Interbed multiple attenuation with an automatic spatially adaptive thresholding operator: a case study in the North Louisiana Salt Basin

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Summary

Interbed multiple contamination is a common phenomenon in land seismic data. In the North Louisiana Salt Basin, it is especially severe, obscuring the Bossier and Haynesville drilling targets.

Existing Least-Squares subtraction-based interbed demultiple techniques perform relatively well in areas with strong dip discrimination between primary and multiple energy but perform poorly in areas with similar dip. We present a novel method based on Least-Squares subtraction that automatically adapts the predicted multiple model to the geology by using the amplitude of the multiple generator(s) as a reference threshold. This proposed method significantly reduces primary attenuation in comparison to a traditional Least-Squares subtraction.

We apply this method in a cascaded demultiple workflow on a field dataset in the North Louisiana Salt Basin to demonstrate its efficacy in attenuating interbed multiples while minimizing primary attenuation.

Introduction

Since Chesapeake pioneered the unconventional shale revolution for oil and gas development, 3D seismic data has always been a key component of the tool set used in locating reservoirs. In the North Louisiana Salt Basin, Chesapeake has used more than a dozen 3D seismic surveys, shot over the period of 2009-2012. These seismic surveys have been processed multiple times through PSTM and have generally served Chesapeake well in landing wells in the optimal shale zone. In structurally complicated areas with extensive faulting in the SE of the project area, the Natchitoches Fault Zone, multiples seriously interfere with primary events, resulting in a distorted representation of the subsurface, thus creating interpretation uncertainties. Faults were badly obscured and difficult to interpret correctly; even the production shale zones were difficult to map in these zones. The multiples made it almost impossible to interpret anything geologically reasonable in the deep section. Figure 1 provides a cross section highlighting some of these challenges.

Many attempts have been made to address the multiple issues in the data including SRME (surface related multiple elimination). SRME predicts surface related multiples by convolution of seismic data with itself and removes the multiples by adaptive subtraction (Verschuur et al., 1992). SRME quickly found widespread success in marine seismic ever since Delft's pioneering work (Dragoset and Jericevic, 1998), but it has met challenges to consistently be successful in land data (Kelamis and Verschuur, 2000). Low S/N ratio, irregular acquisition geometry, and rugose free surface all contribute to the challenges in land data.

In this work, we applied the same prediction and subtraction principles as SRME, but we went beyond SRME by adapting the predicted multiples to the interpreted multiple generation horizons using the horizon amplitudes as a contributing factor in subtracting the multiples. We will describe the method first, then present the application case to the data from the North Louisiana Salt Basin.

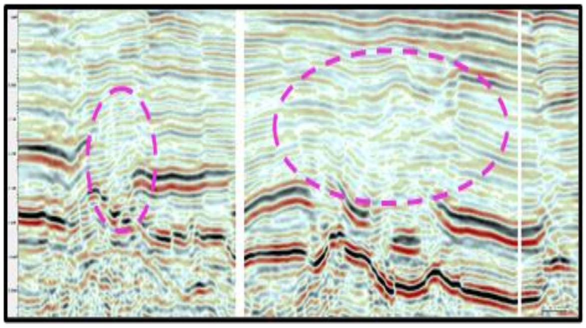


Figure 1 - Legacy PSTM Stack. Seismic data are owned or controlled by Seismic Exchange, Inc

Method

The input data consisted of several surveys which went through a standard pre-processing workflow which resulted in azimuthally binned EPOCS-Reconstructed tiles as input to migration.

Two main zones of multiple contamination were identified: within the target interval and sub-salt. Target zone multiples were difficult to identify due to variable amplitude and dip generally conformable to that of the actual structure. Subsalt multiples were easily identifiable and generally dissimilar to the structural dip. The demultiple process was designed as a cascaded workflow with three separate phases:

1. Pre-migration on azimuthally binned tiles targeting sub-salt zone multiples,
2. Post-migration pre-stack Multi-domain Multiple Attenuation (MDMA) targeting all multiples, and

3. Post-migration post-stack Spatially Adaptive Multiple Attenuation (SAMA) targeting specific areas in the target zone where the multiple contamination was severe and not adequately attenuated by the previous two passes.

Removal of sub-salt multiples in Phase 1 followed a standard SRME prediction and adaptive subtraction workflow (Kelamis and Verschuur, 2000).

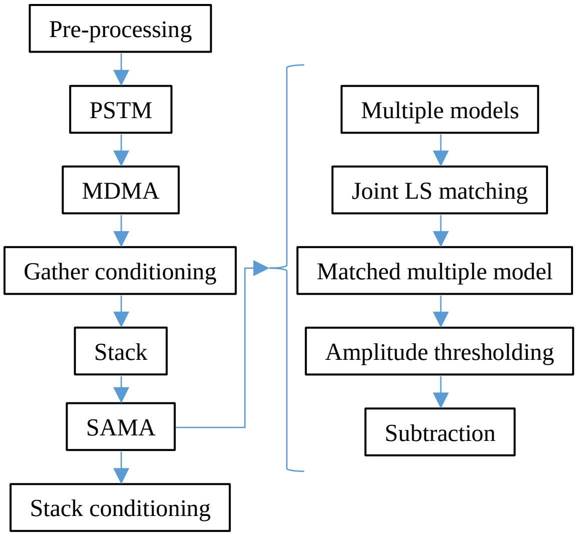


Figure 2 - Processing workflow with emphasis on the SAMA phase

The MDMA application (Phase 2) utilized a joint weighted adaptive subtraction (Mei, Y., and Z. Zou, 2010) with contribution from all multiple generators. The multiple model for each generating horizon was predicted on post-stack data. A total of six multiple generating horizons were used to predict six multiple models. Subtraction was applied on each pre-stack tile. Sub-salt multiples were aggressively weighted. Target zone multiples were given less weight to minimize primary attenuation.

The SAMA workflow (Phase 3) was aimed at further reducing the multiple contamination in the target zone where the previous MDMA was not as effective. Three multiple generating horizons were identified as contributing to multiple contamination in the target zone (Figure 3).

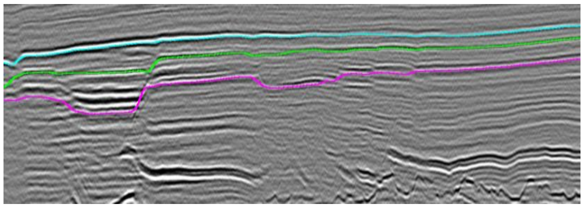


Figure 3 - Stack showing multiple generators for the target zone

Multiple models were generated for each of these horizons and put through a joint least-squares matching with equal weighting, resulting in a matched multiple model. The next step was to create a weighting function for this multiple model that would reduce or eliminate primary attenuation.

The travel-time from source to receiver of generated multiples is greater than that of the generator, thus are subject to additional attenuation effects. It is unreasonable to expect that multiples generated from a horizon would exceed the amplitude of said horizon. It was determined that the cyan horizon in Figure 3 was best correlated to the remnant multiple. The cyan arrows in Figure 4 show the multiple generator. The dotted line on this section separates the areas of high and low multiple contamination which are also the areas of high and low amplitude along the main multiple generator.

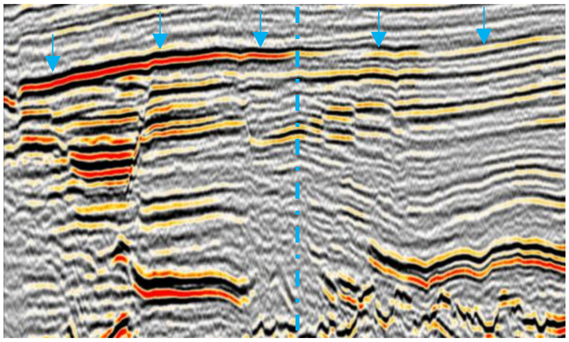
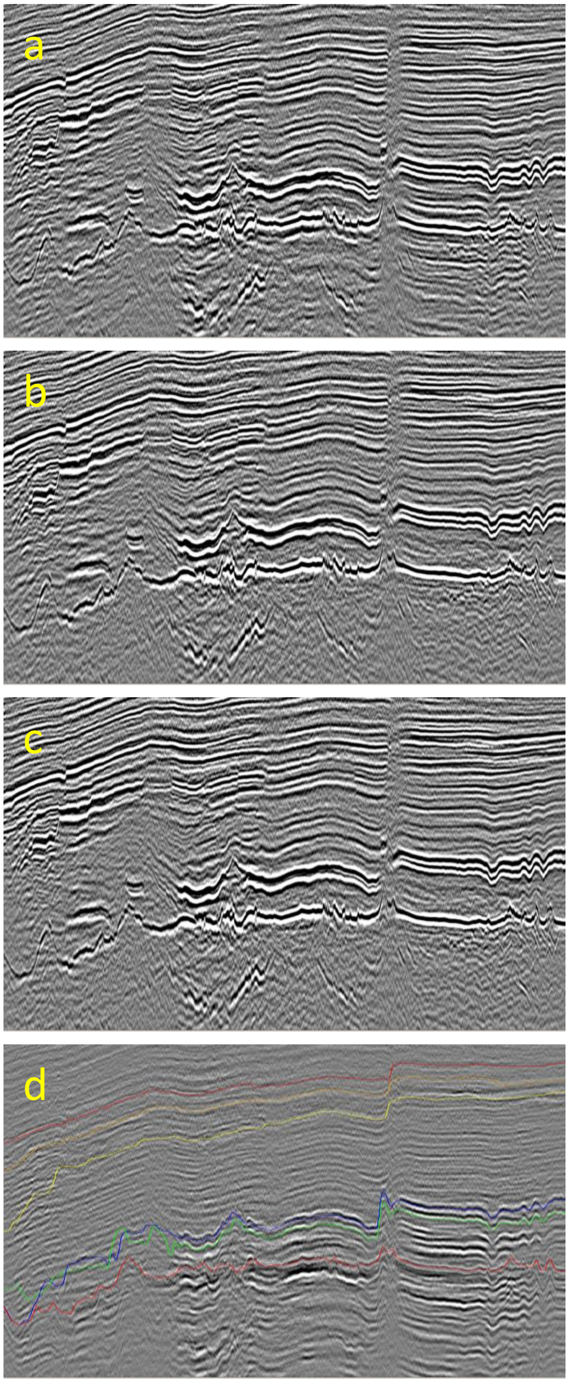


Figure 4 - Stack with cyan arrows identifying the main multiple generator

The matched multiple model was then weighted based on the extracted amplitude of this horizon. A threshold was determined based on a percentage of the multiple generator amplitude, with the model being retained below this threshold and attenuated above it. Different levels of thresholding were evaluated and 85% was found to achieve the optimal result.

The weighted model was limited to the target application zone and subtracted adaptively.

Results



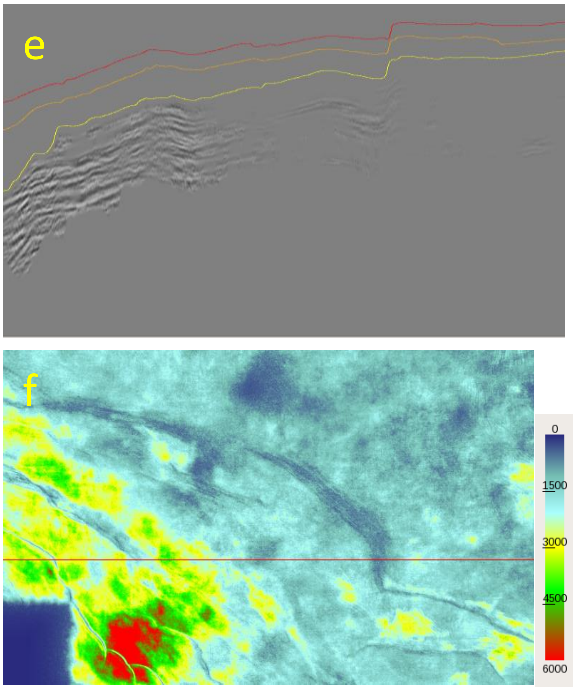


Figure 5. Attenuation of interbed multiples: a) Raw PSTM stack, b) stack after pre-stack MDMA, c) stack after post-stack SAMA, d) MDMA difference, e) SAMA difference, f) aerial view of main multiple generator amplitude.

Figure 5 shows an example stack section at various stages of the post-processing flow.

Figures 5a, 5b and 5d are the before/after/difference plots of MDMA. As mentioned previously, MDMA was weighted to have less impact on the target zone (yellow-to-blue horizons) with no spatial weighting. With layers of interleaved primary and multiple events, this was necessary to limit primary signal attenuation; however, in areas where there was a distinct dip differences, MDMA was effective at attenuating the overlying multiple. This MDMA demultiple phase worked as intended.

Figure 5f shows an aerial view of the extracted amplitude along the red horizon with low amplitudes in blue and high amplitudes in red. There is a concentration of high amplitudes at the bottom left of the picture which corresponds to an area of high residual multiple contamination on the stack section. Low extracted amplitudes correspond to areas of low multiple contamination. The red line corresponds to the vertical sections in 5a-5e. Figures 5b, 5c & 5e are the before/after/difference plots of SAMA. The spatial weighting is apparent in the difference plot where the left side of the section has more multiple contamination (and a higher weight) whilst the right side has little multiple contamination (and a lower weight). The SAMA demultiple phase worked as intended, targeting specific multiple contamination zones.

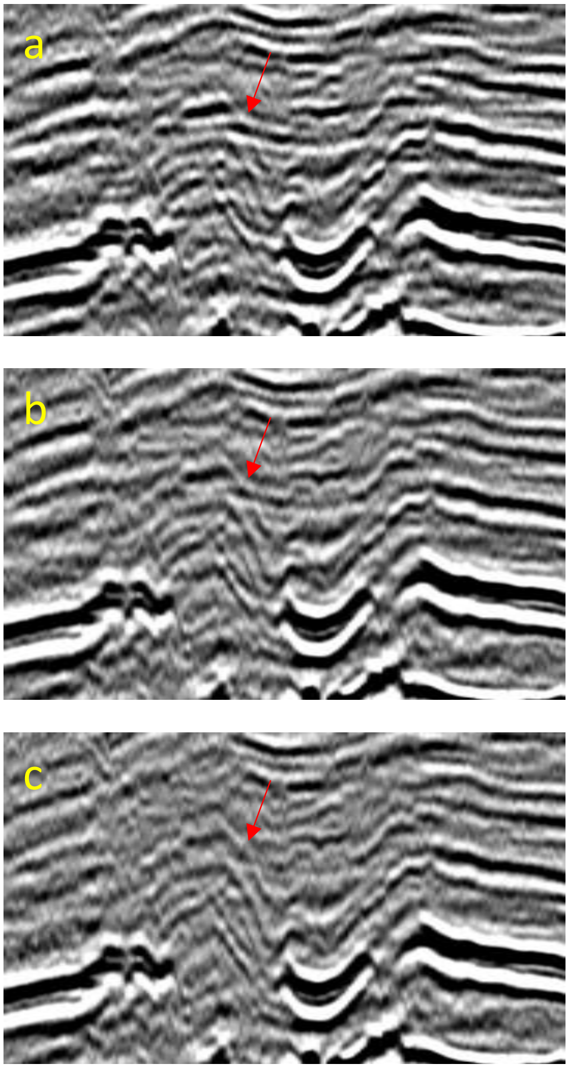


Figure 6. Attenuation of interbed multiples: a) Raw PSTM stack, b) stack after pre-stack MDMA, c) stack after post-stack SAMA, the red arrow shows an interbed multiple event not fully attenuated by MDMA that was better addressed with SAMA.

The benefit of SAMA can be seen in the zoomed in section, Figure 6. MDMA does a good job of identifying the multiple indicated by the red arrow but fails to remove it completely. The addition of SAMA removes the multiple and reveals the underlying structure.

Conclusions

Attenuation of land interbed multiples is difficult in areas of poor dip discrimination and strong multiple energy while still preserving primary events.

We have demonstrated a cascaded demultiple workflow by using standard model-and-subtract demultiple techniques, along with a new spatially variant weighting function that uses properties of the multiple generator to customize the multiple model, while greatly reducing the impact on primary events but still aggressively targets the multiple events.

This workflow can be generalized to other seismic data where multiple contamination is not effectively removed by other techniques.

Acknowledgments

We would like to thank our colleagues for their valuable discussions and suggestions. We thank the management of Chesapeake Energy and In-Depth Geophysical for the support and permission to publish this result. We thank Seismic Exchange, Inc. for the courtesy of seismic data show rights, as the seismic data are owned or controlled by Seismic Exchange, Inc.