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Broadband Marine Seismic Data Acquisition: Opportunities and Challenges

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Introduction

Broadband seismic data is the primary requirement for improving resolution, enhanced imaging of thin beds and stratigraphic features, seismic inversion etc. In recent past, advancements in marine seismic acquisition have evolved around improving the bandwidth of recorded seismic signal. These include the improvement in the low frequency response of the streamer, higher fidelity of recording units and more recently, broadband acquisition techniques aimed at attenuating the source and receiver ghost notches.

The hydrophone in a towed streamer always records two wavefields that constructively interfere with each other. The up-going pressure wavefield propagating directly to the hydrophone from the earth below and the down-going pressure wavefield reflected from the "free air" sea surface immediately above the streamer. The consequence is that a series of "ghost" notches are introduced into the frequency spectra and the reflection wavelet is undesirably elongated, reducing temporal resolution. For zero angle reflections, the frequency of notches is always at 0 Hz and integer multiples of Vw/2d where Vw is the speed of sound in water, and d is the receiver depth. In conventional acquisition, the streamer is towed close to the sea surface so that the first ghost notch occurs beyond the desired high frequency range. However, this results in attenuation of lower frequencies (Fig. 1a). Thus, streamer depth in a conventional marine acquisition has historically been a trade- off between low and high frequency requirement.

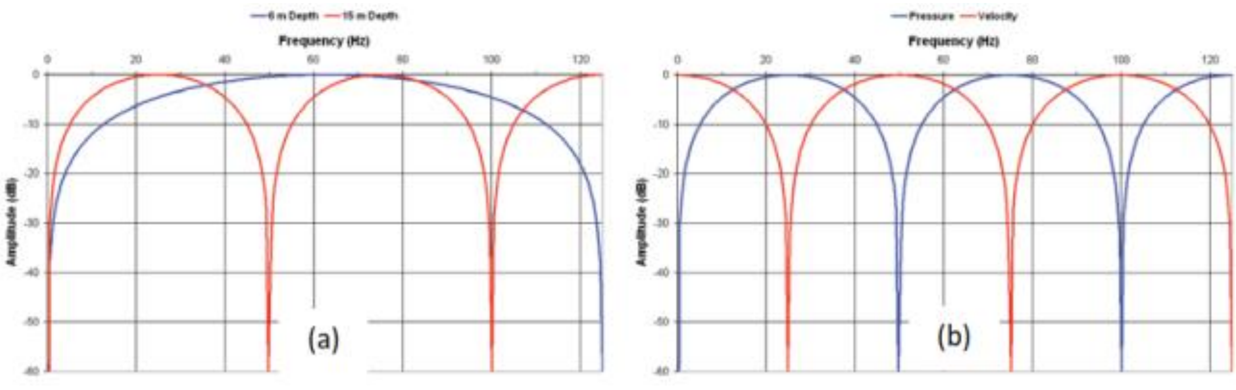

Fig.1(a), Receiver ghost amplitude spectra for a hydrophone towed at 6 m (blue) and 15 m (red) depth. The wavefield is assumed to have vertical propagation (zero angle of incidence). Fig. 1(b), Superposition of the ghost spectra for both the hydrophone (blue) and velocity (red) sensor at 15 m depth for zero angle reflections.

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Marine Broadband Acquisition Technologies

Different acquisition technologies have been proposed to overcome the receiver ghost notch problem and deliver an improved low and high frequency spectral response. These include: deep-towed dual sensor streamers; the variable depth streamer and pairs of over-under streamers towed at different depths. Currently, the following three proprietary marine acquisition techniques are commercially available in the market, which use different ways to deliver broadband seismic data:

- *Dual sensor streamer:* Dual-sensor streamer acquisition technique combines collocated pressure and velocity sensors in a single streamer. The spectral notches in the frequency spectrum of the velocity sensor are complimentary to those for hydrophone (Fig.1b), thus the combination of pressure and velocity data removes the ghost event (down-going wavefield) and therefore delivers broader signal frequency bandwidth.

deconvolution and mirror migration) to enhance the signal bandwidth.

- *Over-under streamer:* This acquisition technique uses a sparse deep towed marine acquisition spread in combination with a conventional shallow towed spread (Fig. 2b). The shallow spread gives the high frequencies while the deep spread provides the enhancement in low frequencies and therefore can be more sparsely sampled.

Broadband Technology Application

PETRONAS Carigali has applied each of the above marine broadband acquisition technologies over the past couple of years to address some specific seismic imaging issues in Malaysia. These technologies have been applied to different geological settings and part of the data is still under processing. In this paper, our current assessment of the potential of these technologies is presented based on the results of these surveys, together with the challenges which need to be overcome before their full potential is exploited.

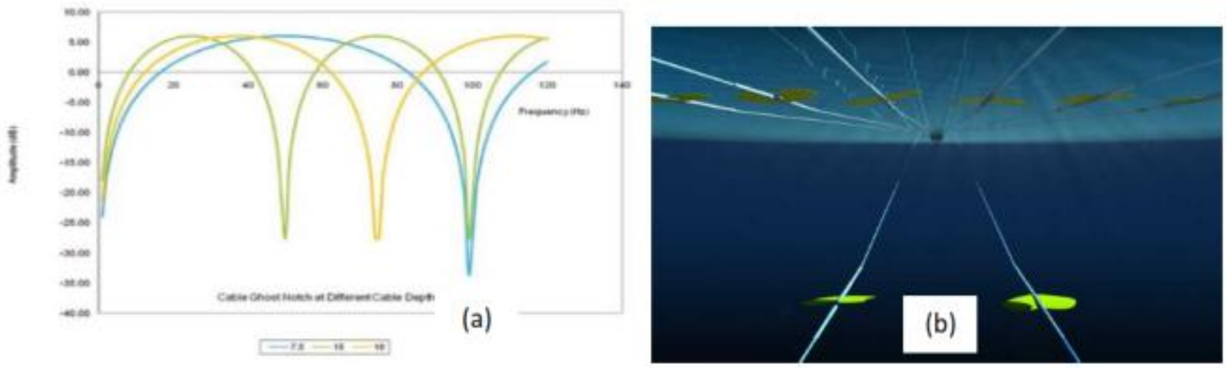

Fig. 2a, Notches in the amplitude spectrum caused by ghosts at different streamer depths lead to compromises in data quality during survey design (Robert Soubaras, 2010); Fig.2b, Over-under technique uses two sets of streamers-closely spaced shallow streamers for dense sampling of shallow wavefield & widely spaced deep streamers for sparse sampling of deeper wavefield (WesternGeco website).

- *Variable depth streamer:* In this technique, a combination of solid streamers and a variable depth towing configuration is used to deliver an improved bandwidth in the final image. In variable depth configuration, the receiver ghost notch varies along the cable (Fig. 2a) and this 'notch diversity' is exploited by the proprietary deghosting and imaging techniques (e.g. joint

Dual sensor streamer surveys

Two dual sensor 2D streamer surveys were carried out offshore Malaysia in 2009-10. In the first survey area, hydrocarbons have been discovered in pre-carbonate stratigraphic clastic sequences. However, structural interpretation, seismic attribute analyses and resources evaluation are hampered due to poor quality of the conventional 3D streamer data, especially below the thick carbonate formation (Fig. 3a). The dual sensor streamer survey was intended to improve the seismic image of the pre-carbonate sequence. Several 2D lines were shot with a 6 km long dual sensor streamer towed at 25m depth. The multi-level source was also tested along one 2D line to address the source notch issue. Few 2D lines were acquired on top of the legacy seismic lines and processed through pre stack time migration concurrently, to allow a fair comparison of the conventional and dual sensor streamer data. Key data processing steps included- low frequency compensation (LFC) for the velocity sensor data and dual sensor summation. The second survey was a regional 2D survey, acquired with a streamer length of 8 km, to assess the hydrocarbon potential of deeper sediments.

The comparison of processed datasets shows that a combination of dual sensor streamer and multi-level source achieves improved seismic image at both shallow and deeper levels (Fig. 3a & 3b). However, a significant portion of the improvement in the data quality in the deeper portion is contributed by the multi- level source. Also, the improvement in the target zone remains marginal, primarily because of the thick carbonate section which absorbs and scatters major part of seismic energy in a 3D sense. The future dual sensor streamer acquisition in such geological setting should probably be of 3D nature with a multi-level/detuned source array and probably a multi azimuth (MAZ) or a wide azimuth (WAZ) survey, for better results.

Another important consideration would be the streamer tow depth, which probably should be kept shallower (say ~15m), to better leverage the mid to high frequency response of the pressure sensor data, which tends to drop off at ~25-30 Hz for 25 m tow depth. The vendor should also put efforts to improve the low frequency response of the velocity sensor. Currently, frequencies below 15-20 Hz recorded by the velocity sensor are unusable due to the motion noise, and need to be reconstructed using the pressure sensor data.

Variable depth streamer surveys

Three variable depth 2D streamer surveys were carried out by PETRONAS Carigali in the year 2011, offshore Malaysia with the objective to improve the imaging of both shallow and deep clastic targets. The depths of the exploration targets in these areas vary between 1 to 7 km which necessitated broadband acquisition to preserve both the low as well as the high frequencies. The data was acquired with 6 km long streamer in the shallow water area and with 8 km long streamer in the deep water area. The streamer depth varied from 5m at the shallow end to 50m at the deep end. The data was processed through PreSTM and the key steps included the proprietary joint deconvolution and mirror migration to remove the receiver ghost notches.
A comparison of the fast track PreSTM outputs of the conventional and the variable depth streamer datasets (Fig. 4a and 4b) reveals that the variable depth streamer delivers a much improved seismic image and amplitude spectrum at both low and high frequency ends.

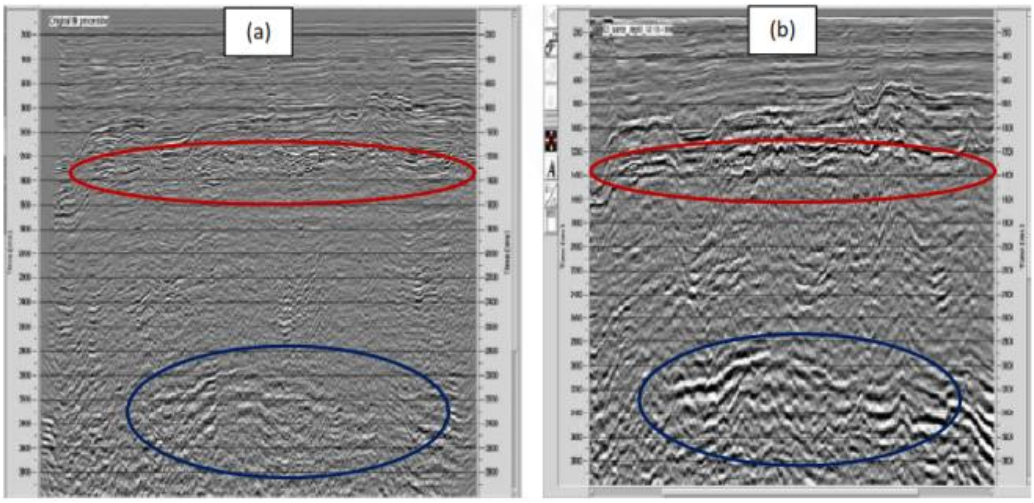

Fig.3a, (left): PreSTM section of Legacy 2D seismic data reprocessed using identical processing flow as the dual sensor streamer data. Fig. 3b (right): PreSTM section of pilot test data recorded with dual sensor streamer and multi-level source. The target pre-carbonate sequence is marked in red ellipse & the deeper prospects in blue ellipse. Improvement at both shallow and deeper levels is observed in the dual sensor streamer data.

Over-under streamer survey

A 3D over-under streamer survey was conducted by PETRONAS Carigali in 2010 in deepwater offshore Malaysia. The depth of the clastic targets in the survey area varied between 2-6 km and the acquisition was carried out using two sets of 8 km long streamers. The shallow spread consisting of 8 streamers was towed at a depth of 7m (@ 100m separation) and the deep spread consisting of 2 streamers (@400m separation) towed at a depth of 20m.

these technologies offer the following operational and geophysical advantages over the conventional towed streamer acquisition:

- Better estimation of quality factor (Q) during data processing
- Better S/N ratio and extended operational window due to deep tow depth
- Better potential for seismic inversion due to richer low frequency content

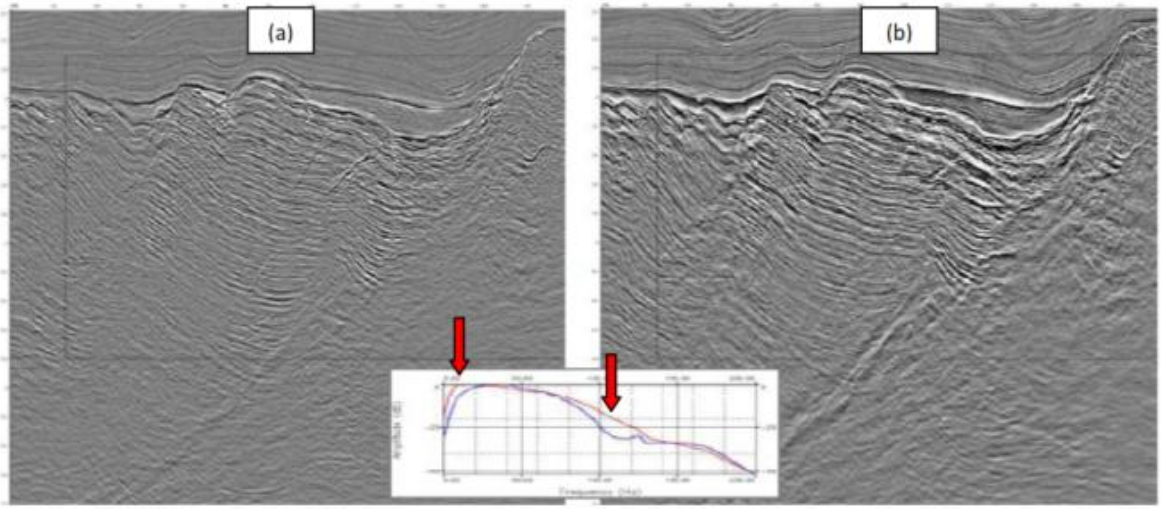

Fig.4, Fast track PreSTM sections from the variable depth streamer survey. (a) Conventional 2D seismic data and (b) Variable depth streamer data. Significant improvement is observed in overall quality of the image in the section to the right as well as in the signal bandwidth at both low and high frequency ends (inset-red arrows). The two lines were located on top of each other to allow a fair comparison.

The key steps in data processing included wavefield interpolation for the deeper streamers and proprietary optimized deghosting scheme to deliver a broadband spectrum. Based on the preliminary QC processing, the over-under streamer data shows improvement in the overall signal bandwidth. However, at the time of writing this paper, the data processing is still ongoing and the final evaluation of the results shall be based on the processed outputs.

Opportunities and Challenges

As evident from the above examples, each of the broadband acquisition technologies described here enhances the signal bandwidth and therefore improves the seismic imaging through effective removal of receiver ghost. In addition,

Some of the challenges which need to be addressed to effectively implement and leverage these technologies include:

- Application domain for dual sensor, variable depth and over-under streamer technologies is currently confined to approximate water depths > 35m, >70m and > 40m respectively due to the streamer towing configuration.
- Each of these technologies need to be combined with multi-level or detuned sources in order to remove the source ghost. The dual sensor streamer has already been combined with the newly introduced multi-level/detuned source to address the source notch issue.
- The processing of the above datasets is proprietary up to a certain stage and therefore

restricted to the respective acquisition contractor.

- In dual sensor streamer, the low frequency portion (<15-20 Hz) of the velocity sensor currently needs to be reconstructed using the pressure sensor data. This limits the usage of velocity sensor data for low frequency enhancement.
- In variable depth streamer, the key process of deghosting using proprietary joint deconvolution and mirror migration is still under evaluation by the users, especially in terms of amplitude preservation.
- For over-under streamers, the trade-off between the wavefield sampling requirement and the separation between the deep streamers is critical in terms of the quality of end results. Also, the vertical and lateral alignment of the two sets of streamers needs to be maintained within tight tolerances for effectiveness of the wavefield interpolation.

Conclusion

The current focus of exploration has shifted to stratigraphic and deeper plays. The broadband surveys conducted by PETRONAS Carigali have demonstrated their ability to enhance the seismic bandwidth and address some of the imaging issues commonly encountered in Malaysian basins. However, the ultimate choice of the optimum technology should be based on the geological setting, operational environment and the cost and the quality of end results may also vary accordingly. In order to realize the full potential of these technologies, some of the operational and data processing challenges mentioned above need to be addressed. The future marine seismic acquisition trends are expected to involve multi azimuth (MAZ), wide azimuth (WAZ) or full azimuth (FAZ) implementations of the broadband acquisition technologies.

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