Staggered Source Acquisition to Improve Image's Fidelity

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Summary

To image complex subsurface structures, we need to apply wavefield recording layouts for seismic data acquisition, which increases acquisition costs significant and also leads to challenges for data processing. Costs for receivers has reduced rapidly while costs for sources just gradually change as acquisition technology improves for land seismic exploration. We propose an acquisition layout of staggered sources for 3D land seismic data acquisition. The layout of staggered sources divides conventional 6-shots in one shot line within one swath into 3 staggered sub-shot lines with 2 shots for each sub-shot line while total number of sources for a survey is kept same as the conventional acquisition layout. The proposed layout has been tested on a synthetic 3D model derived from the field survey through forward modeling, illumination analysis, RTM PSDM, and turning ray tomographic inversion for near surface models. The tests demonstrate that the proposed staggered sources result in stronger illumination, subsurface image with higher fidelity, and more reliable near surface models than the conventional layout of sources without increment in acquisition cost. Therefore, the staggered sources are cost effective to improve subsurface imaging, which has been suggested for further field surveys.

Introduction

During last decade, seismic acquisition has gradually evolved into an era of "wavefield recording" (Stork, 2011) from "CMP fold" (Stone, 1994). In contrary to focusing on uniformed surface folds for CMP fold, wavefield recording emphasizes on illuminating subtle aspects of subsurface structures. To achieve better illumination, acquisition layout for wavefield recording requires denser sources, denser receivers, and lager observing apertures than conventional layout for CMP fold, which .significantly increases costs of acquisition and also leads to challenges for data processing. However, to take advantages of wavefield recording, geophysicists perform forward modeling based on geological information from interest areas. Then a cost effective acquisition layout is designed. Here, as an example, we apply these technologies to Taxinan Foothill area located at Tarim basin (Li., et. al, 2020).

The interest area has both extreme difficult surface geological settings as shown in Figure 1 and complex overthrust subsurface structures as shown in Figure 2.In 2010, a 3D seismic survey was carried out in the area using conventional layout of CMP fold while it remains a challenge to derive reliable interpretation from the corresponding 3D depth imaging. Thus, seismic simulation came to thought to identify factors affecting imaging and to find cost effective acquisition parameters. The 3D velocity model has been derived from regional geologic settings and well loggings. Figure 2 shows a 2D velocity profile for one inline located at the middle of model. Since seismic acquisition equipment has been improved significantly, costs for receivers are reduced rapidly. In other hand, costs for sources just decrease gradually, especially for land data acquisition and make a large portion of total costs. Therefore, .in this study, we propose an acquisition layout of staggered sources. Then forward modeling is made for both layouts of conventional CM fold and staggered sources. Next, illumination analysis, prestack depth migration, and near surface model estimation are followed for both synthetic data sets from two layouts respectively.

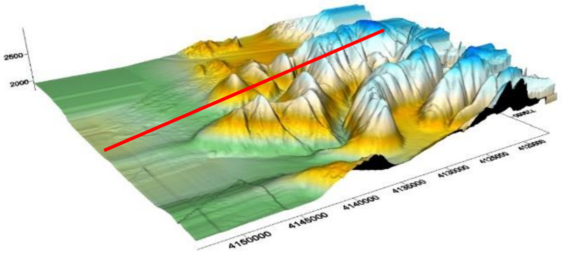

Figure 1. Elevations of study area. The relief is ~900 meters. The highlighted redline stands for one inline in the middle.

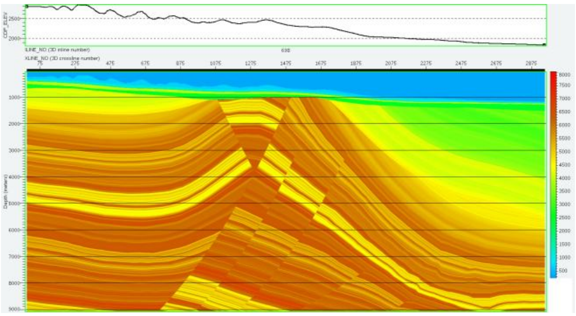

Figure 2. One inline velocity profile corresponding to the red line in Figure 1. The vertical axis is depth from 0 to 9000 m and the horizontal axis is distance for 29500 m.

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Staggered Sources and Forward Modeling

The field 3D seismic survey has been carried out in the study area with conventional seismic acquisition recording. The survey template is the 3D orthogonal swath shooting system as shown in Figure 3. There are 6 shots aligned in one source line with 60 meter interval between shots. There are 16 receiver cables with interval 300 meters and interval between receivers is 30 meters. Maximum inline and crossline offsets are 9340m and 2550m respectively. For whole survey, the template rolls 360 meters and 300 meters along inline and crossline respectively.

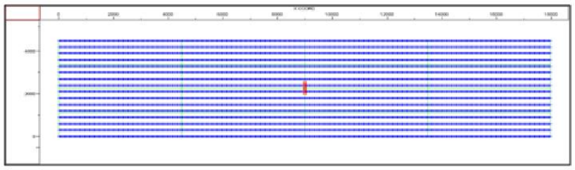

Figure 3. The template of swath shooting used in the 3D field acquisition. The red dots in the middle stand for sources. The blue dots are for receivers.

To improve imaging quality of structures with large dip angle without increasing acquisition cost and inspired by staggered grid finite difference algorithm for seismic forward modeling (Liu and Sen, 2010), we propose staggered sources for a 3D acquisition layout. Figure 4 and 5 demonstrate layouts of conventional and staggered sources respectively. To reduce distance among sources. a group of 6-shots within one source line in Figure 4 is divided into 3 separated sub-groups along shooting direction with 2 shots for each sub-group in Figure 5. The interval between the staggered source lines is 120 meters and source interval within subgroup is 60 meters. The staggered layout is designed in such a way that the staggered source acquisition consists of same number of shots as the conventional acquisition within one swath. Therefore, the proposed staggered sources require no cost increasing.

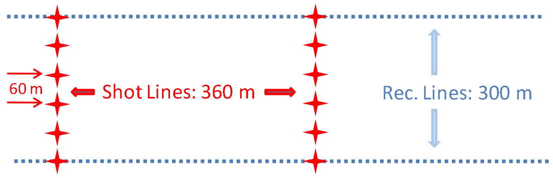

Figure 4. Two adjacent source lines in conventional swath acquisition. The red crosses are sources and blue dots stands for receivers.

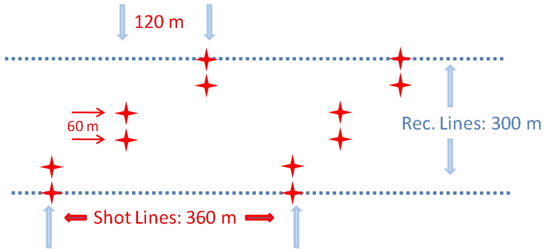

Figure 5. Layout of staggered sources corresponding to two source lines of the conventional swath acquisition in Figure 4. .The red crosses are sources and blue dots stands for receivers.

We compute 3D synthetic seismic shot gathers for both conventional and staggered source layouts. Both of them have same receiver layouts. The inline offset's range is from -9000m to +9000m with interval of 20m and crossline offsets are from -2040m to +2040m with interval of 120m. Two swathes are generated for both layouts. Total number of shots is 672 for each source's layout. A sample shot is shown in Figure 6.

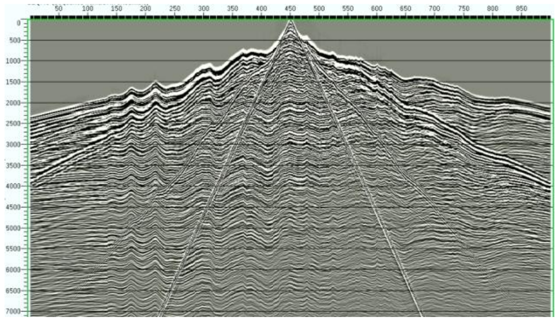

Figure 6. Sample shot gather located at the center of model generated by 3D acoustic FD modeling with Rick wavelet and maximum frequency of 35 Hz.

Staggered Sources for Strong Illumination and Subsurface Imaging with High Fidelity

To examine effectiveness of staggered sources over conventional sources, we perform illumination analysis and prestack depth migration on corresponding two data sets individually. Illumination analysis is to study how different acquisition layouts illuminate areas of a complex subsurface model (Xie, et. al, 2006). The typical algorithms for illumination analysis include ray-tracing and wave equation methods. The former is computing cost effectively but not reliable for complex structures. The latter can provides a more accurate illuminating map for complex models while it costs more computational load.Since current study area is very complex, we apply 3D wave equation based algorithm to generate 3D total illumination volumes. The exact same acquisition layouts as forward modeling are used for inputs to illumination analysis. The illuminations from individual source are all stacked together for total illumination on all grid cells of model. Figure 7 and Figure 8 compare illumination volumes from conventional and staggered sources respectively. The staggered sources show stronger and more uniformed illumination than the conventional sources. It is obviously that the vertical strips in the conventional are almost vanished in the staggered which means the smaller distance between shot lines reduces acquisition footprints. We also note that staggered source's illumination shows more consistent with structures than the conventional, especially in steep dip zones. To further demonstrate advantages of staggered sources, RTM 3D prestack depth migration is applied on the two data sets respectively. The RTM stacks are shown in Figure 9 and 10 from the conventional and the staggered correspondingly. The similar phenomena show up as illuminations. The staggered sources lead to higher fidelity in subsurface imaging than the conventional. The true faults become clear and sharp while the "fake faults" caused by the acquisition footprints become mush week. Again, we attribute the high fidelity of imaging to small intervals among staggered sources. However, we do not increase total number of sources for the whole survey.

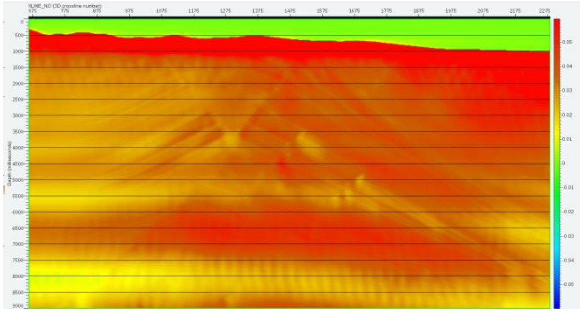

Figure 7. The inline vertical profile of 3D illumination volume from the conventional sources located at the middle of model.

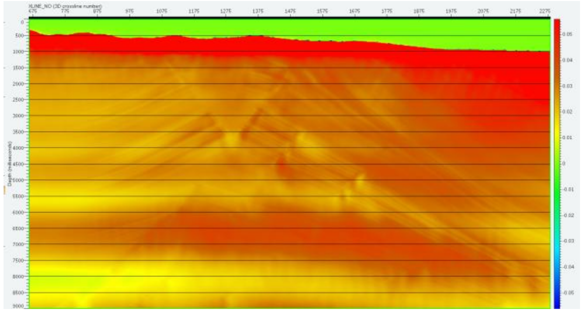

Figure 8. The inline vertical profile of 3D illumination volume from the staggered sources located at the of model.

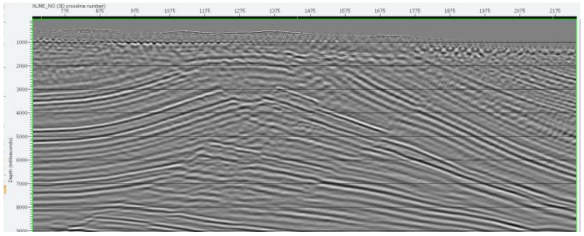

Figure 9. The stack inline vertical profile of 3D RTM prestack depth migration from the conventional sources located at the middle of model.

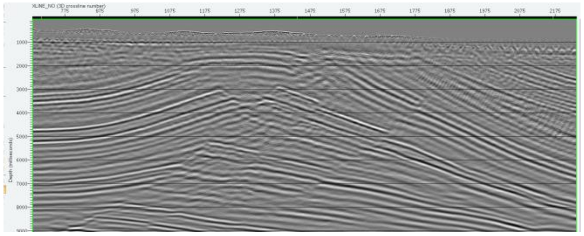

Figure 10. The stack inline vertical profile of 3D RTM prestack depth migration from the staggered sources located at the middle of model.

Staggered Sources for Accurate Near Surface Model

In land seismic processing, an accurate near surface model is critical for prestack depth migration, especially for foothill areas. The current workhorse for building near surface models is 3D turning ray tomographic inversion based on first arrivals from the seismic survey. Therefore, accurate of model from inversion depends on acquisition layouts if first arrives are precisely picked. We pick first arrives for both data sets over full offset ranges using same parameters. Then 3D turning ray tomographic inversion is performed on both first arrives. After 9 non-linear iterations, the inversions converge. The inverted velocities are shown Figure 11 and 12 respectively from the conventional and the staggered. The true model is presented in Figure 13. Since a rule of thumb of quart of maximum offset is the maximum reliable depth for turning ray tomography, the models are only displayed to depth of 1400 m. By comparing all three models, the model from the staggered sources is more consistent to the true model than the model from the conventional sources with respective to values of velocities and trends of subsurface structures.

Conclusions

We have proposed the staggered sources for land seismic data acquisition. The layout of staggered sources divides conventional 6-shots in one shot line within one swath into 3 staggered sub-shot lines with 2 shots for each sub-shot line. Then, interval between sub-shot lines is only third of conventional shot lines while total number of sources for a survey is not increased. .The proposed layout has been tested on a synthetic 3D model derived from the field survey through forward modeling, illumination analysis, RTM PSDM, and turning ray tomographic inversion for near surface models. The tests demonstrate that the proposed staggered sources result in stronger illumination, subsurface image with higher fidelity, and more reliable near surface models than the conventional layout of sources without increment in acquisition cost. Therefore, the staggered sources are cost effective to improve subsurface imaging, which has been suggested for further field surveys.

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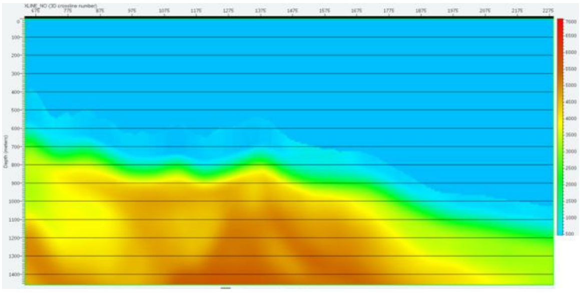

Figure 11. The inline vertical profile of 3D turning ray tomographic velocity inversion from the conventional sources located at the middle of model. The vertical axis is depth from 0 to 1400 m and the horizontal axis is distance for 16500 m.

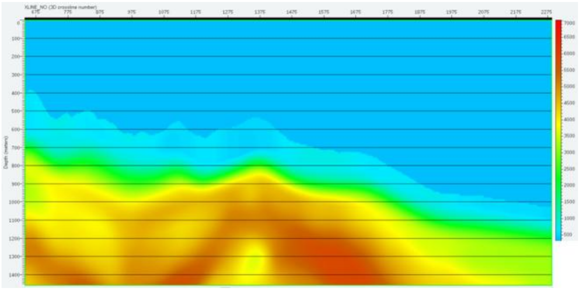

Figure 12. The inline vertical profile of 3D turning ray tomographic velocity inversion from the staggered sources located at the middle of model.

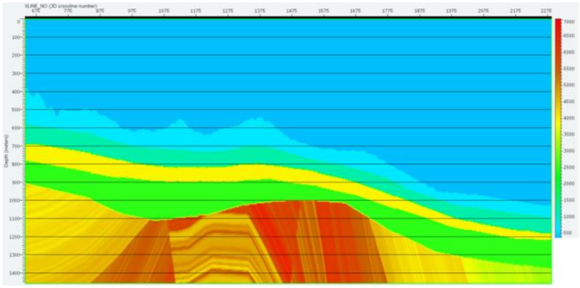

Figure 13. The inline vertical profile of 3D true velocity model located at the middle of model.

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