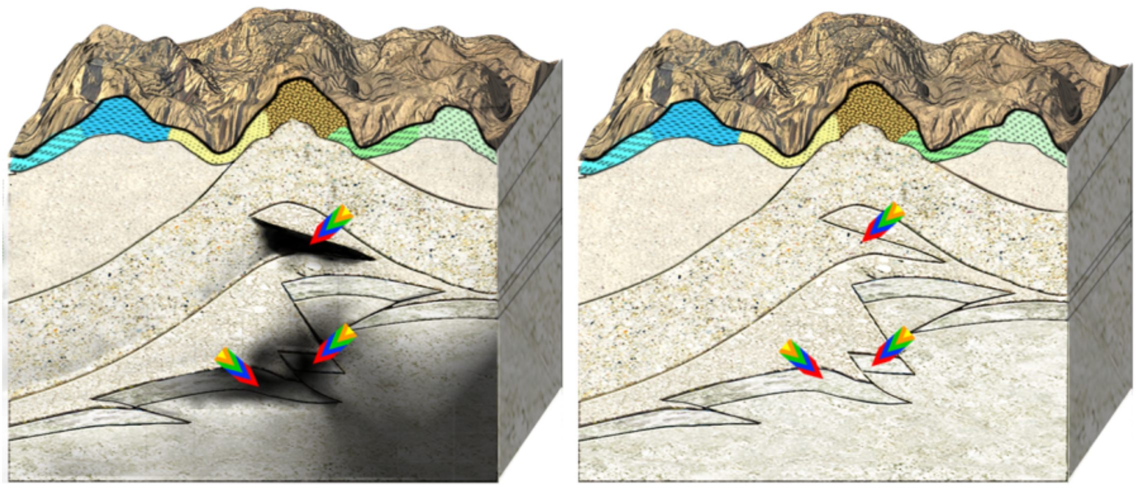


Fig. 3. Typical tectonic model in the Sichuan basin.

The main difficulties for seismic exploration in these areas are as follows: (1) the shallow refraction wave, surface wave, side interference wave and source-induced secondary interference wave are highly developed. This so called 'weak signal + strong interference' (Yang et al., 2016) leads to the low SNR of seismic data. (2) accurate near-surface modeling and static correction are difficult. (3) spatial sampling is irregular, due to complex near-surface conditions, and the raw data characteristics such as fold, azimuth and the maximum offset are distributed unevenly, resulting in local information missing on common offset gathers. (4) complex subsurface structures make the wavefield complicated and the migration repositioning inaccurate.

CONVENTIONAL GEOMETRY TECHNIQUES IN FOOTHILL REGIONS

Designing a geometry which can greatly improve the uniformity of illumination (van Veldhuizen et al., 2008) for underground targets and obtain high quality seismic data in foothills regions is an all-time technical goal. Unreasonable geometry as shown in Fig. 4a with exploring shadow and reasonable geometry as shown in Fig. 4b with none exploring shadow were compared (Hu et al., 2017). Perfect illumination would be the like in Fig. 4b. However, cost and risk should also be considered to make a balance between technology and economy. To reach the balance, geometry parameters should be determined reasonably according to different needs at different stages.



(a) (b)

Fig. 4. The comparison of the uniformity of illumination for underground target between (a) unreasonable geometry and (b) reasonable geometry.

Development history of conventional geometry techniques

Fig. 5 shows the developing history of seismic geometry technique in foothill regions. Conventional (mountain) 2D geometry (Fig. 5a) has been applied since 1975 and it can obtain 2D seismic data with low SNR (Fig. 5e). Then conventional 3D geometry (Fig. 5c) has been employed since 1981 and later from 2002, wide-line 2D geometry (Fig. 5b) (He et al., 2003) was applied. Most recently, wide-azimuth high-density 3D (Fig. 5d) has been applied and the SNR of seismic data (Fig. 5h) acquired has been improved significantly (Lu et al., 2016). High-density 3D geometry with none exploring shadow is considered technically the most reasonable technique in foothill regions. Nevertheless, it can also be seen that the cost of high-density 3D geometry technique is the highest (Fig. 5 upper).

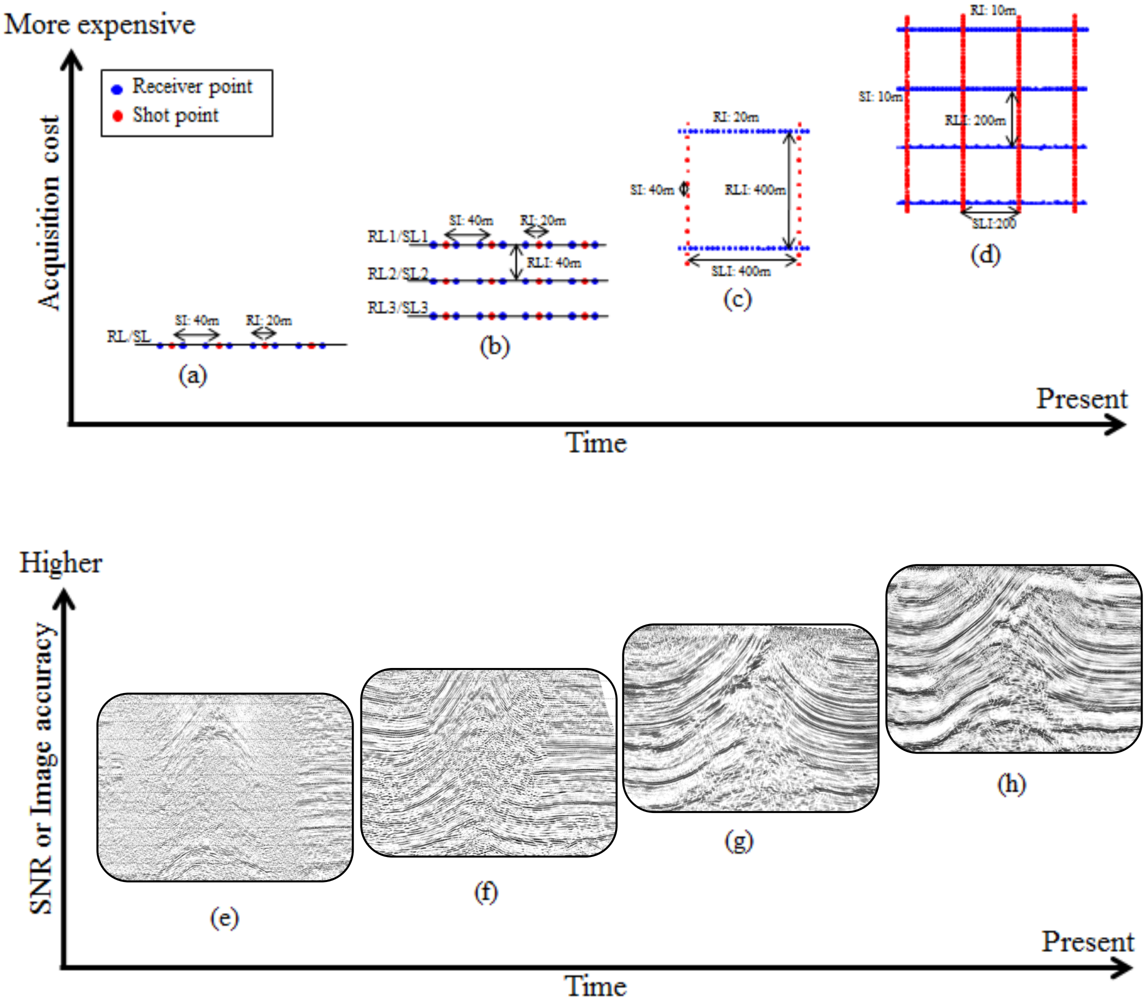


Fig. 5. The development history (upper) and application effect (below) of seismic geometry technique in foothills regions. (a) Mountain 2D geometry (From 1975 to present) and application effect (e). (b) Wide-line geometry (From 2002 to present) and application effect (f). (c) Conventional 3D geometry (From 1981 to present) and application effect (g). (d) Mountain high density 3D geometry (From 2012 to present) and application effect (h).

Merits and drawbacks of widely applied geometry

Wide-line 2D and high density 3D are widely applied geometry in foothill regions in western China in recent years. It has been found that wide-line 2D geometry can improve the SNR of seismic data effectively (Fig. 5f) thus help identifying exploration target zones. However, its imaging accuracy is limited according to verification of the real drilling data. High density 3D in mountain areas is commonly defined by trace density equal or greater than 60×10^4 trace/km^2. It can improve the SNR and imaging accuracy of seismic data significantly. However, the total cost is so high that it increases the exploration risk correspondingly.

SWATH 3D GEOMETRY TECHNIQUE

Considering the disadvantages of the wide-line 2D and high density 3D, in order to improve imaging accuracy while reducing exploration risk, the swath 3D technique is developed.

Characteristics of Swath 3D Geometry

The swath shooting is an improved practice in the industry today in 3D seismic data acquisition. In swath shooting, the receiver lines are fixed and all the shots pertaining to the swaths are recorded with the same beam receiver lines. Swath shooting is characterized by uneven distribution of offsets from bin to bin though the pattern of a family of offset distribution repeats from one set of bins to another. On the other hand, in the recent years, swath shooting replaced the high density 3D shooting when full azimuth coverage is less important, especiallythe geological target is striped. In swath shooting (Fig. 6), the shot is considered to be at the centre of the swath patch and the data is recorded accordingly.

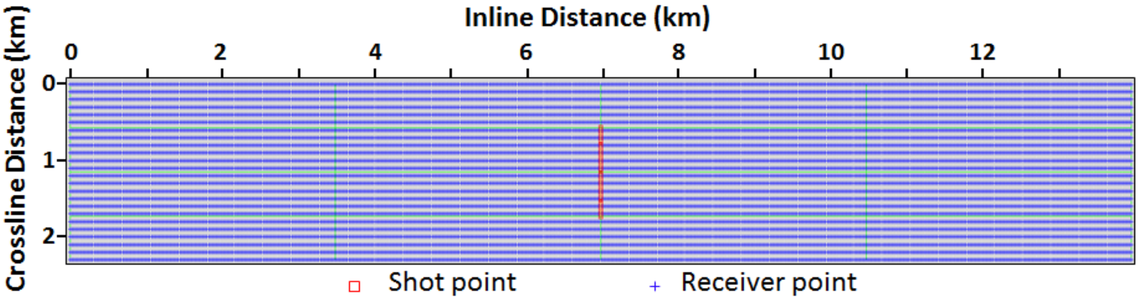
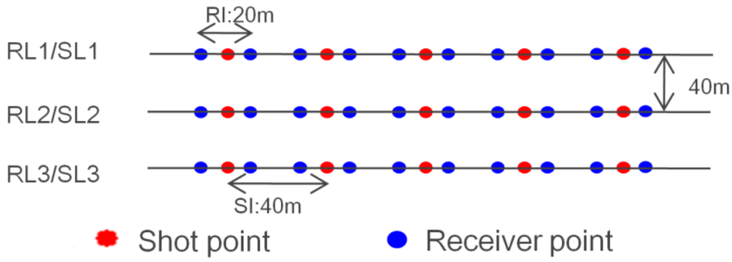


Fig. 6. Swath 3D geometry template (24R48S560T). The bin size is 12.5 m × 12.5 m, the fold is 320, and the receiver line interval is 100 m.

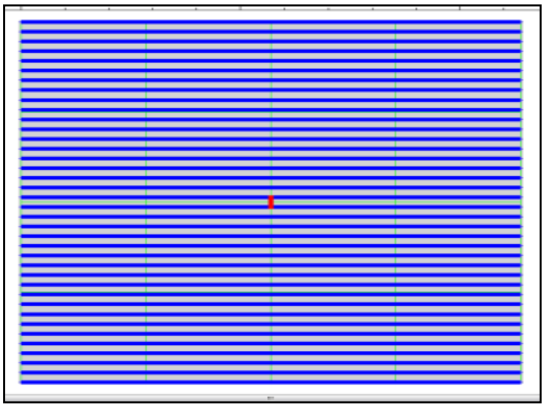
The proposed swath 3D geometryis the special high-density 3D acquisition geometry to obtain narrow-strip subsurface information. It is characterized by high trace density, small receiver line interval and no lateral scrolling. It is mainly used to solve the imaging problem of complex geological targets (Wang et al., 2017).

Comparison with other geometry techniques

At present, commonly used seismic acquisition techniques in low SNR areas include wide-line 2D, high-density 3D and swath 3D methods. Wide-line 2D technique (Fig. 7a) is mainly used for 2D seismic imaging. It has large bin size, high fold number, and low acquisition cost and is easy to implement in 'double-complex' foothills regions. It can improve the SNR of seismic data effectively. However, imaging accuracy of wide-line 2D is not high enough since it is based on 2D theory. High-density 3D technique (Fig. 7b) is mainly used for full or wide azimuth 3D seismic imaging, which can describe the thin reservoir and micro-fracture zones accurately (Zhang et al., 2018). This technique, characterized by small bin size, single-point source/receiver arrangement and full or wide azimuth, aims to obtain high-fidelity and high-resolution data. It is difficult to implement high density though in complex mountain areas because of its high acquisition and processing cost.



(a)



(b)

Fig. 7. (a) Wide-line 2D geometry (3 shot lines and 3 receiver lines). The bin size is 10 m ×18 m and the fold is 1080. (b) High-density 3D geometry(36R20S720T). The bin size is 5m×5m , the fold is 324, and the receiver line interval is 200 m.

The swath 3D technique (Fig. 6) is mainly used for narrow strips 3D seismic imaging. Its vertical and horizontal folds are higher and the receiving line interval is smaller than those of 3D high-density. Subsurface information obtained in the crossline direction is much richer than that of the wide-line 2D technique and is processed based on 3D theory, which improves both the SNR and imaging precision of seismic data. Its technical performance and cost is lower than high-density 3D but higher than wide-line 2D (Table 1). Besides, its full fold area of seismic data is smaller than that of high-density 3D.

Table 1. Comparison of different geometry in foothills regions.

Geometry type	*Wide-line*	*High-density 3D*	*Swath 3D*
2D/3D	*2D*	*3D*	*3D*
Bin size	*large*	*small*	*middle*
Fold	*high*	*high*	*high*
Azimuth	*narrow*	*full/wide*	*narrow*
Imaging accuracy	*low*	*high*	*high*
Acquisition cost	*low*	*high*	*middle*

Key points in designing the swath 3D Geometry

Table 2 is a comparison of geometry parameters between conventional 3D and swath 3D in the same area. As is known, parameter design of swath 3D geometry is basically the same as that of conventional 3D. However, it should be noted that the number of source points of swath 3D geometry is multiplied by the number of conventional 3D geometry template while the receiver line interval is greatly reduced. The goal is to increase the trace density within a certain strip (Yan and Xie, 1998). During field operation, conventional 3D geometry template (Fig. 8a) scrolls in both inline and crossline direction. However, the proposed swath 3D geometry template (Fig. 9a) only scrolls in inline direction, without crossline scrolling. Figs. 8b and 9b show trace distribution via azimuth and offset of conventional 3D and the proposed swath 3D template. Red areas (Figs. 8c and 9c) are full-fold areas of the two 3D geometries which are both approximately 25 km^2. It can be seen that the swath 3D geometry provides the full-fold data within a certain strip. In this particular variant of the design, the source points extend over half of the receiver patch (in the crossline direction). The parameters of the proposed swath 3D geometry are determined according to different geologic requirements, and Fig. 10 exhibits the field layout of swath 3D geometry. Finally, high-quality seismic data are obtained, which could lay a solid foundation for follow-up processing and interpretation.

Table 2. Comparison of geometry parameters between conventional 3D and swath3D.

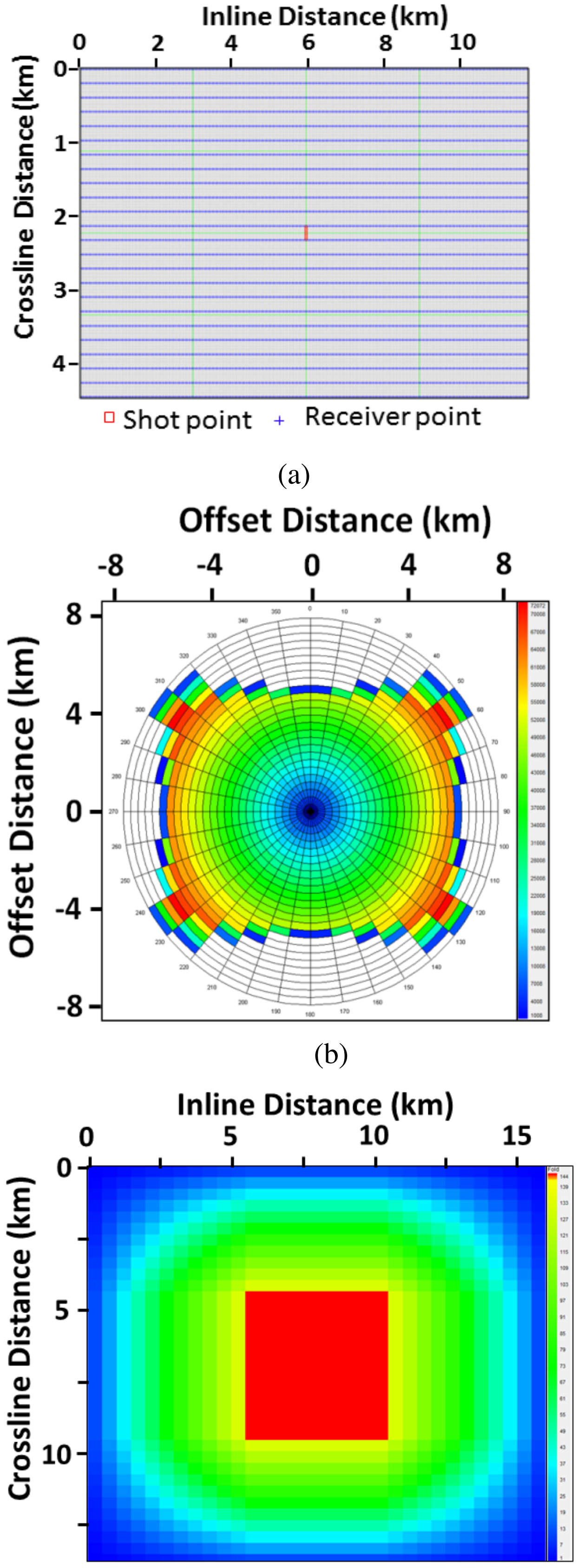
	Conventional 3D	*Swath 3D*
Geometry type	*Orthogonal*	*Orthogonal*
Geometry mode	*24R8S240T*	*24R48S560T*
Receiver channels	*5760*	*13440*
Fold	*12×12=144*	*20×12=240*
Bin size (m)	*25×25*	*12.5×12.5*
Receiver interval (m)	*50*	*25*
Receiver-line interval (m)	*400*	*100*
Source-point interval (m)	*50*	*25*
Source-line interval (m)	*500*	*350*
Aspect ratio	*0.8*	*0.25*
Trace density (Trace/km^2)	0.23×10^6	1.536×10^6

RESULTS

Compared to 2D seismic data (Fig. 11a), it can be seen that the SNR of seismic data (Fig. 11b) obtained by proposed swath 3D method has been greatly improved and the continuity of seismic events in the upper and middle part of the profile becomes better. Based on the higher quality PSTM seismic data (Fig. 12b), the location of fault point and structure are more accurate.

CONCLUSION

Through successful implementation of the proposed swath 3D seismic geometry method in foothill regions, the following conclusions could be drawn: (1) Swath 3D geometry effectively improves the SNR and imaging accuracy of seismic data in foothill regions. (2) Application of this method provides better imaging of geological targets thus reduces exploration risk in the focal areas to a certain extent. (3) This kind of geometry has the characteristics of higher fold number and higher trace density than prior acquisition geometries, which enables that the seismic data obtained by this technique could be used to test and optimize key parameters of high-density 3D geometry.

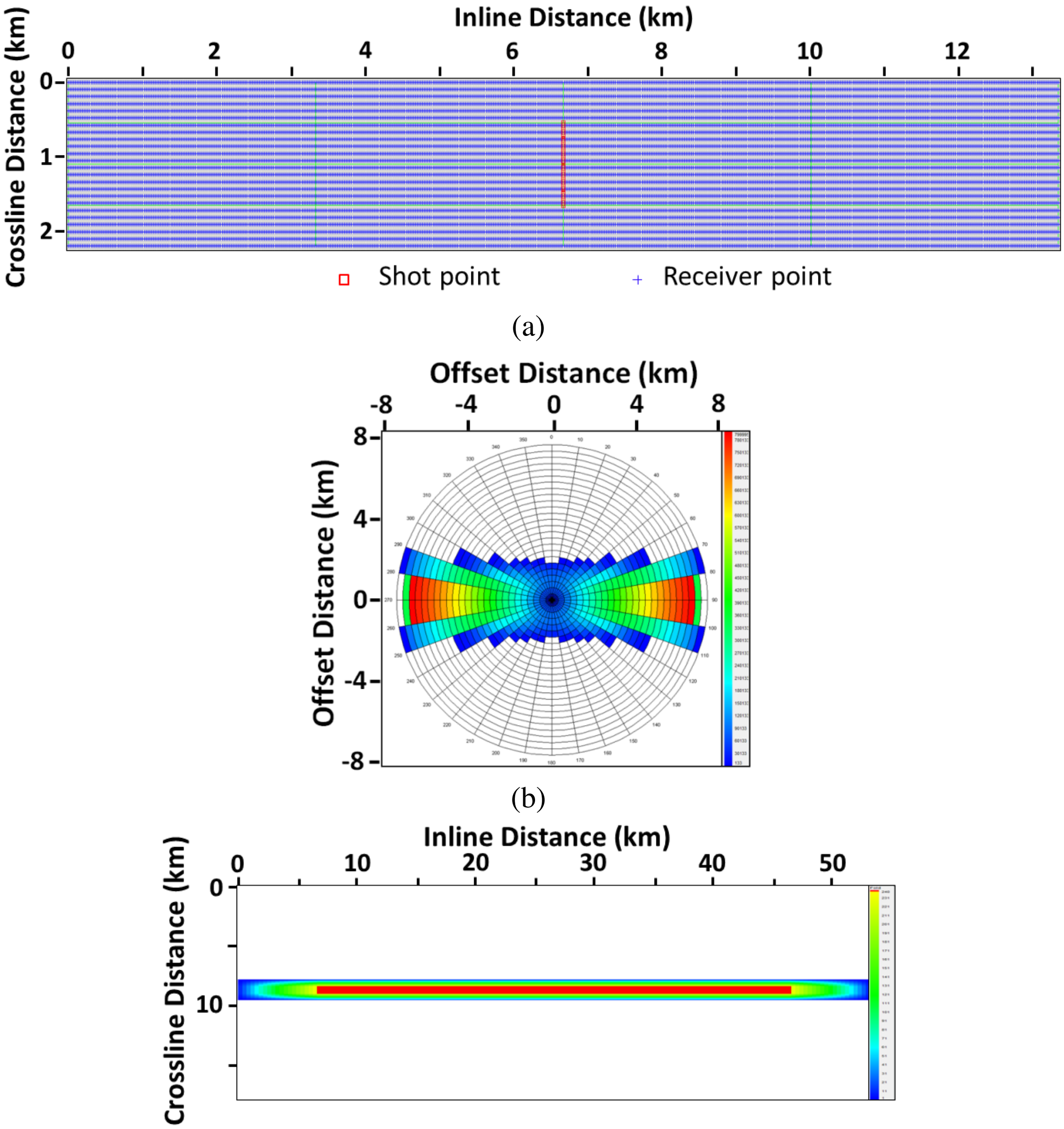


(a)

(b)

(c)

Fig. 8. Template (a), rose map (b) and the fold distribution (c) of conventional 3D geometry.



(a)

(b)

(c)

Fig. 9. Template (a), rose map (b) and the fold distribution (c) of swath 3D geometry.

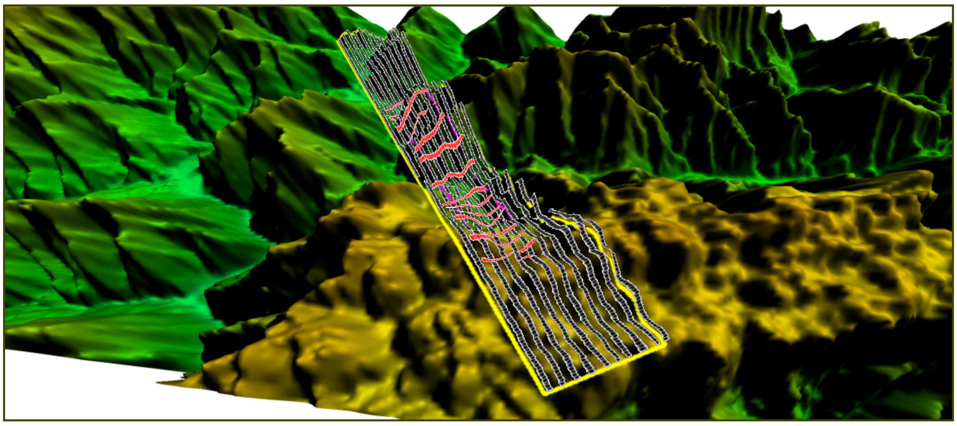
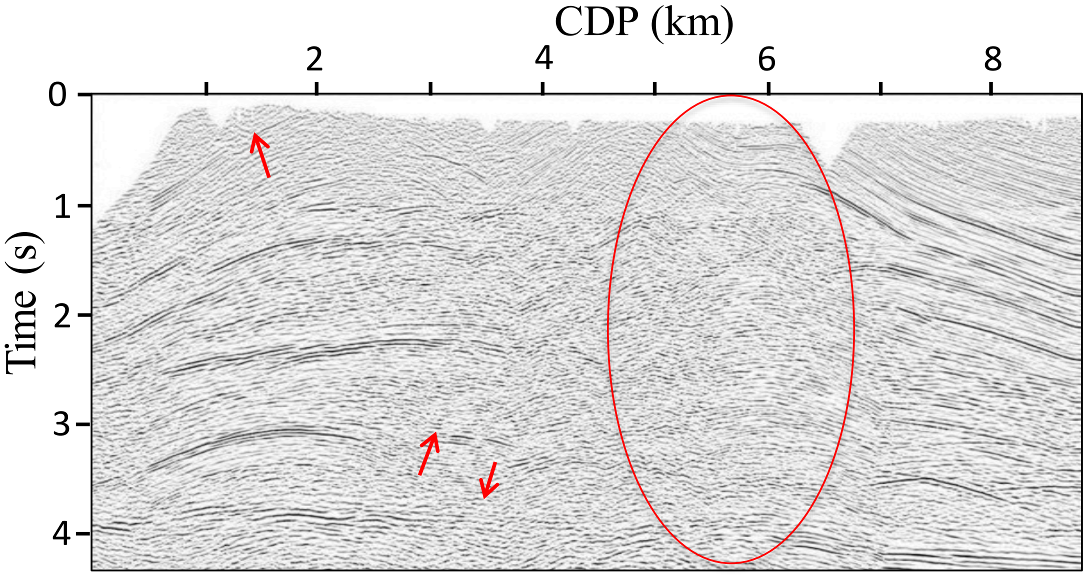
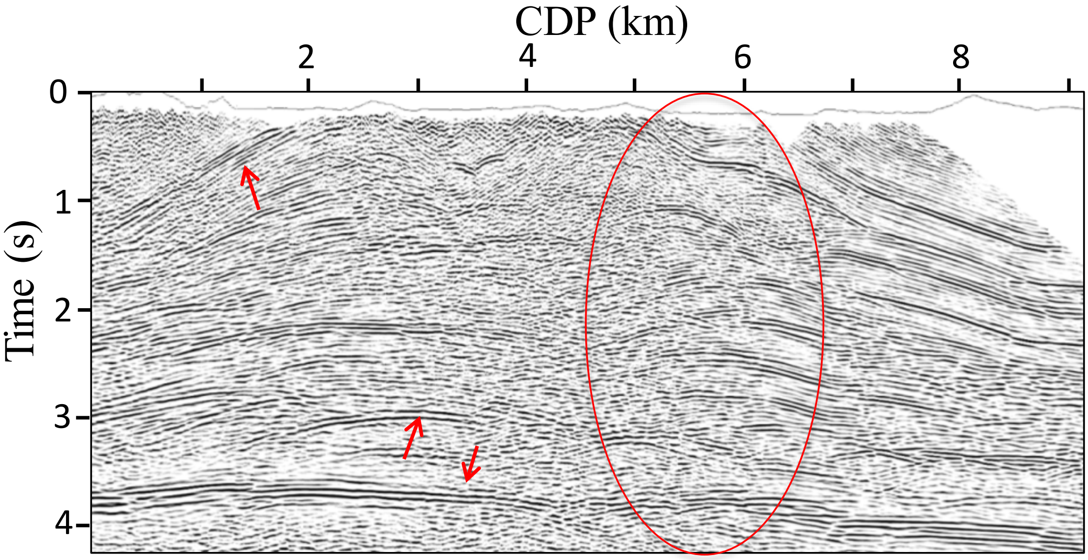


Fig. 10. Field layout of swath 3D geometry (Red lines represent shot lines, and black lines represent receiver lines).

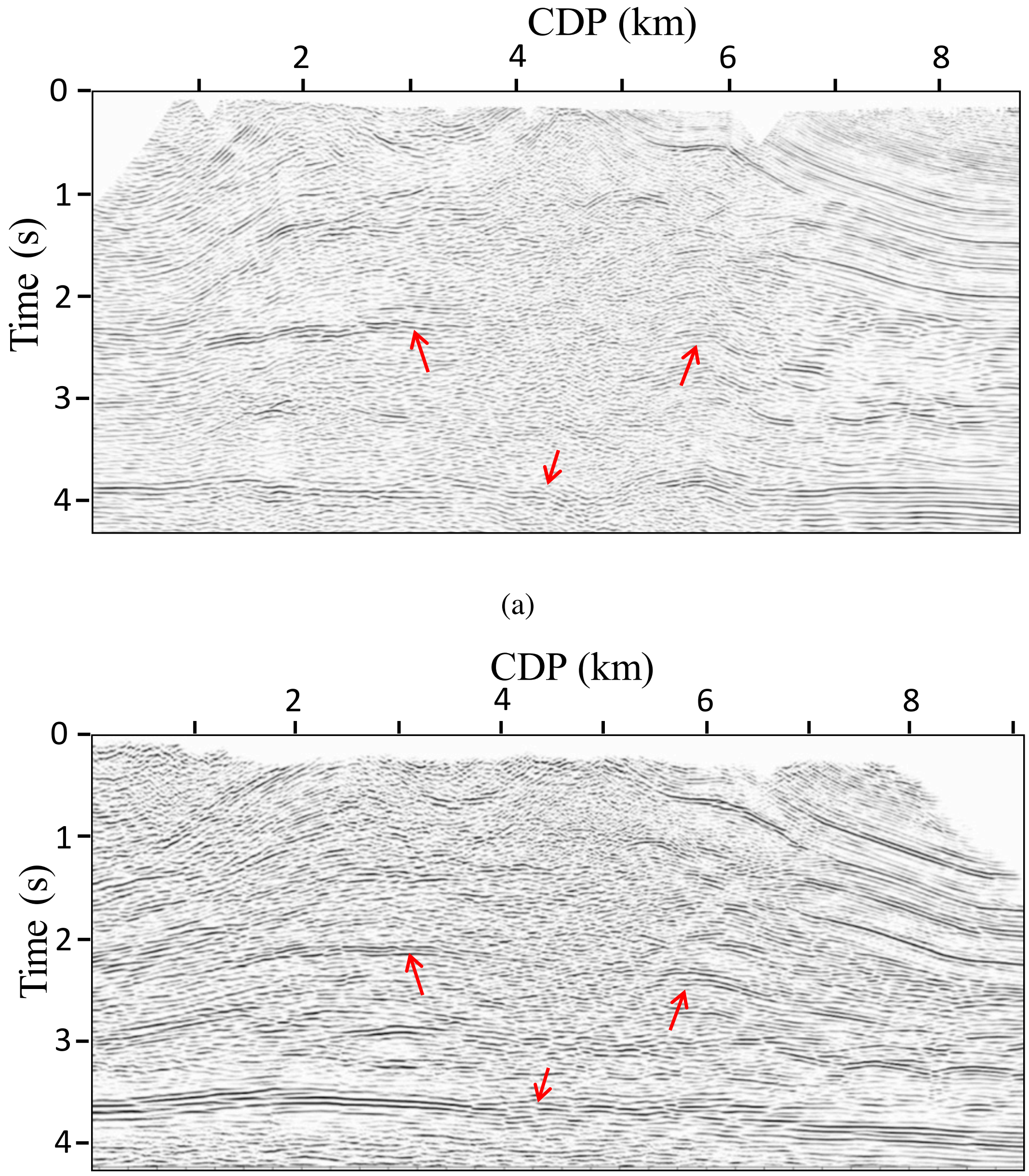


(a)



(b)

Fig. 11. Comparison of stack section between wide line data (a) and swath 3D data (b).



(a)

(b)

Fig. 12. Comparison of PSTM between wide line data (a) and swath 3D data (b).

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