Higher Trace Density Recording for Foothills 3D Surveys

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Summary

The benefits of high trace density 3D seismic recording for improved imaging have been well established, particularly in areas of complex geology (Lansley, 2004 and Bogardus, 2006.) However, it is surprising to note that in some of the areas where these benefits are most needed (e.g. foothills,) many 3D surveys are still being acquired with relatively low trace densities. This paper will discuss some possible reasons for this and potential strategies for increasing survey trace density in a cost-effective manner in foothills areas.

Introduction

High trace density surveys were first introduced to the industry onshore more than seven years ago and have been used extensively in some areas (e.g. Middle East, Oklahoma and Alaska). In other areas (e.g. Wyoming, Texas and Mexico) a number of surveys have been acquired, all showing significant improvements in data quality. Many of these surveys were acquired using vibrators for the source as this enables both higher source and receiver density to be achieved while maintaining the operational balance of the crew and without significantly increasing the operational cost. The increases in trace density achieved, when compared with typical surveys in the same area, range from a factor of six to more than twenty. The benefits from high density recording are two-fold: first, finer spatial sampling (i.e. smaller bin size) that reduces the liklihood of aliasing either steeply dipping reflection energy or noise; and second, enhanced statistics improves many processing steps including, but not limited to, deconvolution, statics, velocity evaluation, noise suppression, multiple attenuation and migration.

In regions where the surface topography is rougher and vibrator operations are limited by both operational and environmental restrictions, shothole explosives are frequently the preferred source. As a general rule, explosives operations carry higher costs per unit area, particularly in areas with difficult drilling. Heliportable operations are commonly used and the weight of the recording equipment to be transported becomes an important factor in the equation when calculating the cost of the crew. The source density (number of source locations per square kilometer) is also a major factor. Historically these considerations have resulted in operators decreasing the field effort to reduce the cost. Examples of this include the time during the mid-80's when "sparse 3D's" were a trend in Western Canada foothills operations (Bouska, 1996.) These surveys typically have very low trace densities and correspondingly poor fold, offset and azimuth distributions.

Discussion

First, let us review the data quality improvements seen in high density data acquisition. Figure 1 shows a data example from the Wichita Mountain Front in Oklahoma. In this area there is a 3D survey that was recorded in 1995 using explosives, that was overlapped by a Multi-Client high density 3D survey recorded using vibroseis in 2003. The trace density of the original survey was 36,864 traces per square mile (24 fold in 110 x 165 ft bins) while the new survey has a trace density of 663,552 per square mile (72 fold in 55 x 55 ft bins,) a factor of 18 difference. Both of these data volumes have pre-stack time migration performed with similar algorithms at approximately the same time. The imaging of the new high density data is clearly much improved over the original data, with better frequency content, fault definition, and preservation of steep dips. Even the deeper events, for which explosives typically have been the preferred source, have better energy penetration and imaging with the vibroseis high density recording.

A simple way to think of trace density is that it is the product of the source density (shotpoints per unit area, square mile or square kilometer) times the number of traces recorded per shotpoint that are within the usable offset range for a given target depth. (Note that this is not necessarily the total number of traces being recorded if some of these have long offsets that do not contribute positively in the imaging process. These traces, however, may provide useful information for other data processing algorithms such as for near-surface corrections.) Hence, one way to increase the trace density is to increase the number of traces within this offset range. Reducing the group interval (easily accomplished in the field) is the primary way in which the trace density is increased and the smaller bin sizes for improved imaging are achieved. Increases in trace density from 200 to 400% are quite common. Another way would be to reduce the receiver line interval, but this has a much greater impact on the cost of the survey and is therefore not frequently used.

Many foothills surveys have also been recorded with relatively narrow azimuth ranges, typically aligned with the longer offsets in the dip direction. Increasing the crossline width of the recording patch can be quite easily achieved with modern recording systems and this may also be used to increase the trace density. Although it may at first appear that this would increase helicopter time by a large amount, once the initial recording patch has been deployed the amount of equipment to be moved per shotpoint remains the same, only the crossline distance for the move has increased. Resulting trace density increases are typically from 150 to 200%.

Continuing on the receiver topic, another consideration (especially for heliportable operations), is the reduction in deployment time and cost by using smaller arrays (or, in fact, no array) of geophones. Arrays were originally designed to attenuate near surface noise problems (e.g., long wavelength ground roll and other scattered noises.) As group intervals became smaller, they were used as spatial anti-alias filters for the sampling (Anstey, 1986 and Ongkiehong, 1988.) As they become smaller still, todays arrays have limited effectiveness for this and in rough topography are frequently replaced with contoured or podded geophones in order to eliminate signal attenuation due to intra-array statics. Ronen et al (2005) discuss the benefits of using 3C digital sensors instead of arrays of conventional geophones in rough terrain.

The second part of the equation is the shot density issue. Obviously, increasing the number of shots per square kilometer will increase the cost of a survey. However, when taken into consideration with the elements discussed previously and the fact that all of these factors are multiplicative, a small increase in the shot density can be quite substantial. For example, if we reduce the group interval by a factor of 2 and increase the crossline width of the recording patch by a factor of 2, then we have increased the trace density by a factor of 4. A 25% increase in the shot density would increase this ratio from 4 to 5.

This discussion, so far, has concentrated on how survey trace densities can be increased for surveys to be recorded solely with a single source type. There are many foothills areas where surveys may be acquired with combinations of different sources, such as explosives together with accelerated weight drops and/or vibrators. In these areas, even greater improvements in trace density and data quality can be achieved with a small incremental cost.

Conclusions

High trace density surveys have been shown to greatly increase the seismic image quality in areas of complex geology, yet are typically not being recorded in many foothills regions, primarily due to perceived cost limitations. Advances in modern seismic data acquisition systems and the required data processing and computer technologies allow us to provide high trace density data volumes. The benefits of high density 3D volumes include improved structural and stratigraphic imaging, better well placement and field development. The small incremental expenditure is far outweighed by the reduced finding and development costs. Future efforts in foothills exploration should pay close attention to the project economics and high risk of traditional “sparse 3D” parameters versus those of high benefit, high density 3D.

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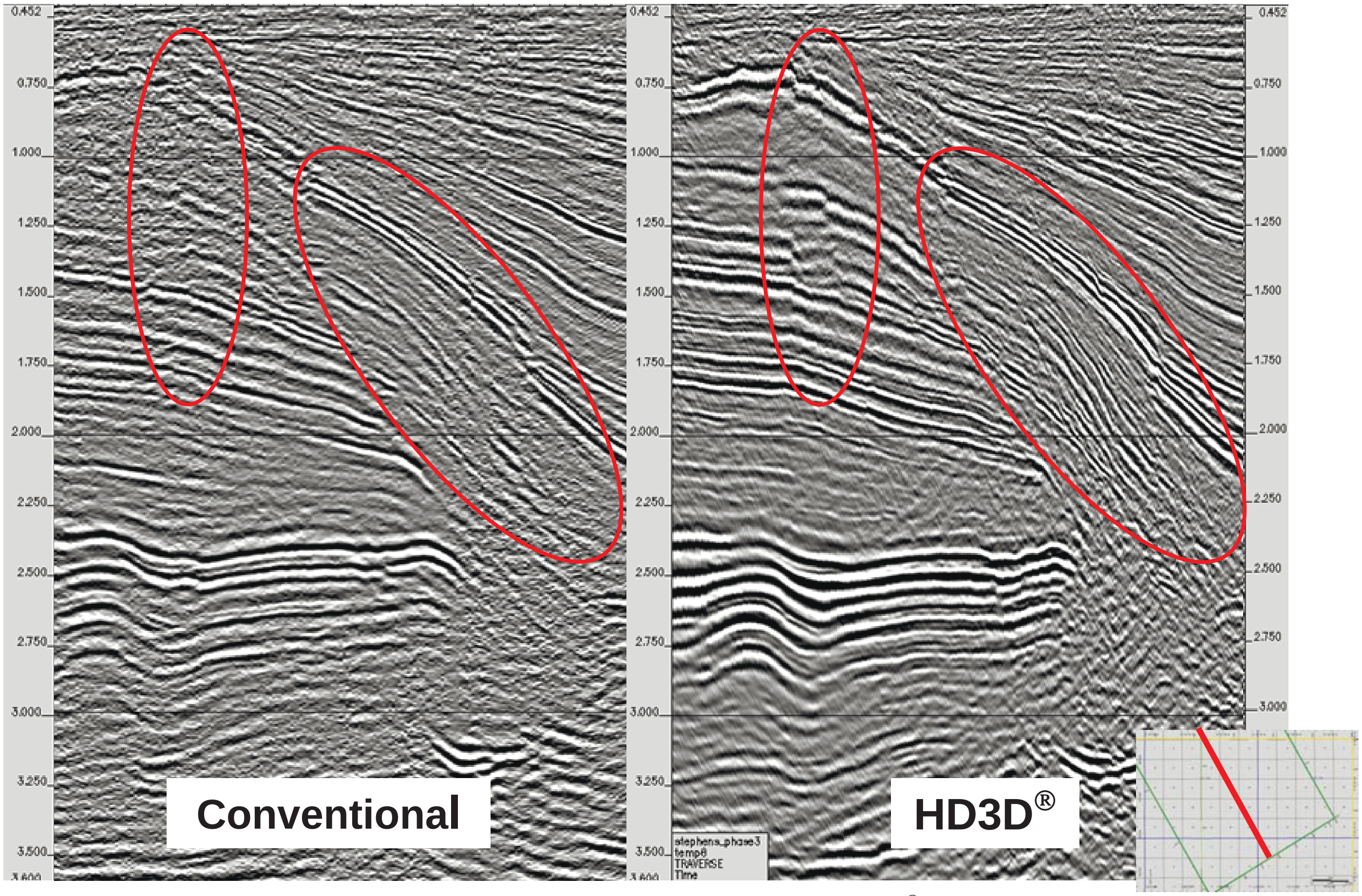

Dip line from conventional dynamite survey.
Note: Structural / stratigraphic imaging issues.

Dip line from HD3D® vibroseis survey.
Note: Improved structural and stratigraphic imaging combined with improved bandwidth.

Figure 1. Comparison of dip lines from two surveys acquired over the same surface area. Image on left was acquired with dynamite source, 110 X 165 ft. bins and 36,864 traces per square mile. The image on right was acquired with Vibroseis source, 55 X 55 ft. bins and 663,552 traces per square mile. Both surveys were migrated with a Pre-STM Kirchhoff curved-ray migration algorithm.