Combining Dual-Sensor Data with Pre-stack Depth Migration – Imaging the Ghost and Primary Reflection at Teal South

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Summary

In a dual-sensor Ocean Bottom Cable (OBC) survey, both hydrophones and geophones are used to record the seismic signal. Primary reflection and water-column reverberations exhibit different behavior on hydrophone and geophone data. Rather than focusing on eliminating the reverberation by careful calibration of the hydrophone and geophone data, we present here a method of using pre-stack depth migration to use the reverberations as well as the primary reflection as part of the imaging. Combining the subsurface image from both not only significantly reduced the multiple effect as noise but also has extended the coverage. We demonstrate by applying the method to the Teal South 4D_4C survey.

Introduction

In a dual-sensor OBC survey, both hydrophones and geophones are used to record the seismic signal. A vertical geophone in the sea floor sediment records the particle velocity as seismic energy arrives, whereas, a hydrophone in the water immediately above the sea floor record the corresponding pressure change. Since only the geophone is sensitive to the direction in which the seismic energy is propagated, primary reflection and water-column reverberations exhibit different behavior on hydrophone and geophone data. As shown in Figure 1, if reflected energy arrives at the receiver station vertically, the hydrophone and geophone will record the up-going primary reflection with same polarity, but all the down-going reverberations with opposite polarity. A simple scale factor of $(1+r)/(1-r)$, where r is the water-bottom reflectivity, is all that is needed to combine the two signals, thereby eliminating all the reverberations. In practice, this calibration method is complicated by the varying angle of incidence at different offsets, reverberations at the source side, and also from time to time, by the dramatic differences (e.g. in frequency content, wavelet shape, noise level) between the two signals. While some promising methods have been, or are being, developed (Barr, et al, 1997) for combining the two signals to yield better results, most of the methods treat the reverberations as noise to be eliminated.

In contrast, many projects at Texaco indicate that water-column reverberations can actually be useful. If treated properly, the down-going reverberations actually provide better imaging than the up-going reflection because of better coverage of the subsurface area, especially in deep water. Others (Godfrey, et al, 1998) also report this.

Pre-stack Depth Migration

Shot record or receiver record pre-stack depth migration, which allows shots and receivers to be placed at different datums, provides a convenient way of imaging both the primary reflection and the water column reverberations. Primary reflections (up-going) can be imaged by treating the receiver as being at the sea floor (“up-going image”). One-way reverberations (down-going) can be imaged by treating the receiver as being above the water surface at the virtual position of the actual location if “mirrored” by the water surface (“down-going imaging”).

The hydrophone data up-going image and the down-going image have similar amplitudes but opposite polarities. If the up-going and down-going energy is not separated in the input data, each of the images is not multiple-free. Besides the correctly imaged energy, the incorrectly imaged energy will remain as multiples, even though with weaker amplitude due to insufficient focusing. The down-going energy will appear below the correct image of the reflector on the up-going image and the up-going energy will appear above the correct image of the reflector on the down-going image. This is true for both hydophone and geophone data. The difference is that with hydrophone data the incorrectly imaged events have polarity opposite to the correct image, while with geophone data the incorrectly imaged events have the same polarity as the correct image. Stacking the four images (hydrophone up-going image – hydrophone down-going image + geophone up-going image + geophone down-going image) will yield a subsurface image with significant suppression of multiples as well as an improved “primary” image.

Imaging the reverberations that undergo more than a single pass through the water column or that involve reverberation at the source side need more complicated treatment. Since both are weaker (on the order of r) than the simple one-way reverberation at the receiver side, we do not recommend imaging them.

For better subsurface imaging, calibration of the four separate migration images is still necessary before stacking

Imaging the Ghost and Primary Reflection

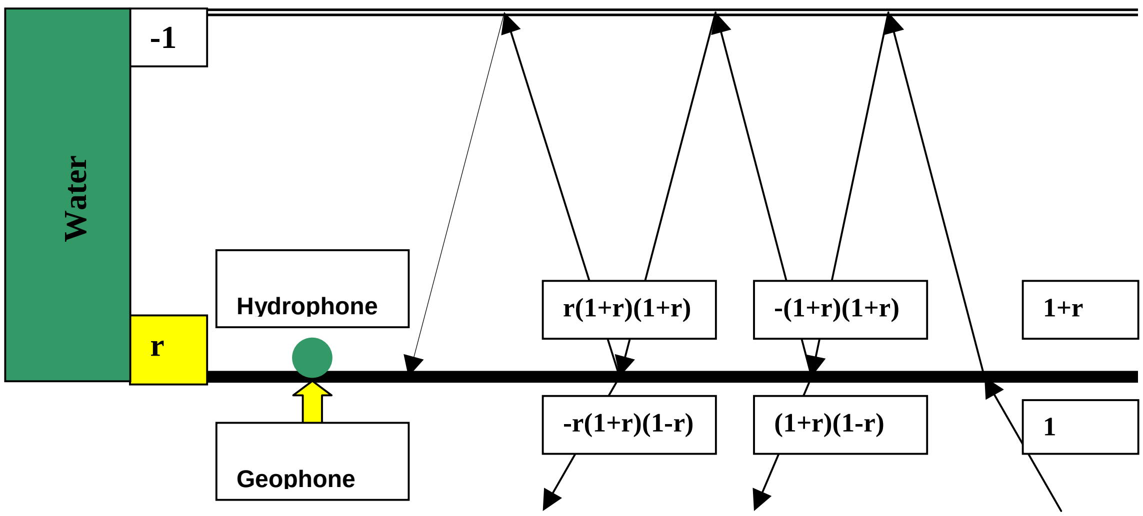

Figure 1. Dual sensor survey

them into a final image. Since the calibration is performed on migrated data, which usually has higher signal-to noise ratio than the input data, the calibration is more robust and can be achieved better than calibration before migration.

How much we can benefit from using down-going image of the ghost depends on the water depth. The deeper the water, the more different travel paths the down-going and up-going energy will follow, and thus the more different information of the subsurface they will provide. With increased oil and gas operations in deep water, we can expect more benefit from the application of this technique in the future.

Teal South

In 1997, a four-component 3D seismic survey with 24 ocean bottom receiver stations and a 9 sq. km. grid of shots was acquired at Texaco's Teal South field (in Eugene Island Block 354 in Gulf of Mexico). The water depth at survey area is about 85 m. For this study, only the hydrophone and vertical geophone data was used for P-wave imaging. The two other horizontal components contain mostly S-wave energy.

In data processing, a filter was applied on the geophone data to keep out the low frequency, low apparent velocity energy that appears to be some crossover from the shear wave event. Besides that, data processing was kept the same on both the hydrophone data and the geophone data.

3D pre-stack depth migration was performed on both the hydrophone and geophone data. With the application of the up-going and down-doing imaging method, we have four separate images. They are hydrophone up-going image, hydrophone down-going image, geophone up-going image and geophone down-going image. Figure 2 shows part of Inline 133 of the hydrophone up-going image. The down-going images are to some extent better than the up-going images. Auto-correlation indicates strong multiple contained in these images.

Stacking these four images was finished in three steps. First, down-going image from the hydrophone data was reversed in polarity and stacked with the up-going image from the hydrophone data to produce one combined hydrophone-image. Up-going image and down-going image from geophone data was stacked into one combined geophone-image. Second, a single filter was designed to match the amplitude and frequency content between the combined geophone-image and the combined hydrophone–image. Then a final image (Figure 3) was obtained by stacking the combined hydrophone-image and the combined geophone-image with the match filter applied. All the correctly imaged events were constructively stacked, while the incorrectly imaged events interfered destructively and the multiple effect was to a larger extent eliminated.

Improvement of the final image (Figure 3) over the more traditional up-going image (Figure 2) was noticed on both the shallow and deep parts of the section. In the shallow part, reflectors including the water bottom have continuous coverage on the final image. In contrast, on the up-going image, the wide spacing of the receivers provides uneven coverage of shallow reflectors. In the deep part, at about 1400ms to 1750ms, two parallel faults are more clearly seen on the final image than up-going image.

Conclusion

Ghost reflections, which are normally treated as noise to get rid of, can contribute to subsurface imaging via an implementation of pre-stack depth migration. Combining four images (hydrophone up-image – hydrophone down-image + geophone up-image + geophone down-image) can yield subsurface images that not only exhibit substantial multiple attenuation, but also improved reflection coverage. Using this method to combine the hydrophone and vertical

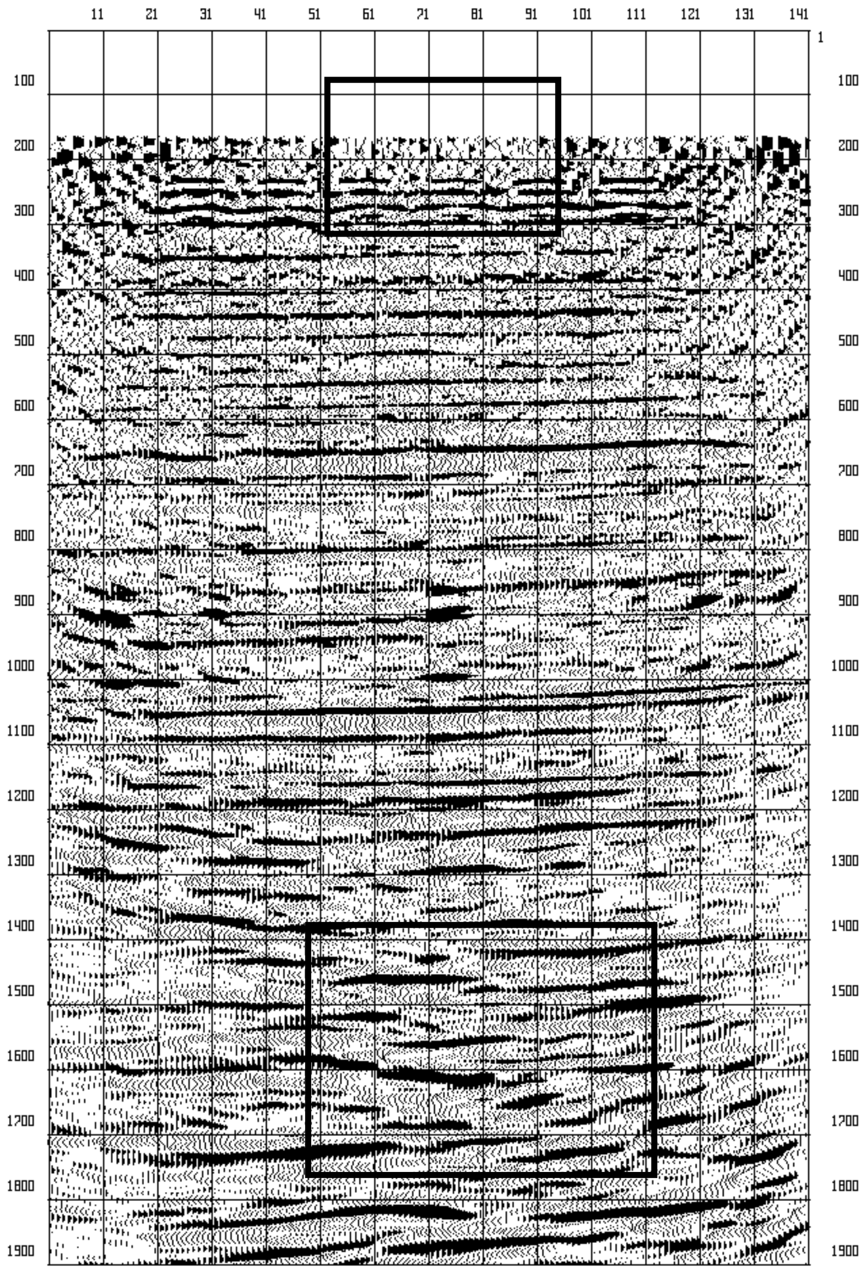

Figure 2 Hydrophone Up-going Image

geophone data of the Teal South 4D 4C project produced high quality P-wave images.

References

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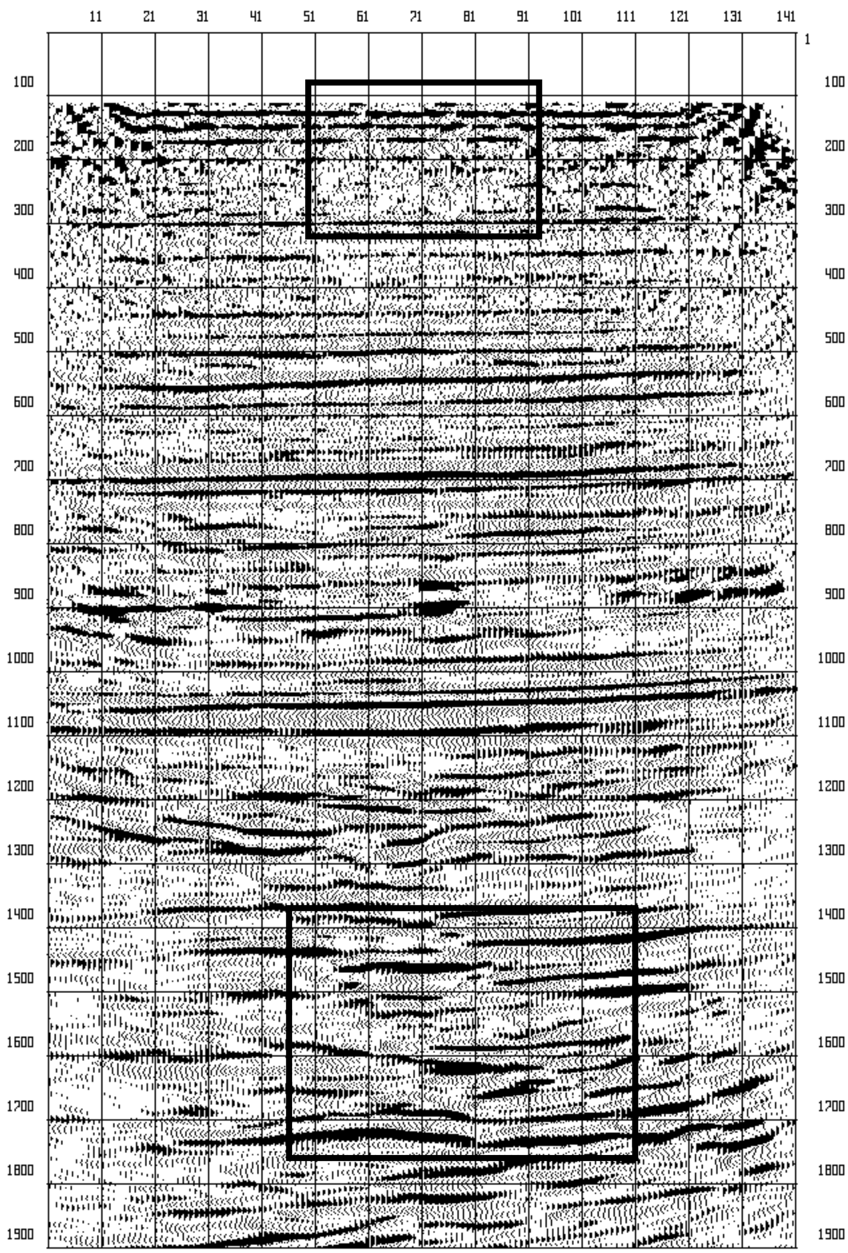

Figure 3 Final Image