Continuous recording and processing methodology for high fold 2D seismic data – a case study from the Foz do Amazonas Basin

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Abstract

Frontier exploration basins present competing seismic imaging requirements due to the need for clear images of play fairways, prospects, and deep crustal structures necessary to define a tectonic framework. In the past these competing requirements have always resulted in a compromise between higher fold and record length. The Foz do Amazonas Basin is located off the northwest coast of Brazil, covering some 750,000 km² from the French Guiana border to the southeast edge of the Amazon Cone. This frontier basin holds considerable promise for oil and gas exploration, and imaging objectives include the need to identify deep tectonic structures, potential source rocks as well as stratigraphic and structural reservoir and seal elements.

In conventional seismic recording, a source is triggered and seismic data is recorded for a fixed period of time before the system is cycled, and a new source is triggered. This implies that the record length is limited by the source time interval. Consequently a choice must be made between imaging fold (i.e. minimal source interval) and record length. By utilizing modern recording systems with continuous recording capabilities, it is possible to record seismic data with an arbitrary record length and a source interval that generates maximum fold of coverage.

We present a case study comparing two different recording geometries, illustrating improved imaging in the shallow sedimentary section due to a higher fold acquisition geometry. This improved imaging is achieved without compromising the image of the Moho, which is masked by the energy from the overlapping shot.

Introduction

Recording fold is the most powerful tool available for maximizing signal to noise ratio in seismic data. However in order to image the Moho discontinuity at depths of 15 km or more, a record length of at least 15 seconds is required. Cvetkovic et al (2017) define an uncompromised dataset as one with dense shot spacing (higher fold) and long record length, however conventional acquisition geometries would require boat speeds too slow for effective streamer operations in a scenario where record length was necessarily shorter than the SP interval.

In general continuous recording refers to a methodology where shot time is precisely recorded using a clock synchronized to the recording system. Node systems make extensive use of this technology to continuously record seismic data without the need for a connection to the energy source. In the case of streamer operations, an arbitrary record length is parsed from the continuous data stream, and this data record is written to a SEGD file with its time zero precisely associated with the shot time.

In order to achieve the imaging objectives for the Foz do Amazonas Basin, a source spacing of 25 m and a 15 second record length were chosen for the acquisition geometry. Figure 1 shows an example of a shot record with both the primary and secondary shot energy from the previous shot (N – 1) and the subsequent shot (N + 1).

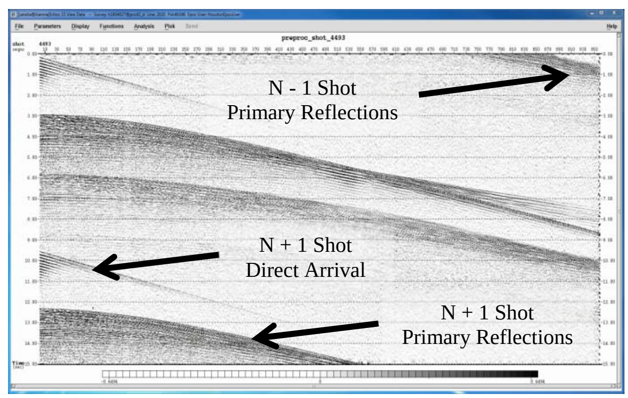

Figure 1 – Blended Shot Record

Figure 2 illustrates the effectiveness of the de-blending process on the same shot record. While a very low level of residual secondary energy is visible, the methodology is shown to be very effective in removing blended shot energy.

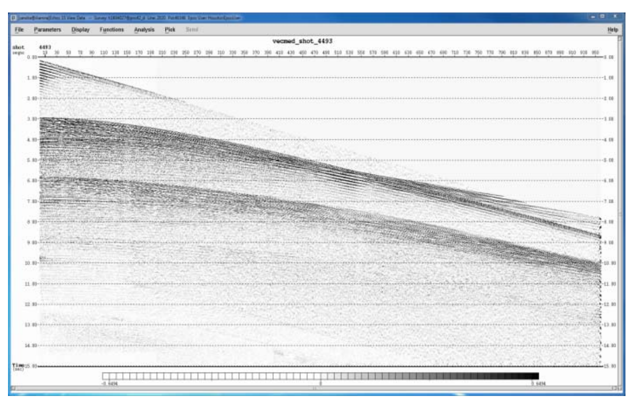

Figure 2 – De-blended Shot Record

Figure 3 shows an example of a brute stack of the same line prior to the removal of the blended shot energy. In areas of shallow water or very deep water, the secondary shots are well below any zones of interest, however for some water depths the secondary shots can interfere with primary reflections.

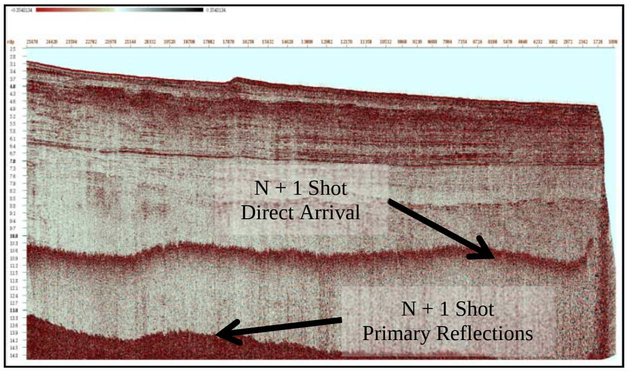

Figure 3 – Brute Stack with Blended Shot Records

Figure 4 illustrates the effectiveness of the de-blending process, including the additional attenuation attributable to the stacking process.

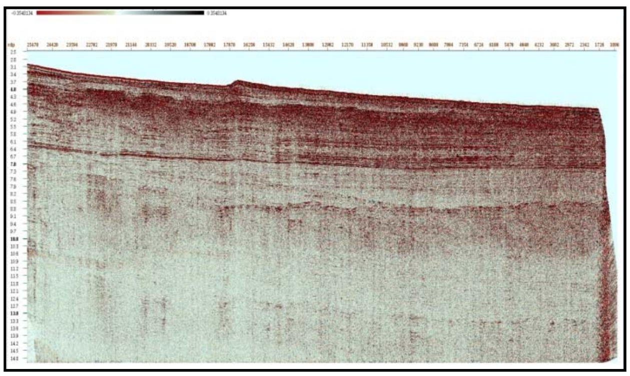

Figure 4 – Brute Stack After De-blending

Method

The de-blending processing flow is a two stage approach, including model-based adaptive subtraction followed by statistical noise removal (Seher and Clarke, 2016). The first stage estimates parts of the blended wavefield and subtracts those components from the seismic data, primarily attenuating the lower frequency band of the blended energy. The direct arrivals are modeled in the common channel domain, while reflected energy is modeled using a parabolic Radon transform in the CDP domain. For the reflected energy the physical separation between the primary and secondary shots creates moveout differences which are sufficiently large for separation and attenuation by stacking. The second stage exploits statistical differences of the energy and frequency between the primary signal and secondary noise. The applied noise attenuation techniques include Karhunen-Loève transforms, vector median filtering and time-variant frequency filtering.

In this methodology, the first stage attenuates the lower frequencies of the secondary shots, the second step addresses the higher frequencies, which appear more random. In their 2016 paper Seher and Clarke note that these statistical methods exploit frequency differences between the low frequency target energy at late times in the seismic record, and the higher frequency blended signal. This method is unique in that it exploits a characteristic of the blended seismic wavefield that is rarely considered in seismic de-blending.

To attenuate the higher frequency components of the secondary shot, a median filter in the common channel domain and a time-variant filter are applied to the data. The random differences in timing between shots caused by current induced variations in boat speed benefit the second de-blending step by making the data appear more random. Small variations in boat speed equate to small amounts of the secondary shot to be attenuated in this step. Figure 5 shows a field shot record and stacked image before and after attenuation of the direct wave and the reflected energy from the secondary shot.

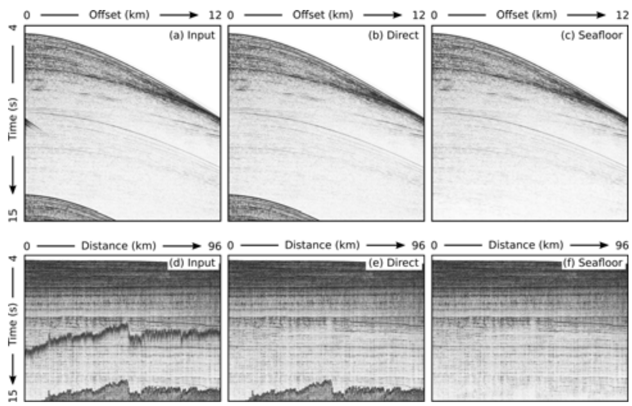

Figure 5: Observed shot gathers (a-c) and near-offset stacked seismic sections (d-f) before and after attenuation of the direct wave and near seafloor reflections (modified from Seher & Clarke, 2016.)

Examples

Directly to the southeast of the Foz do Amazonas Phase 3 survey, in the Pará Maranhão Basin, is a 2012 seismic survey acquired with a 15 second record length and a 37.5 m SP interval. Both surveys used a 12 km streamer, resulting in a 33% lower acquisition fold for the Pará Maranhão survey compared to the Foz do Amazonas Phase 3 survey. Figure 6 shows a map illustrating the overlap between the two surveys.

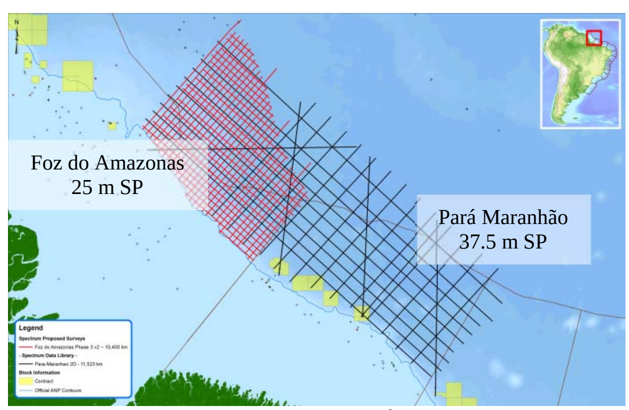

Figure 6 - Amazonas Phase 3 and Pará Maranhão 2D Surveys

A recent 2016 reprocessing of this survey produced a high quality data set including a well imaged Moho across much of the survey area. This enabled a well constrained quality control of the blended Amazonas Phase 3 survey acquisition. We compared images of the Moho event from interleaved lines in the 2012 Pará Maranhão survey with comparable lines in the Amazonas survey. Figure 7 shows an image of the Moho reflection from the Pará Maranhão survey, and Figure 8 shows a brute stack of an adjacent line on the Amazonas Phase 3 survey. Figure 9 shows a similar image of the Moho reflection on a preliminary PSTM stack.

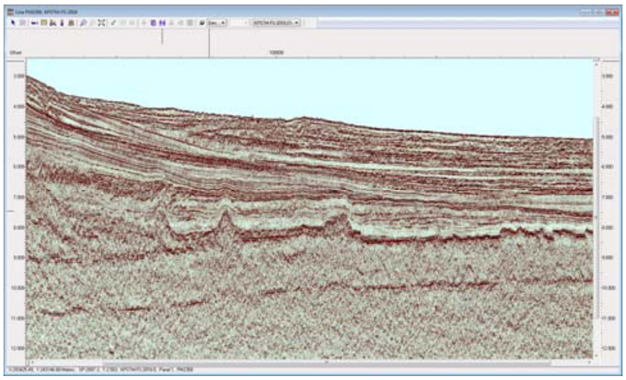
Figure 7 – PSTM Stack from Para Maranhao Survey

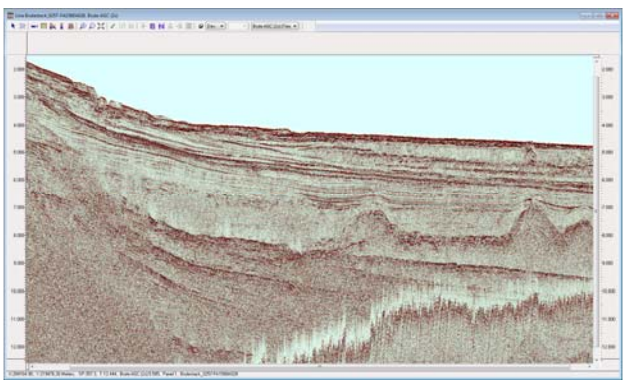
Figure 8 – Brute Stack from Amazonas Survey

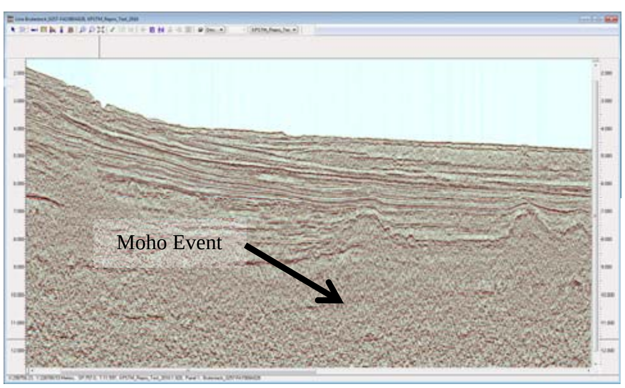

Figure 9 – Preliminary PSTM Stack from Amazonas Survey

Results

A primary imaging objective in the Foz do Amazonas Phase 3 project was the Moho, in order to provide a clear basis for understanding the tectonic architecture of this basin. In spite of the blended shot energy present at the end of the record, a clear image of the Moho is observed. However, the shallow section is an equally important objective and the ability to resolve detailed stratigraphy is crucial for understanding the exploration potential of this basin. Figure 10 is an image of the section immediately above the basement, where we would expect to see potential source rocks, reservoirs and traps. The section is characterized by a series of stratigraphic sequences overlaying a crystalline basement. The imaging of this sequence will benefit from the higher fold acquisition geometry which results from a 25 m source interval, compared to a 37.5 m source interval.

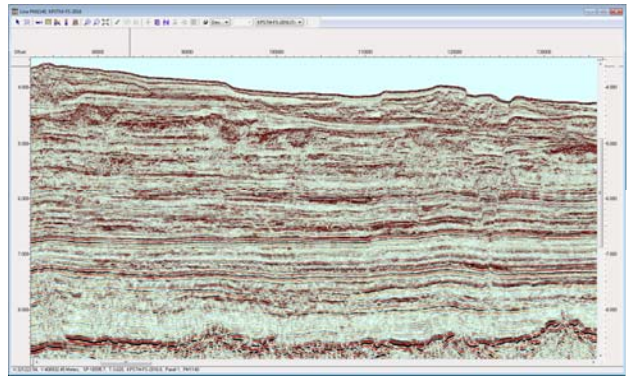
Figure 10 – PSTM Stack of Shallow Section

Conclusions

We demonstrate that a high fold, long record length acquisition geometry can satisfy competing seismic imaging requirements, including the need for clear images of play fairways, prospects, and deep crustal structures necessary to define a tectonic framework.

Innovative acquisition technologies that enable record lengths that extend beyond the nominal shot time interval, combined with robust de-blending techniques allow us to record high fold data suitable for improved stratigraphic imaging. This high fold data is acquired with record lengths sufficient to image deep targets without compromising acquisition efficiency.

Acknowledgments

We thank Spectrum Geo Inc. for permission to publish this work. We also gratefully acknowledge the valuable insights offered by Richard Clarke and Milos Cvetkovic.

References

Seher, T. and Clarke, R. [2016] Accelerating deepwater seismic acquisition through continuous recording. *86th SEG Annual Conference and Exhibition*, Expanded Abstracts, 82-86.

Cvetkovic, M. et al, [2017] Effective 2D programs for frontier basin exploration, submitted to *79th EAGE Conference and Exhibition,* Expanded Abstracts.