Enhanced imaging with broadband seismic data processing in “under-explored” areas
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Introduction

Over the recent years, there has been a significant amount of research and development related to marine broadband technology, both to remove the effect of the marine “ghosts” (reflections from the sea surface) and to obtain a broader bandwidth of usable seismic frequencies (both low and high). These works are generally separated into acquisition and processing solutions. In this article we focus on a processing-based broadband solution to improve imaging in the frontier or “under-explored” areas using conventional flat streamer acquisition configuration. The data examples cover acquisition in deep water (offshore Brazil) and shallow water (offshore Croatia).

Overview

A well-known issue in conventional marine flat streamer data is the interference from the free-surface ghosts (from both source and receiver sides). These ghost reflections interfere, either constructively or destructively, with primary reflections and distort the frequency (by creating spectral notches) and the phase spectrum of the recorded seismic data. Figure 1 illustrates that marine ghosts are unavoidable since both seismic source and streamer cable are towed beneath the sea surface.

![Figure 1](image_url)

**Figure 1** Ray paths of source and receiver ghosts in typical towed marine seismic acquisition

In general, the effect of the sea surface ghost on constant-depth towed streamer is greatly influenced by source and receiver depths as well as water velocity and sea state. Shallow towing depth will help to avoid the ghost notches by recovering higher frequencies but attenuate lower frequencies, whilst deep tow recording recovers low frequencies at the expenses of attenuating high frequencies.

Over the years, developments in broadband acquisition techniques (such as variable-depth or dual-sensor streamer) have addressed the notch issues. More recently, many processing-based methods have been introduced because broadband processing can be a cost effective solution to remove the severe ghost notches, enhance the seismic resolution and improve structural and stratigraphic images, especially for marine seismic data acquired using conventional flat streamer.

Broadband-processed data has marked benefits for imaging and seismic inversion as it outlines detailed high-resolution features of shallower traps as well as providing deeper penetration and significant improvement for imaging deeper targets.

De-ghosting, bandwidth recovery and Q-compensation

The ghost removal process used in our broadband processing is a non-linear inversion process that adapts the least-squares minimization method (based on either minimum energy or minimum absolute amplitude) to estimate both the source and receiver
ghost times as well as the reflection coefficients at the air/water interface for both the source and receiver ghosts. The process derives a recursive filter which is then applied to the pre-processed seismic data to create a ghost-free data.

After proper de-ghosting, the amplitude spectrum of the resulting full-stack section should show improvement in recovering both the low frequencies and the notches that were weakened by the ghosts. However, the seismic spectrum may often have a linear decay or roll-off of amplitude in the high-frequency content, especially in the deep part of the section. The loss of higher frequencies is due to the earth’s absorption effect (“Q”) and can easily be recovered with the application of pre-stack amplitude-only Q-compensation.

![Figure 2 Comparative amplitude spectra of stack sections with and without broadband processing](image)

**Figure 2 Comparative amplitude spectra of stack sections with and without broadband processing**

**Deep water data example: Offshore Brazil**

The first data example is located in deep water in the Sergipe Basin on the northeast coast of Brazil. This area has been attracting much of attention since Petrobras drilled the successful Barra well in 2010, and the subsequent Barra-1 appraisal well. Other discoveries in the deepwater area of the basin include the Muriu and Farfan finds which are in the turbidite channel systems of Mid to Late Cretaceous and Early Tertiary age. Stratigraphic hydrocarbon plays (such as channel-fill sediment, rifted basin fill and faulted Paleozoic sediment) are key to exploration opportunities in this area. Hence, improved identification and mapping of these potential reservoirs is essential.

The seismic line shown in Figure 3 is a deep-towed 2D dataset that was acquired in 2014 with a flat streamer and a single air-gun source at depths of 15m and 10m respectively. Note the result from the final pre-stack time migrated stack with broadband processing shows a significant uplift in the low frequency content and temporal resolution.
The expanded bandwidth (in particular at the lower frequency end) of the broadband-processed seismic section shows greater resolution of seismic events as well as better penetration of signal in the deep section.

Shallow water data example: Offshore Croatia

The second data example is from the shallow water area of the Croatian Adriatic Sea. The Adriatic offshore hydrocarbon province lies below the shallow waters between Italy and Croatia on the northern margin of the Mediterranean Sea. The Italian Adriatic is relatively well-explored whilst the eastern Croatian margin remains comparatively “untouched”. Despite the generic similarities, the nature of the carbonate oil play offshore Croatia is significantly different from that on the Italian margin. Therefore, high-quality seismic is required to successfully image the Triassic and delineate source kitchens, identify platform margin reservoirs, and support basin modelling to constrain the timing of charge.

The seismic line shown in Figure 4 is a shallow-towed 2D dataset that was acquired in 2013 with a flat streamer and a single air-gun source at depths of 8m and 6m respectively. After broadband processing, interpretable low-frequency signal is made available providing strong discrimination of layers and highlighting subtle features, and subsequently enhancing interpretation across faults and other major structural features as well as improved quantitative inversion.
Conclusions

In recent years, the exploration focus has shifted to stratigraphic and deeper plays, especially in frontier and under-explored areas, and the demand for broadband seismic data has also increased accordingly. In conventional marine streamer acquisition, the reflections from the sea surface can strongly impact the seismic frequencies and bandwidth of the recorded data that is directly related to both source and streamer depths. Traditional processing works well only at frequencies below the first ghost notch. De-ghosting followed by pre-stack application of appropriate inverse-Q filtering will remove this limitation and recover lost bandwidth to produce a broader and balanced spectrum, hence improving the resolution and interpretability of the seismic section.

Broadband data processing has been a hot topic for the last few years and its value is evident from the two data examples with improved resolution and bandwidth providing stronger discrimination of seismic events as well as clearer imaging of deep targets resulting mainly from the increased low-frequency content.

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