Prestack suppression of high frequency ground roll using a 3D multiwindow KL filter: Application to a legacy Mississippi Lime survey

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Summary

Recently the Mississippi Lime has become one of the most active resource plays. Our study area falls in-between the Fort Worth and Midland Basins. The main production comes from high porosity tripolitic chert. Our objective is to use 3D seismic data to map the areal distribution of discontinuous tripolitic facies.

In the early 1990s several 3D surveys were shot in the study area to image shallower objectives. With the advent of the Mississippi Lime play, four of these surveys were merged and reprocessed using careful statics and velocity analysis. Even after prestack time migration, the target zone is contaminated with the acquisition footprint. The data are low (~15) fold and contaminated by highly aliased, high frequency, high amplitude ground roll. Given the sparsity of the survey, modern f-k_x-k_y filters were not able to remove ground roll prompting the development of a new ground roll suppression workflow. In workflow, we first window and low-pass filter (f<50 Hz) the data, 3D patch by 3D patch. We then apply linear moveout to approximately flatten the ground roll phases, estimate the dip about this reference moveout, and compute coherence within a 3-channel by 3-shot by 20 ms window for each sample. Using a Kuwahara algorithm, we choose the most coherent window within which we apply a structure-oriented KL filter. At the end we simply modeled the ground roll from the original data. This 3D filter preserves signal amplitude and is flexible enough to model the piece wise continuous ground roll pattern common with irregular topography.

Introduction

The Mississippi Lime is one of the newer resource plays. The target in our study area is shallow (at about t=1.2 s). The surface infrastructure is in place, and many small operators already hold the acreage from shallower or deeper production. Advancements in horizontal drilling, acidation, hydraulic fracturing, and efficient disposal of large volumes of water make these reservoirs economic. In contrast to some shale resource plays, the Mississippi Lime is laterally highly heterogeneous. The major rock types are tripolitic chert, fractured tight chert, and tight limestone. The tripolitic and fractured chert have good porosity and good production in northern Oklahoma and southern Kansas. The Study area lies between the Midland Basin (Permian Basin) and Fort Worth Basin, Texas. In this area, there is no Woodford Shale, such that the Mississippi Lime lies directly above the Ellenburger Limestone at a depth of 6000-8000ft.

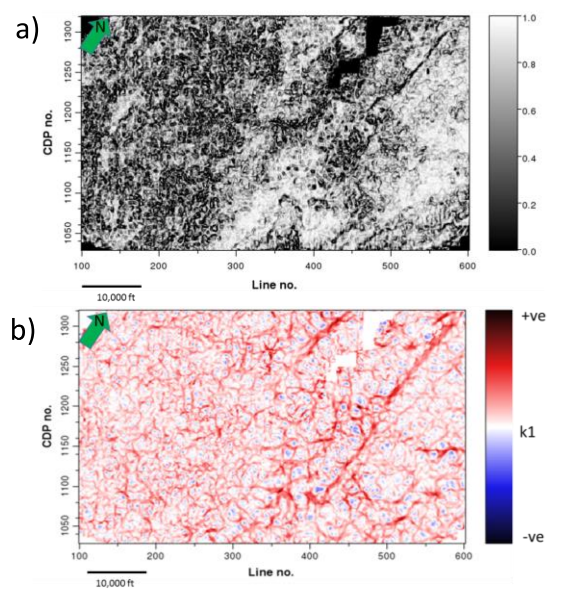

Figure 1. (a) Sobel filter similarity, (b) most positive principal curvature time slice at the level of zone of iterest (Mississipi Lime). The acquisition footprint dominates the over the geology. Note strong EW and NS footprint in both images.

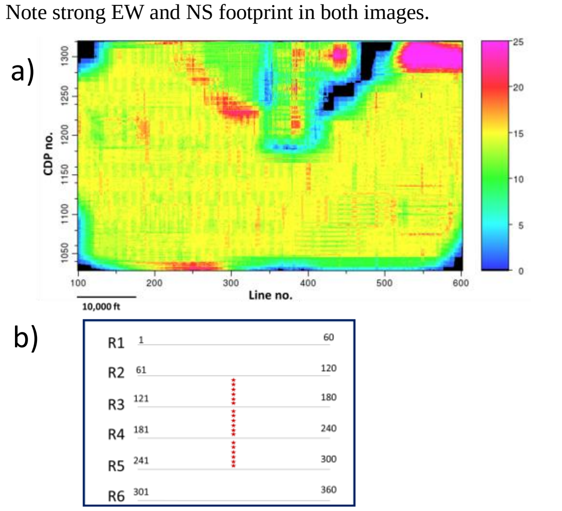

Figure 2. (a) Fold Map of the surveys area; color scale shows fold value. (b) A representative receiver path. Receiver lines run EW while shot lines run NS within the patch, forming a 3D volume. Ground roll will be filtered within this patch by exploiting low velocity 3D linear moveout within overlapping 3 receiver by 3 shot data windows.

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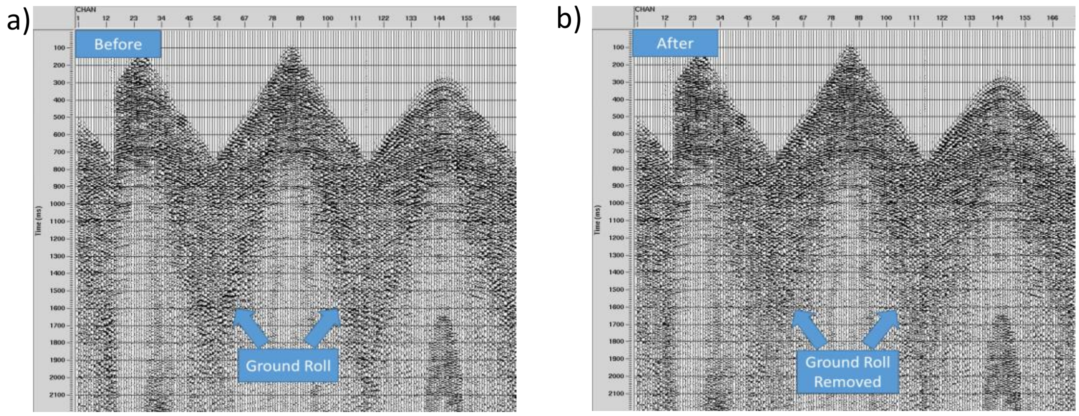

Figure 3. A typical shot gather (sorted by shot –channel) (a) before and (b) after ground roll suppression.

Four seismic surveys were shot in the early 1990s, three of which had EW receiver lines and one which had NS receiver lines. The merged surveys occur at an area of 80 mi^2. Initially we followed the conventional land processing workflow for Mississippian play Dowdell (2013) and Aisenberg (2013) including a 15 Hz low-cut filter, iterative static and velocity analysis, and prestack time migration. Unfortunately, the resulting images are still contaminated by acquisition footprint (Figure 1). The seismic data are very low (~15) fold (Figure 2a). Examination of the migrated gathers (not shown) reveals strong ground roll aliasing into the images. On the original shot gathers, the ground roll appears as strong amplitude, aliased, coherent events that persist up to 50 Hz. (Figure 3a and 4).

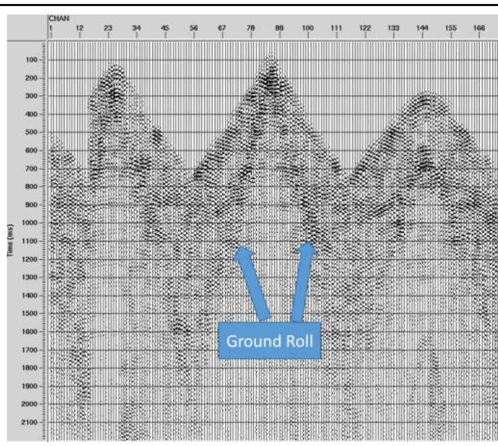

Figure 4 : Ground Roll present after filtering on band pass filtered data 40-50Hz.

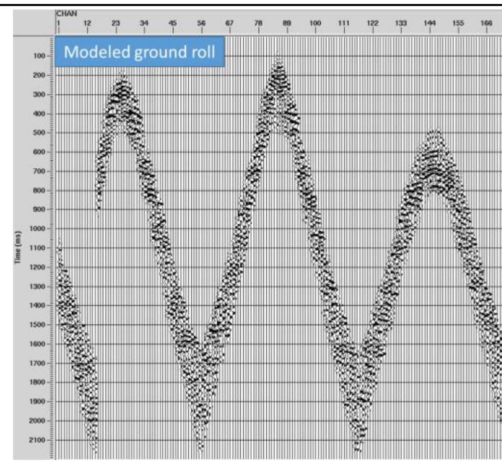

Figure 5: Windowed ground roll for the shot gather displayed in Figure 3a. Note the flat and negative dipping events typical of aliased data.

Motivation

5D interpolation has been shown to be an effective means of suppressing acquisition footprint on seismic attribute volumes (e.g. Chopra and Marfurt, 2014). Unfortunately, in our case where we have strong amplitude coherent aliased noise, 5D interpolation software will interpolate the noise as well, making matters worse.

The low vibrator sweep up to 85 Hz and the presence of ground roll up to 50 Hz (Figure 4) precludes the use of a simple low-cut filter. The aliasing, which prevents accurate 5D interpolation, also prevents the use of modern the f-k_x -k_y filtering. We therefore set out to model the ground roll. We recognize that the ground roll (1) is high amplitude, (2) is band limited (f< 50 Hz), (3) exhibits outgoing low group

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and phase velocity with few backscattered events, and (4) is piecewise coherent. We are also fortunate that our data were acquired in patches (Figure 2b), facilitating the implementation of a 3D dip filter across channel number and shot number dimensions.

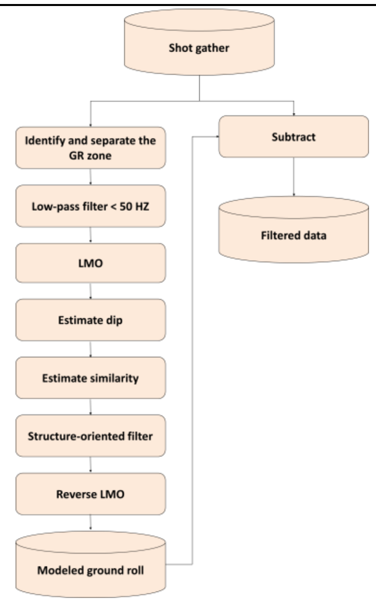

Figure 6. Ground roll suppression workflow.

Method

Figure 6 summarizes our workflow. Our first step is to window the ground roll contaminated zone based on an average group velocity (Figure 7a). In this manner, subsequent filters will not impact reflection events outside the ground roll window. The windowed zone includes geological reflections of all frequency ranges (10-85 Hz) so our second step is to apply a low pass filter, f<50 Hz that removes the signal in the higher frequency range ($50 < f <$ 85 Hz). In the third step, we apply linear move out (LMO) based on an estimate of the ground roll phase velocity of 5000 ft/s (Figure 7c), thereby approximately aligning the ground roll and misaligning the higher apparent velocity geological reflections of interest. At this point, we have created a patch of data (Figure 2b) that is amenable to 3D structure-oriented filtering using a KL filter (Marfurt, 2006). We compute the inline (Figure 7d) and crossline components of dip as well as coherence (Figure 7e) within a 3 channel by 3 shot by 20 ms analysis window. Each sample forms part of 9 spatial by 11 vertical (or 99) windows. The most coherent (Kuwahara) window (i.e. the one that best represents moderately dipping coherent ground roll) is declared the winner. If the window is sufficiently coherent ($c > 0.3$) we apply a Karhunen-Loeve (Principal component) to model the strongest event (the moveout-corrected ground roll) at the current sample of interest. If the window is incoherent ($c < 0.3$), only misaligned signals (or random noise) exists, and no filter is applied.

The result of the previous step provides the modeled ground roll (Figure 7f). The final step is to subtract the modeled ground roll from the original data. Figure 3b shows the result of this step.

Result and Disscussion

Comparing the shot gathers of before and after ground roll suppression shows that a great deal of high amplitude aliased ground roll has been successfully removed on the shot gather (Figure 3b) while the reflection events of interest have been preserved. When sorted to CMP supper gathers, the filtered data provides significantly improved velocity spectra.

Conclusions and limitations

The presented method has shown a significant amount of improvement in signal to noise ratio (by reduction in the noise). The data are now amenable to detailed velocity analysis and subsequent application of 5D interpolation.

This technique works well for aliased ground roll suppression where f-k_x-k_y techniques fail. The explicit search for sample-by-sample phase velocities allows the filter to adapt to dispersive ground roll wave trains. The short, overlapping 3D window implementation allows the filter to model piecewise continuous ground roll events that are broken by irregular topography and discontinuities in the weathering zone. Our survey is dominated by radially-traveling ground roll, allowing us to approximate the moveout using a user defined velocity and the source-receiver offset. If backscattered ground roll were a problem, a more compute intensive search about a 3D moveout cone rather than within the source-receiver sagittal plane would be required.

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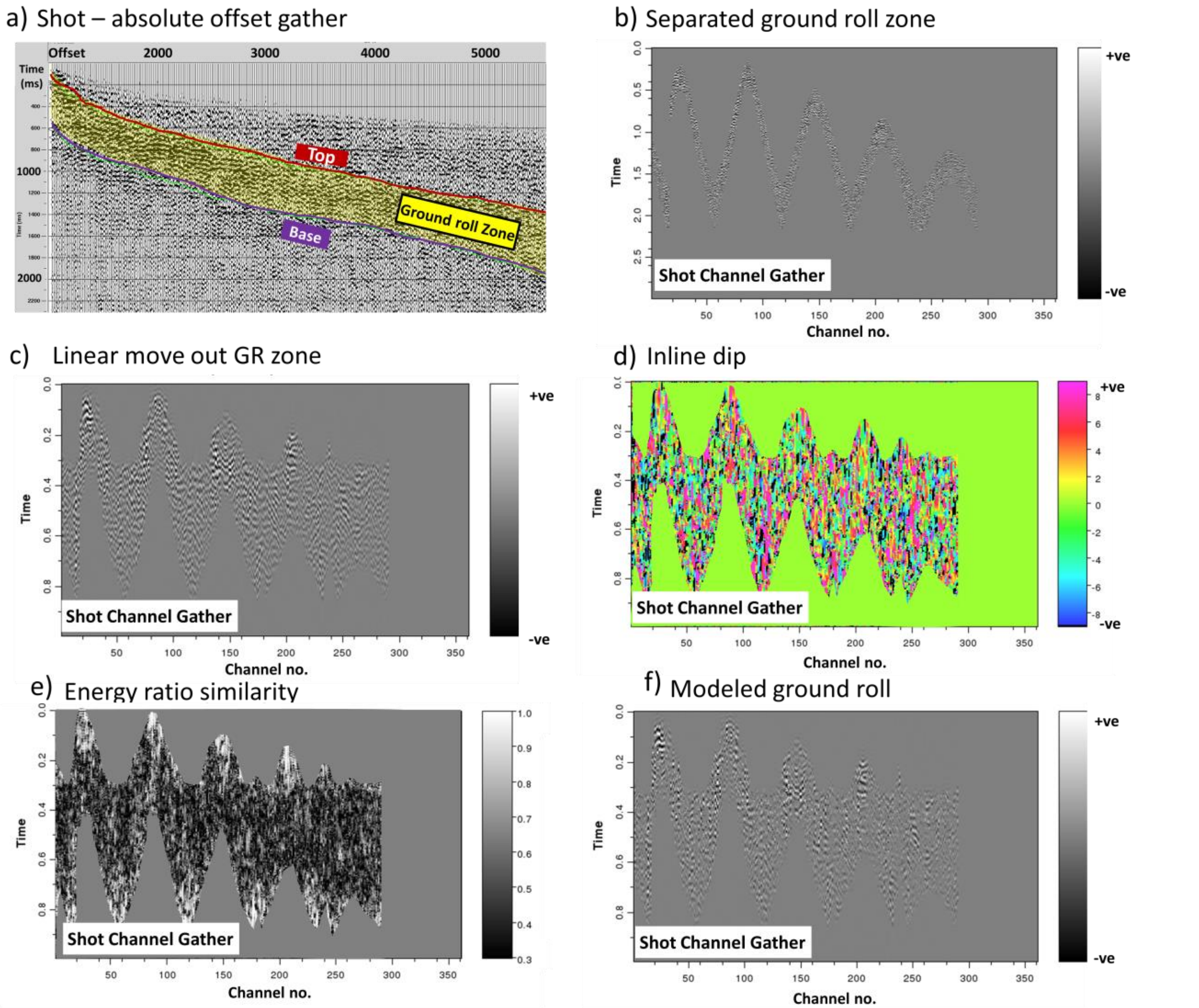

Figure 7. (a) Common shot gather sorted by absolute offset; with strong ground roll window indicated by yellow. (b) Windowed data shown (a) sorted by channel and high cut filtered to $f < 55$ Hz. (c) Windowed data after linear moveout with v_{phase}= 5000ft/s. The ground roll events are relatively flat while signal is steeply dipping. (d) Range-limited inline component, where increasing channel numbers are "in line" and increasing shot numbers are "cross line". Crossline dip computed byt not shown. (e) Coherence computed on the windowed, flattened patch. High coherence indicates coherent ground roll. (f) Modeled ground roll using a Karhunen-Loeve filter within those windows exhibiting a coherence, $c > 0.3$.

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EDITED REFERENCES

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