High-resolution Reservoir Mapping by Simultaneous Vibratory Sources

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Summary

The advancement of the simultaneous-multiple-sourcing (SMS) technology in seismic land acquisition has matured from the research stage to routine production. The key benefits of this technology are to improve data bandwidth, increase spatial resolution, and reduce acquisition cost. However, the increase of productivity also adds more complexity in field acquisition and data processing. Understanding the practical challenges of acquisition and processing associated with simultaneous multiple sources, one can fully realize the potential benefits of this technology. We will demonstrate some of the challenges of this technology by focusing on three main areas: the impact of the phase-encoding scheme, the data organization of the source separation, and noise attenuation on single-source data. We apply our best practices to a number of large 3D data sets. The comparison between conventional and SMS acquisitions indicates that SMS data produce much higher-resolution images than conventional vibroseis. In addition, we will demonstrate that a number of high-fold 3D data sets acquired by SMS technology consistently yield high-resolution images of the reservoir.

Introduction

The use of point source and point receiver acquisition combined with simultaneous sourcing has been used successfully in the last decade to acquire high-fold 3D seismic data at costs comparable with conventional acquisition. HFVS™ and ZenSeis™ are two of the popular SMS technologies used in land acquisitions. Krohn and Johnson (2006) detailed the basic concept of HFVS technology that could be used to increase production rates and reduce acquisition cost or to increase spatial sampling and improve data quality. Their paper mainly focused on VSP and surface seismic test data and touched on some of the source separation issues. House et al. (2009) employed the same HFVS technology to acquire a 3D VSP data set to image a complex compartmentalized portion of the Jonah gas field in Wyoming. They concluded that HFVS technology increased data bandwidth, allowed shorter recording time than conventional recording, and achieved 1.6:1 cost saving when compared to conventional vibroseis. Eick et al. (2009) introduced the concept of ZenSeis™ technology and presented a decade of field trials to bring the SMS technology from the research stage to routine production in recording over one thousand square miles of very high fold 3D seismic data with the point source and point receiver acquisition.

The efficiency of using simultaneous multiple sources also creates complexity in field operations and data processing. There are many challenges related to this technology. Some of the challenges are: sweep length design to compensate weaker energy of single source; synchronization of simultaneous multiple sources; accurate capture of various measured motions such as reaction mass, baseplate, ground force and pilot sweep to be used in the source separation process; proper phase encoding to ensure a unique separation of multiple-source gathers into a single source gather; and proper data organization used in the source separation to prevent incorrectly sequenced data that could affect the inversion results.

Chiu et al. (2008) addressed some of these issues and presented the results on a limited 3D data set. This paper expands further in examining some of the acquisition and processing issues that are unique to simultaneous multiple sourcing and applies our learning to a number of large 3D surveys. We focus on three main areas: (1) the impact of the phase-encoding scheme on data quality; (2) improper data organization used in the source separation that creates significant artifacts; (3) noise attenuation algorithms in reducing strong coherent noise that masks primary reflections especially for single-source data. Although we do not address other acquisition and processing issues, they are equally important in producing final high-resolution images. Since we have acquired a number of 3D land surveys using ZenSeis™ technology, we will demonstrate the success of this technology using examples from three of the 3D surveys, and also compare the result between conventional vibroseis and ZenSeis™ data.

Phase-encoding scheme

One of the requirements of the SMS technology is to encode a unique phase rotation into the vibrator sweep to ensure a unique separation of multiple-source gathers into single-source gathers. A poor phase-encoding scheme leads to a poor source separation. We illustrate the importance of the phase-encoding scheme with two examples. The first example compares two identical experiments with the same source and receiver recording geometry, except that one survey employed an optimized phase-encoding scheme and the other employed a non-optimized scheme. Figures 1a and 1b show a typical shot record with and without the optimized phase-encoding scheme. Cross talk among vibrators is not visible on the shot record with the optimized phase-encoding scheme. The second example examines the artifacts when the acquisition is not carried out properly. Both surveys were acquired with the same source and receiver recording geometry. The acquisition geometry was the same as the first example, having four simultaneous sources with four repeated sweeps at the same source locations. The proper-acquisition sequence produced good-quality single-source gathers (Figure 2a). However, during the acquisition stage, the vibratory phases of sweep 4 were mistakenly duplicated as sweep 1. The incorrect vibratory phases produced unusable data (Figure 2b). The lesson we learned is that the onsite field quality control is a critical step to spot acquisition problems.

Data organization for source separation

The SMS inversion in land acquisition requires the same number of receiver stations within a setup. A setup consists of phase-encoded sweeps at repeated source locations. In this paper, we will illustrate an example of missing receiver stations that create significant artifacts to the inverted data. The missing stations are due to technical field problems in which a portion of receiver spread is not usable and those receiver stations are mistakenly deleted off the data. Consequently, this causes near-offset data to be mixed with far-offset data as well as far-offset data to be mixed with near-offset data. This mixing of different offset data creates considerable artifacts to the inverted data.

Noise attenuation on single vibratory source data

The source separation process converts multiple-source gathers into several, equivalent single-source gathers. However, the inverted single-source gather often yields data records with relatively lower signal-to-noise ratio than conventional vibroseis. Noise attenuation algorithms become a key component to extract primary signals from the noise. From our experience, a localized adaptive eigenimage filter (Chiu and Howell, 2008) works well for single-source data. As an example to demonstrate the effectiveness of the eigenimage filter, the strong source-generated noise (Figure 3a) is dispersive and aliased with strong amplitudes that significantly obscure primary reflections. The primary reflections are clearly visible after the noise attenuation (Figure 3b). The difference plot between the input and filtered data does not show any visible primary reflection energy (Figure 3c).

3D data examples

ConocoPhillips has used ZenSeis™ technology successfully in the past decade to acquire a number of high-fold 3D seismic data sets. We will first compare two 3D surveys that are adjacent to each other. The first survey was acquired by conventional vibroseis and the second survey was acquired by ZenSeis™ at a cost of about 10% higher. Both datasets were considered to be state of the art at the time. Figure 4 compares the data quality between the conventional vibroseis and ZenSeis™ data. The reservoir locates between 1 to 1.1 seconds. The reservoir structures are much better defined in the ZenSeis™ data (Figure 4b). The high-quality ZenSeis™ data, in turn, provide high-resolution images in mapping the reservoir. The increase of data bandwidth and dense spatial sampling of SMS data produce dramatically higher-resolution images of the reservoir channels and faults (Figure 5b). The poorer spatial sampling of the conventional vibroseis causes the reservoir image to degrade (Figure 5a).

Conclusions

The ZenSeis™ technology has been employed to acquire a number of very high-fold 3D data sets. The key benefits of this technology are to improve data bandwidth, increase spatial resolution, and reduce acquisition cost. However, we need to pay close attention to the acquisition and processing issues that can greatly affect the data quality. Applying our best practices in acquisition and processing, we have consistently obtained high-resolution images of the reservoir from a number of high-fold 3D data sets.

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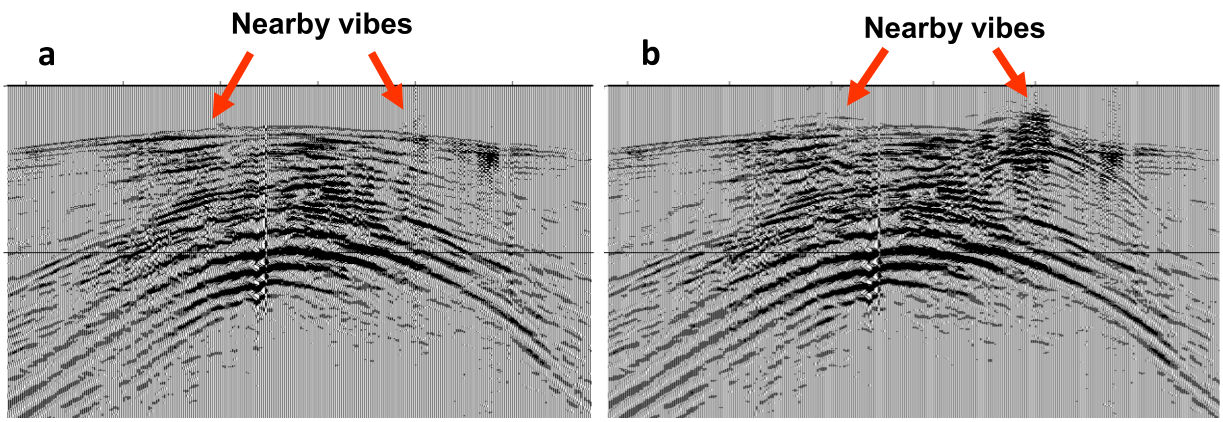

Figure 1. Optimized and non-optimized phase-encoding scheme (both surveys were acquired with the same source and receiver geometry): (a) shot record with optimized scheme, showing that the interference from nearby vibes is not visible, (b) shot record with non-optimized scheme, showing resulting interference from nearby vibes.

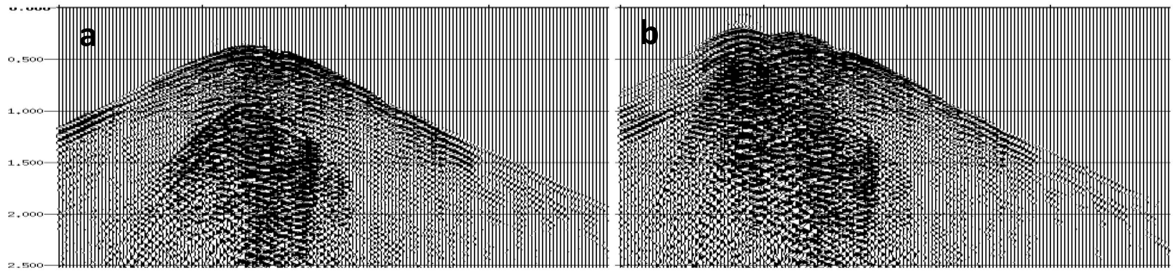

Figure 2. Correct and incorrect phase-encoding sequence (both surveys were acquired with the same source and receiver geometry): (a) shot record after source separation with correct-phase sequence, (b) shot record after source separation with incorrect-phase sequence, producing unusable data.

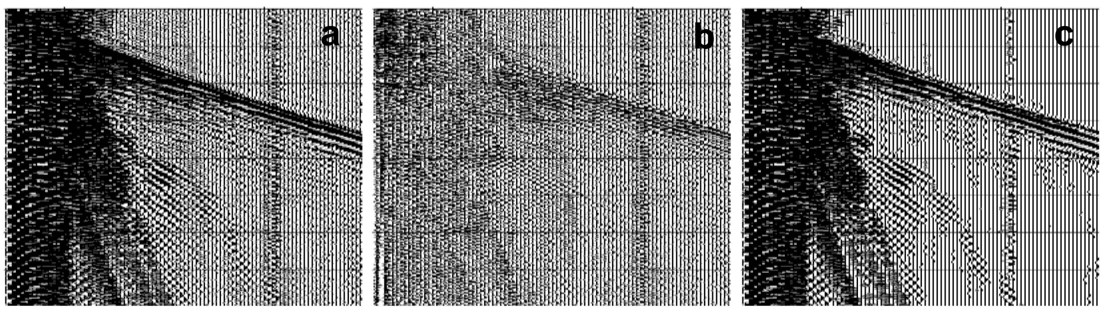

Figure 3. Attenuation of source-generated noise: (a) a shot record containing high-amplitude noise, (b) after localized-adaptive eigenimage filter, (c) the difference.

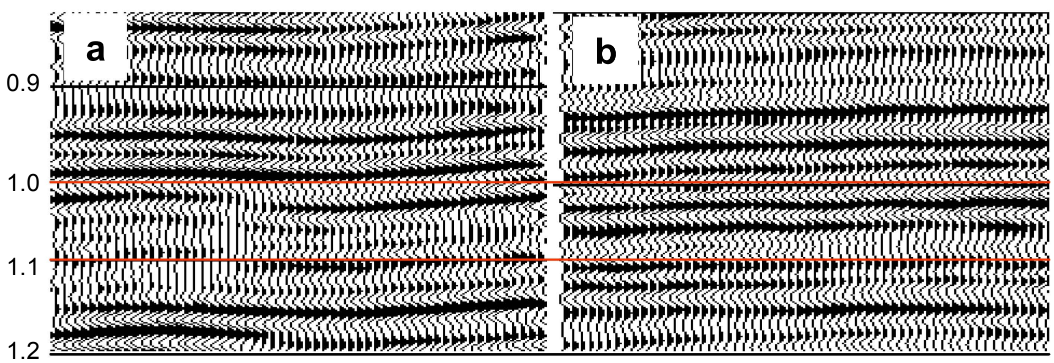

Figure 4. Time migrated profile for adjacent 3D surveys with the reservoir located between 1.0 and 1.1 seconds: (a) conventional vibroseis, (b) ZenSeis™ acquisition.

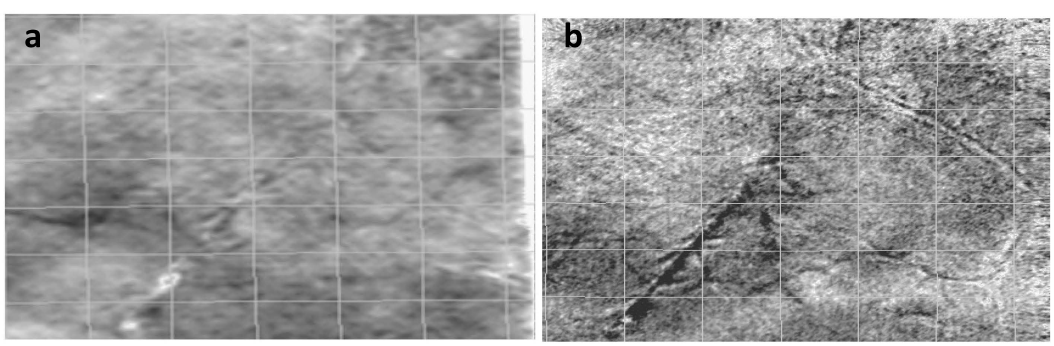

Figure 5. Time slice at the reservoir interval for adjacent 3D surveys: (a) conventional vibroseis. (b) ZenSeis™ acquisition.