An F-K Procedure of Eliminating Guided Wave Energy from Shallow Marine Seismic Data.

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ABSTRACT

An F-K procedure of modeling and removing guided wave energy from seismic data is discussed in this paper. A case study is presented whereby a single sail line pulled from a 3,150 m shallow marine 3D seismic data acquired in the Niger Delta basin, Nigeria, is pre-processed with guided waves removed and without. The aim is to show if modeling and removal of these waves would be beneficial to the processing of the data. The results show that removal of guided waves results in improved signal resolution and event continuity especially at shallow depths.

(Keywords: seismic records, seismology, guided waves, noise, water layer)

INTRODUCTION

Guided waves are waves that are generated by shallowly buried marine sources in the water layer. They propagate along or close to the surface of the Earth. They are persistent mainly in areas with hard water bottom where there is a strong velocity contrast which causes most of the energy of the waves to be trapped and guided laterally through the water layer (Yilmaz, 2001).

These waves constitute noise on seismic records because their amplitudes are significantly higher than those of the body waves we are interested in, when examining reflection/refraction seismology. The amplitudes of guided waves decay exponentially with depth. Guided waves are recognized in shot gathers by their extremely slow velocities and high amplitudes when compared to P and S waves (Figure 1).

DATASET

The dataset comprised a 3,150 km 2D line extracted from a shallow marine 3D seismic survey acquired in the Niger Delta in 1998. The data was processed through a standard 2D marine seismic data processing stream using Landmark's ProMAX® software.

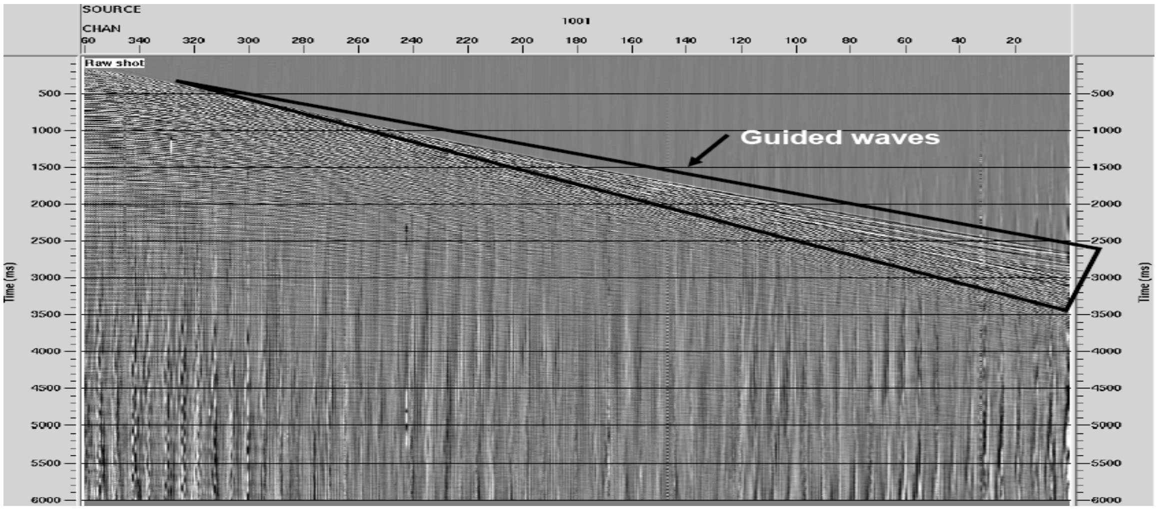

Figure 1: Raw Shot with Heavy Presence of Guided Wave Energy.

The basic pre-processing flow chart is shown in Figure 2.

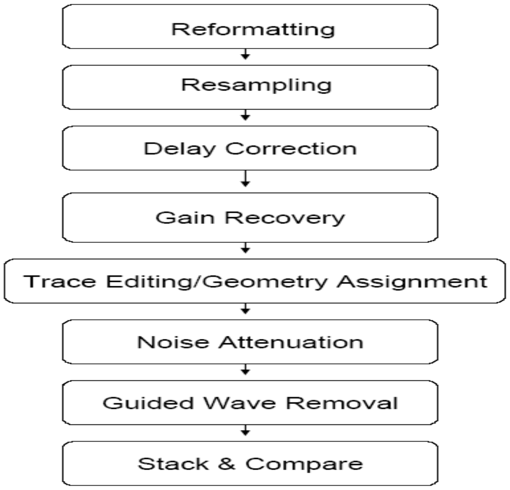

Figure 2: Processing Flow Chart.

The data was first read and reformatted into ProMAX's internal format. A single sample de-spike routine was then run to remove any huge anomalous amplitude from the input data. A filter trial was run on shot records at 2 ms to investigate the band-width present in the field data. It was found that no significant usable frequency was present above 90Hz (Figure 3). Based on this finding, a decision was taken to re-sample the data to 4 ms to save disk space and make the processing faster. The resample was performed along with the application of a temporal anti-alias filter of 90 Hz with a slope of 72 dB/Oct.

An analysis of gain decay was carried out on the field data over near-, mid-, and far-offsets, and following this analysis, we applied a time-variant gain function of 2dB/sec (i.e., a T**2 gain recovery) to compensate for loss of amplitude due to spherical wavefront spreading.

A check on the observer's logs for the data acquisition indicated the presence of an instrument delay requiring a correction of 125 ms on each shot. A bulk static shift of -125 ms was therefore applied to the data to shift events up by 125ms. We built a 2D geometry based on XY coordinates of the shot points and loaded them unto the trace headers.

Major noise issues identified on the data included swell noise and linear cable noise (Figure 4). In order to attenuate the swell noise effectively, we designed a swell noise attenuation filter which decomposed the data into frequency bands, identified and attenuated anomalous amplitudes within affected bands according to some specified thresholds.

Two passes (Table 1 and Table 2) of this filter were run on the data. The first pass was designed with a 600 ms time window to attenuate noise within the frequency range of 0 – 15 Hz in the deeper section of the data, using the time varying threshold shown below.

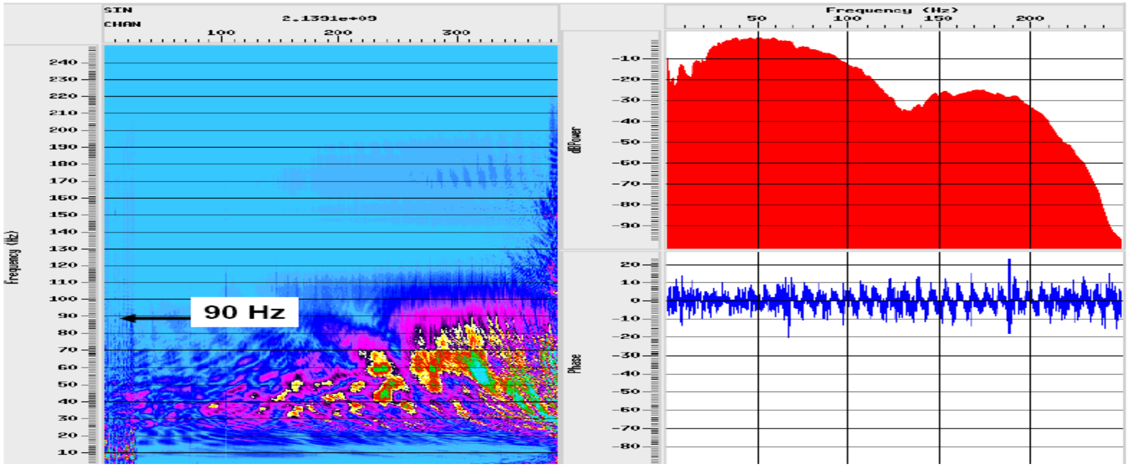

Figure 3: An Interactive Spectral Analysis of Shot.

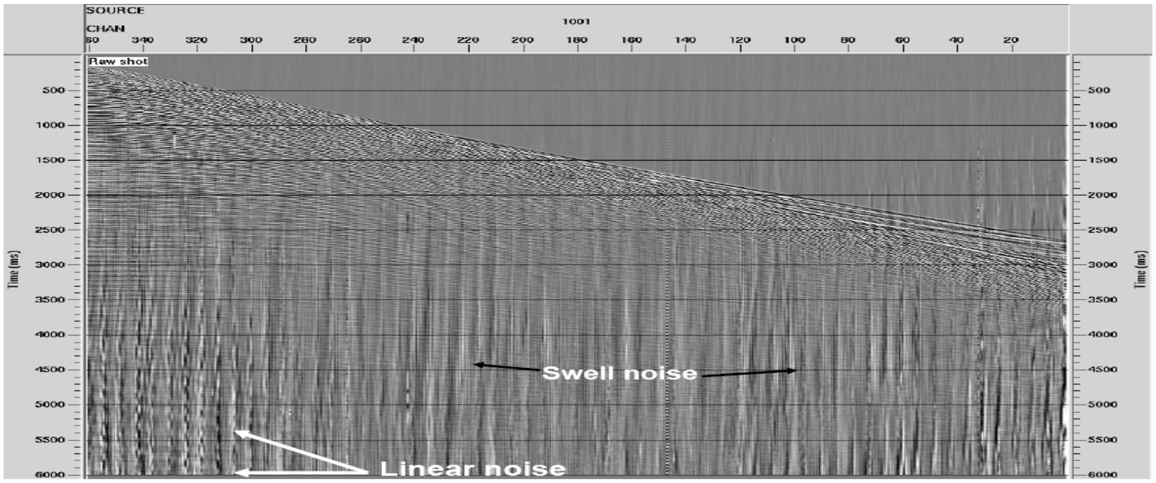

Figure 4: Raw Shot showing Different Noise Types to be Attenuated.

Table 1: Low Pass Swell Noise Attenuation Filter.

Time	Threshold
0	20.0
2500 ms	7.0
3500 ms	4.5
6000 ms	2.5

Table 2: High Pass Swell Noise Attenuation Filter.

Time	Threshold
0	50.0
2500 ms	15.0
3500 ms	12.0
6000 ms	5.5

The second pass was designed to run over the entire frequency range of the data, setting the maximum frequency to 110 Hz. This filter was designed specifically to attenuate spiking channels, swell noise and other anomalies, using the following time-variant threshold.

The shots were sorted to CDP domain prior to the swell noise attenuation. This can be useful in reducing the coherency of noise which affects adjacent traces in shot domain. A mild outer trace mute was applied before the noise attenuation.

The two passes of the swell noise attenuation filter were effective in removing the swell noise but was ineffective in removing the linear cable noise. The swell noise attenuation filter module attenuates noise on a trace-by-trace basis but not in a linear sense, hence it failed to attenuate the linear noise (Figure 5a).

Another filter capable of transforming an input panel of x-t domain traces to a radial trace domain was then designed and applied to the data to attenuate the linear noise. The radial trace transform is a re-mapping of the normal x-t seismic domain with coordinates of source-receiver offset and two-way travel time into a domain whose coordinates are velocity and two-way travel time. Traces in this domain all share the same x-t origin and hence are “radial” to that origin.

Because the radial transform has the same time coordinate as the original x-t domain, the transform operation is implemented as a simple interpolation of trace samples from x-t time slices to r-t (radial-time) time slices. The filter was effective in attenuating a majority of the linear noise. Figure 5 shows the shot after the application of the swell and linear noise attenuation filters. With the swell and linear cable noise removed from the shots, the guided waves became more evident on the data (Figure 5b).

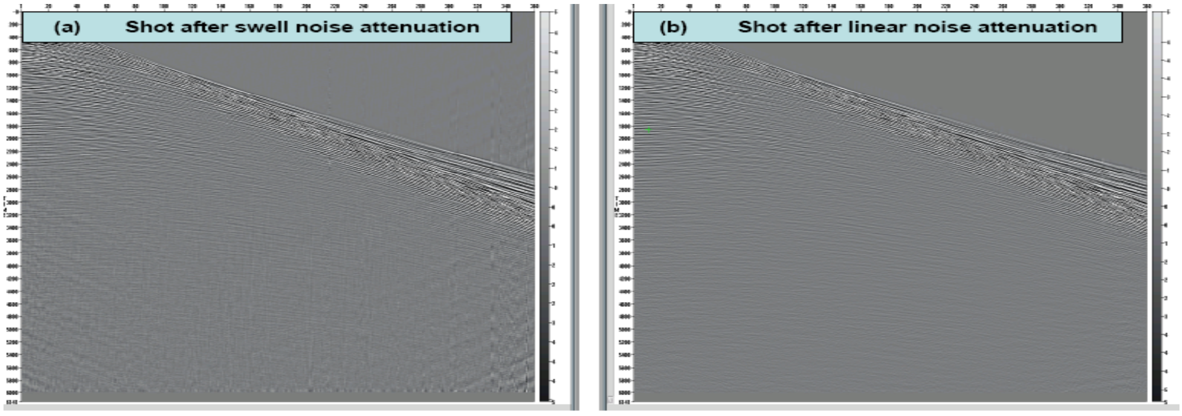

Figure 5: Shot after Noise Attenuation: (a) Shot after Swell Noise Attenuation (b) Shot after Linear Noise Attenuation, the Swell Noise Output Service as Input to Linear Noise Attenuation. The Guided Wave Energy became Evident in the Data after the Noise Attenuation.

THE GUIDED WAVE MODELING PROCEDURE

It is often possible to separate seismic trace data into signal and noise by transforming the data from the x-t space into another space, where a filter is designed to reject the noise or accept the good data. Coherent linear events in the x-t space can be separated in the f-k space by their dips (Yilmaz, 2001).

To model these waves, a linear moveout correction (LMO) is firstly applied to the de-noised shot gathers to prevent the wrap around which occurs in the f-k space. After the LMO correction, the guided wave energy becomes shallower in the x-t space and thus, more steeply dipping in the F-K space. More steeply dipping data in the F-K space implies a higher chance of aliasing. Due to this reason, we carried out an f-k trace interpolation on the LMO-corrected input data to de-alias the guided wave energy.

Next, we transformed the data into an f-k space and picked a polygon around the guided wave energy. In the f-k space, the guided wave energy aligns in the region of the data with very steep dip (Figure 6). We then applied an f-k filter to the data to pass the data within the specified polygon without attenuation, while strongly attenuating the data outside of this polygon.

The procedure above enabled us to have a model of the guided waves together with a load of transform noise. The f-k trace interpolation process we carried out earlier on created a unique header word and on the basis of this, we dropped the interpolated traces from the guided wave model, passing only the real traces which we then transformed back into the x-t space.

To ensure elimination of any transform noise from the model, we applied a top and bottom mute which we had earlier created on the raw shot in the x-t space as shown in Figure 7. Finally, to remove the modeled guided wave energy from the input data, we firstly removed the LMO from the model and interwove the model with the input data. This enabled us to make a subtraction of the model from the input to have output gathers with guided wave energy removed.

RESULTS AND DISCUSSION

When coherent events are transformed from the x-t space to the f-k space, a process which relies on the dips of the events, the different energy present in the events can be isolated (Figure 6). The primary reflection energy is concentrated around k = 0 whereas, the guided wave energy has much higher positive dip.

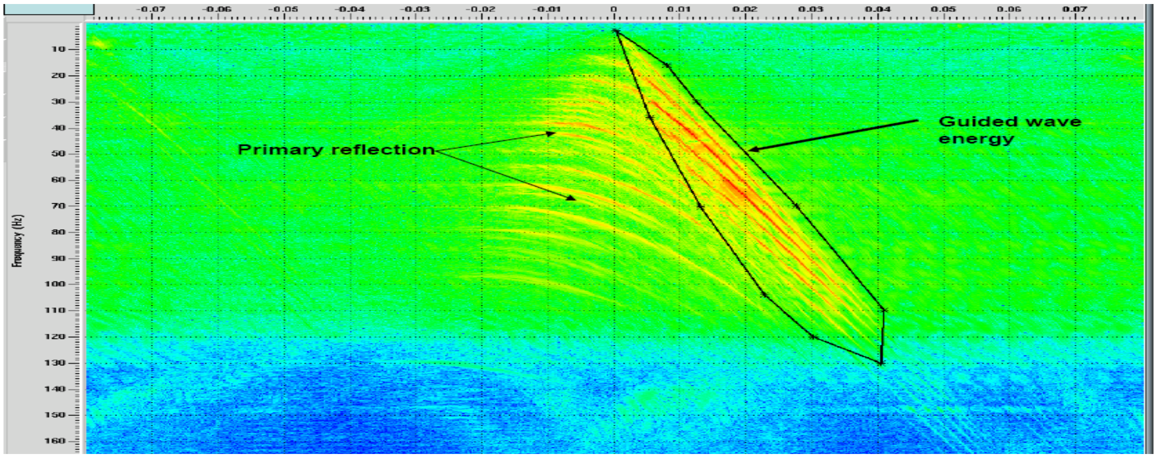

Figure 6: F-K Analysis-Shot with LMO + Trace Interpolation. The Primary Data is Concentrated around K=0 in the Transformation.

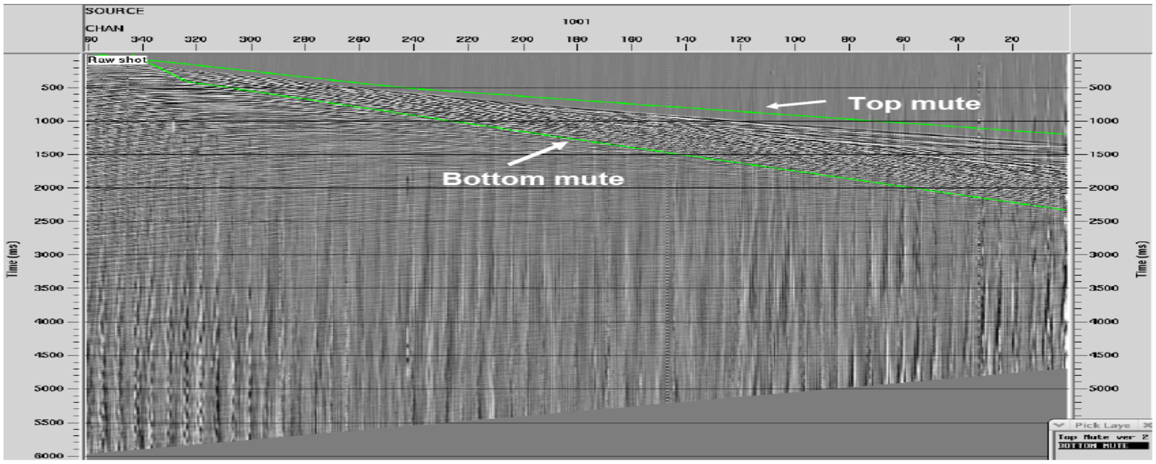

Figure 7: X-T Mute which Removes all Data Except in the Guided Wave Energy-Dominated Region of the Shot. Note the Effect of the LMO on the Shot – Events Appear to be Shallower.

Figure 8 shows a comparison of an input shot to the output of the guided wave removal process.

The difference plot of the input shot and its output after the guided wave removal is shown in Figure 9. The figure shows the extent of guided wave energy removed from this shot, and confirms that removal of the energy would improve resolution of the shallow data without affecting deep targets.

Figure 10 is a comparison of stacks of the de-noised dataset before and after the guided wave removal process.

The stack of the data after the guided wave removal shows clearer event continuity in the shallow section than the stack before guided wave removal.

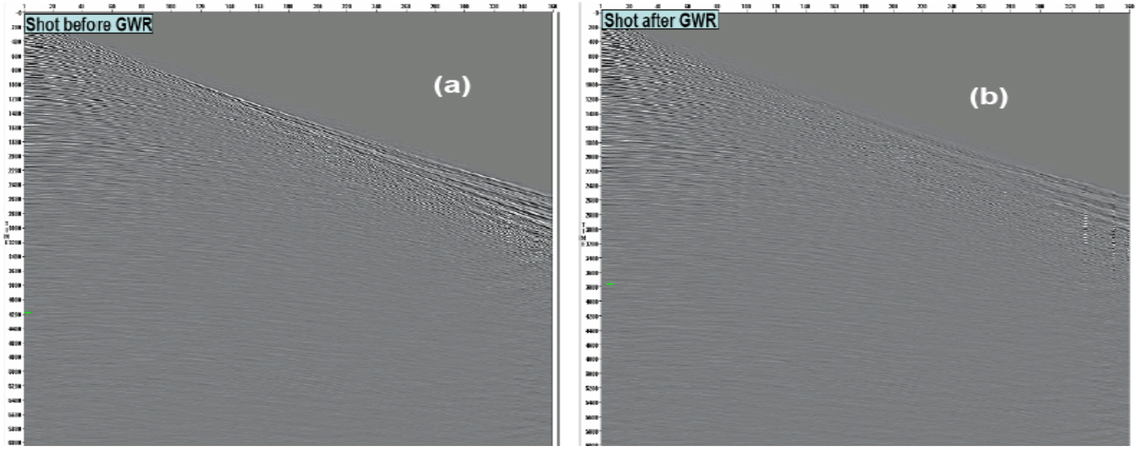

Figure 8: Shot Comparison before and after Guided Wave Removal (GWR). (a) Before (b) After.

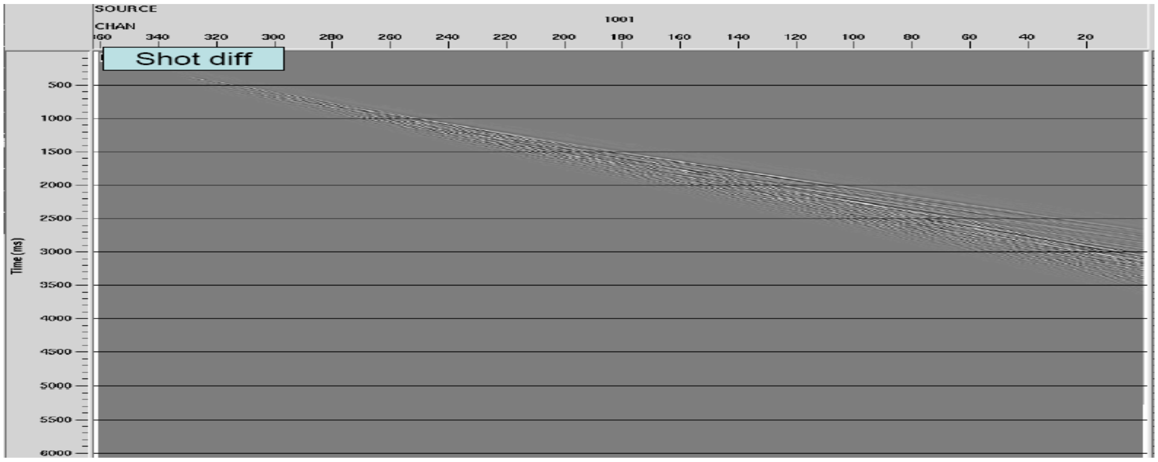

Figure 9: Shot Difference Plot before and after Guided Wave Removal, showing Modeled Guided Wave Energy.

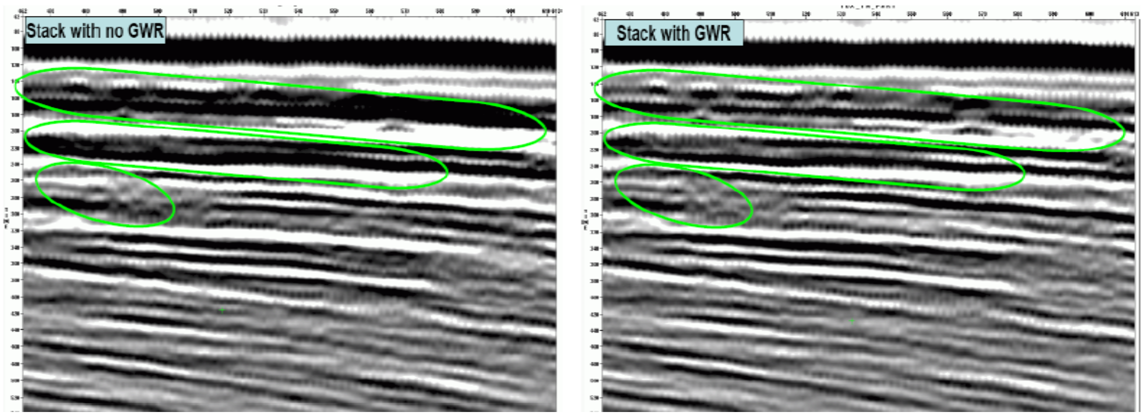

Figure 10: Comparison of Stacks before and after Guided Wave Removal. The Stacks are zoomed over the top of 600 ms.

CONCLUSION

In most cases of marine seismic data acquisition in the Niger Delta basin, Nigeria, long offsets are utilized. However, the data are often truncated to shorter offsets for processing due to their being heavily contaminated with noise at shallow depths, especially guided waves. Guided wave removal will be of interest to site survey investigation which relies on shallow seismic in decision making. Guided wave removal results in improvement in shallow seismic. The removal would also result in an increased AVO benefit.

REFERENCES

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