



## Improving Seismic Resolution through High Frequency Imaging

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### Summary

*It has always been a challenge to resolve thin beds through seismic imaging. Many of the recent hydrocarbon discoveries in India as well as in other parts of the world involve these types of reservoir pays. The conventional thinking assumes that only the beds thicker than one fourth of the dominant wavelength can be resolved. Higher frequency data can improve vertical resolution. The benefits of improving the resolution include better definition of pinch-outs, and resolving internal bed geometries.*

*This paper focuses on the application of a method that attempts to separate the signal from the noise while enhancing only the high frequencies from the existing seismic data. This method has helped in resolving the pays which are otherwise not resolved on normal seismic data. The method has already been applied successfully in many exploratory and development fields resulting either in new discoveries or enhancement of production.*

### Introduction

Resolving thin pays through seismic imaging is a big challenge for explorationists in the oil industry world wide, since the use of seismic started. Conventionally it is assumed that only the beds thicker than one fourth of the dominant wavelength can be resolved on seismic data. However, it is also observed that thin pay sands beyond the accepted resolution limit of seismic are distinctly visible on the seismic. That makes the difference between detection and resolution. In this case, determination of the sand thickness is not accurate despite their presence and depth being known.

Many of the recent hydrocarbon discoveries in India as well as in other parts of the world involve thin reservoir pays. The resolution of the pays is very important to ascertain the size of the discovery. Many attempts have been made in the industry to image thin beds by extracting higher frequencies from the existing seismic data. Techniques to enhance seismic frequencies are critical to achieve optimum thin bed resolution. One common method, spectral whitening, is a method that boosts the amplitudes of all frequencies within a certain pass band to the same level. The problem with this method is that it also boosts the noise level along with signal.

Depending on the signal-to-noise ratio, this may fail to extract the very information we hope to resolve.

This paper focuses on the application of a method that attempts to separate the signal from the noise while enhancing only the high frequency signal from the existing seismic data. This method has helped in resolving the pays which are otherwise not resolved on normal seismic data.

### Theory

This technique employs a branch of mathematics originally developed in Quantum Mechanics for treating technically unsolvable systems (undetermined equations) in combination with the mathematics that evolved for the decoding of encrypted messages. Similar techniques have successfully been applied much earlier in extracting higher frequency signals in optics and in the sound industry (as FM radio transmission) too.

This high frequency imaging technique is based on convolution of the broadband reflectivity series with the band-limited embedded wavelet through the process of polynomial multiplication (one sided convolution). The



method takes an alternative approach by using a one sided convolution as a matrix multiplication, resembling a process used to decode encrypted messages. Here the earth reflectivity is not viewed as being filtered but rather “encoded” within the lower end of the spectrum, which is still observable.

By treating the seismic trace in the vector domain, it can be manipulated to increase the high frequency signal without boosting the ambient noise. Consequently, the signal emerges from beneath the noise level and is recoverable. The resultant signal is very similar to the original “earth signal” or unconvolved reflectivity series and produces a reasonable estimate of the reflectivity series with greater resolution than the input seismic trace. Since the entire spectrum is encoded by the embedded wavelet, it is theoretically possible to regain frequencies up to Nyquist frequency on properly recorded and processed data.

The algorithm works to decode the seismic “message” and extract the acoustic reflectivity series directly from it. The operation is entirely mathematical with no wavelet estimation or other interpretive input applied. The primary requirement is a seismic trace with reasonably good signal-to-noise ratio.

The main objective of high fidelity seismic processing is to improve the seismic image in such a manner that the stratigraphic and structural interpretation is optimised, resulting in a robust interpretation involving thin reservoirs that were not clearly resolvable or visible on the original processed seismic data.

### Examples

The typical workflow used for High Frequency Imaging processing starting from prestack gathers (generally PSTM, now a day) involves velocity picking and smoothing, NMO, RADON, Residual NMO, Wave Number Filter and then the HFI™ algorithm. HFI™ is a trademark technology of M/S Geotrace Technologies Ltd. The workflow is summarized in figure 1.

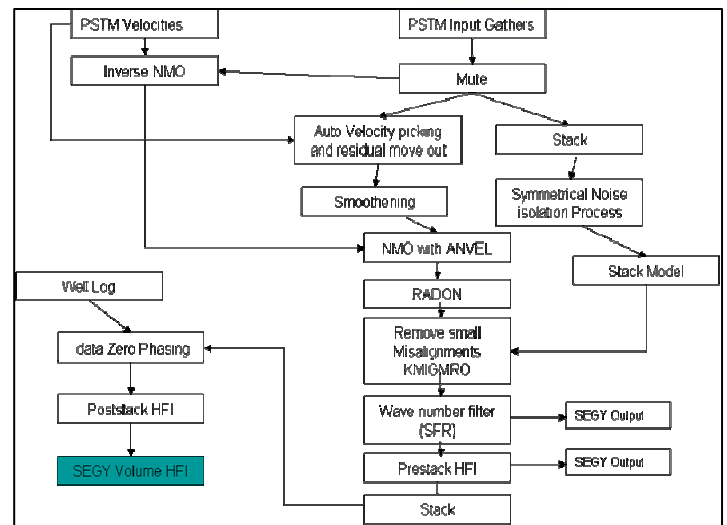


Figure 1 Typical workflow for HFI™ processing.

An example of gather conditioning and HFI is shown in Figure 2. The example highlights the benefit of gather conditioning before application of HFI. The first panel (2 a) shows the input gather data, which is having inherent Overburden Anisotropy, Multiples, Random Noise and Limited Bandwidth. The multiples have been reduced to an extent with application of RADON as shown in second panel (2 b). The third panel (2 c) shows the use of NMO, residual NMO and wave number filter. This has flattened the gathers and cleaned up the random noise. The last panel (2 d) shows gather after application of HFI which have a wider band width.

Seismic stack from the HFI processed gathers represent an overall improvement in imaging better understanding of the geology.



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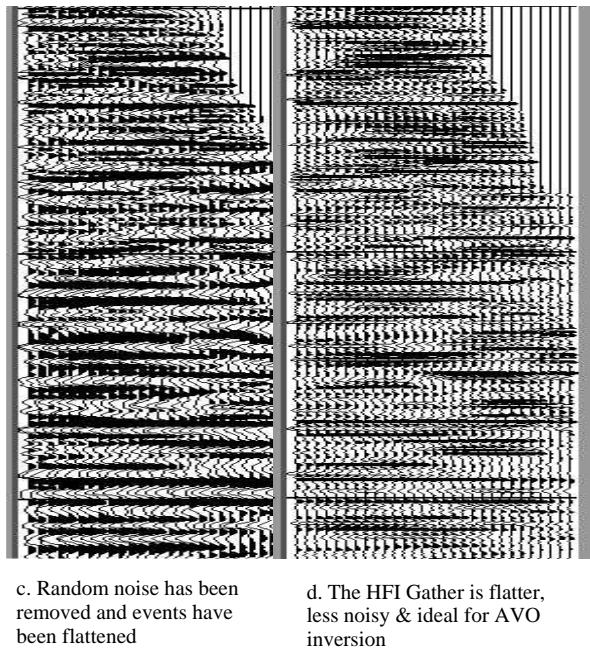
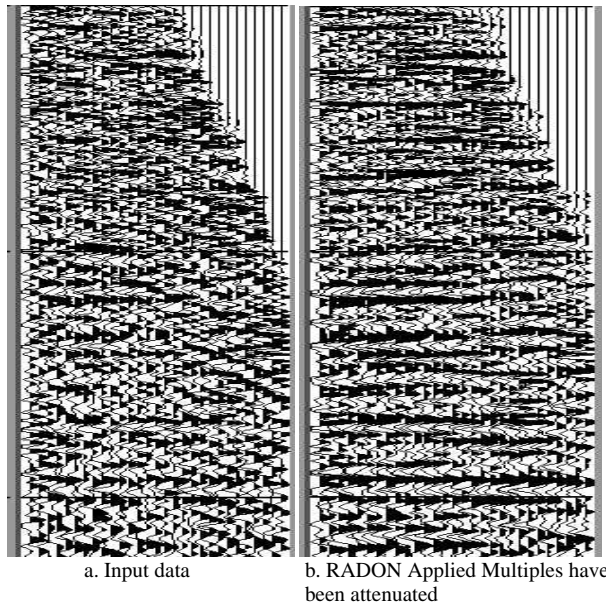


Figure 2. Different stages of gather conditioning and prestack HFI.

Frequency spectrum for the input seismic data and HFI processed data shown in Figure 3 illustrates that the post HFI extra bandwidth towards high frequency is available for better resolution.

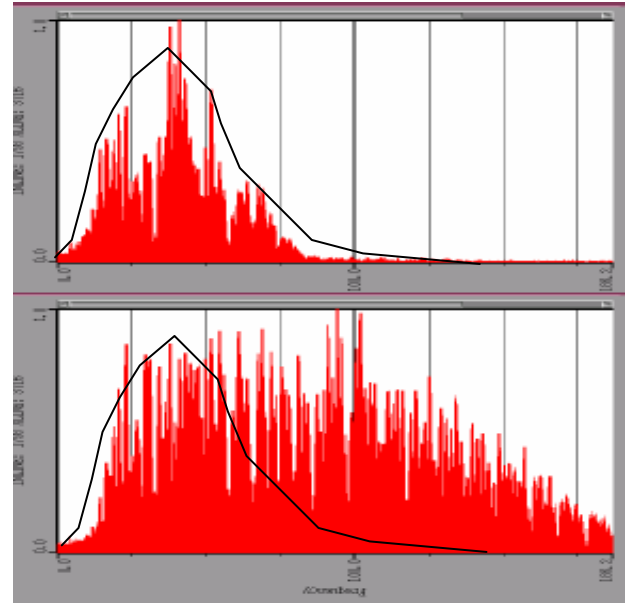


Figure 3. Pre and post HFI Frequency spectrum

A comparison of the input seismic sections and post HFI sections are shown in Figure 4 and Figure 5. In Figure 4, a thin pay sand of about nine metres is very well resolved on HFI processed section, where as the same was estimated of 20 metres based on normal processed data. On Figure 5, Various channel pay sands (left) are much better resolved on High Frequency Imaged section (right). The synthetic trace is overlapped on both the sections. The synthetic correlation on the HFI section is much better considering the higher frequencies contained. Although the input seismic data is also very clean, there is a marked difference seen on HFI section.

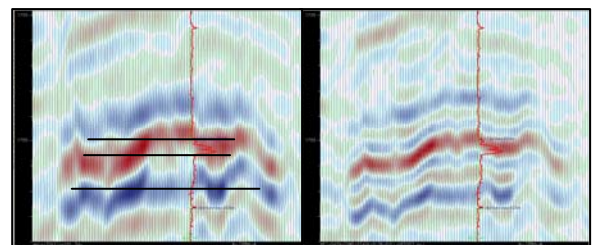


Figure 4 Normal processed section (left) and High Frequency Imaged section (right). Thin pay sand of about Nine metres is resolved.



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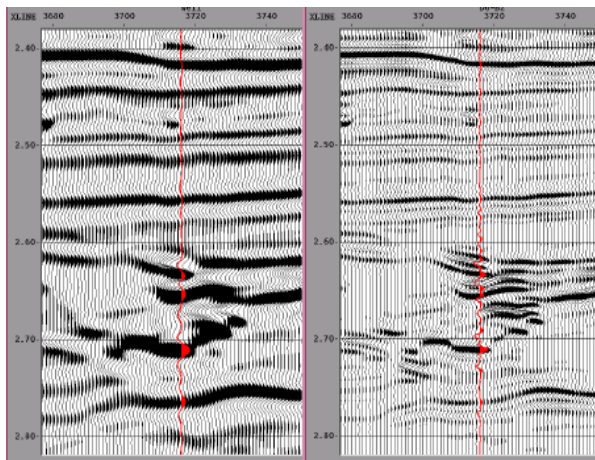


Figure 5 seismic section before (left) and after HFI.

HFI processed data help in the areas where the geology is very complex and heavily faulted. Normal seismic data, because of smearing by the lower frequencies can not accurately delineate all the faults. The HFI data improves the detection of faults. Coherency attributes calculated on the HFI data provide better demarcation of faults on time slices. Seismic section shown as example in Figure 6 shows the remarkable improvement in fault detection after HFI. This also indicates how high frequency data is important in complex fault interpretation. Same set of seismic sections are shown with and without fault interpretation.

Predicting results ahead of drilling is often a good measure of the success of any processing technique. So often along with interpreting thin beds, several rock properties at new well locations need to be measured in light of the High Frequency processing. The successful use of HFI data in prediction of lithology and fluid can only validate the process further.

The results obtained based on inversion and AVO analysis on HFI data and their subsequent validation give the confidence of not using any artificial mathematics for improving the frequency content.

One such example is shown in Figure 7. The normal seismic data indicated three prospective bright amplitude zones interpreted as hydrocarbon bearing (Figure 7a). The HFI processing (Figure 7b) and subsequent computation of AVO attributes (Figure 7c) indicate that all the zones are not hydrocarbon bearing. The distinction is very clearly brought out on HFI data.

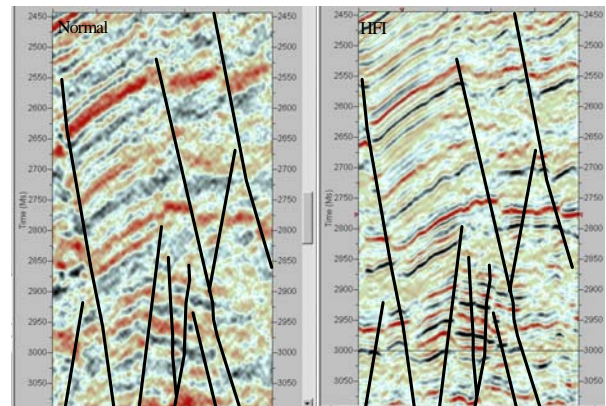
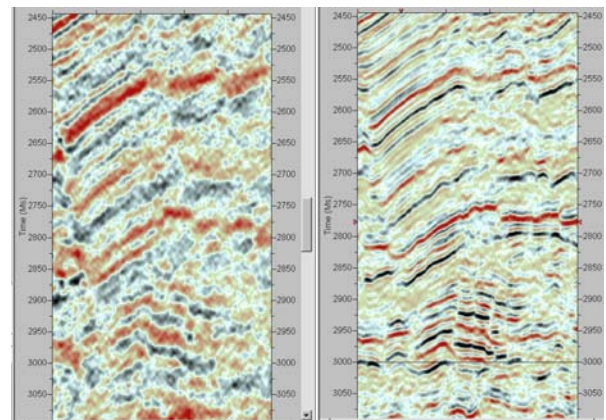
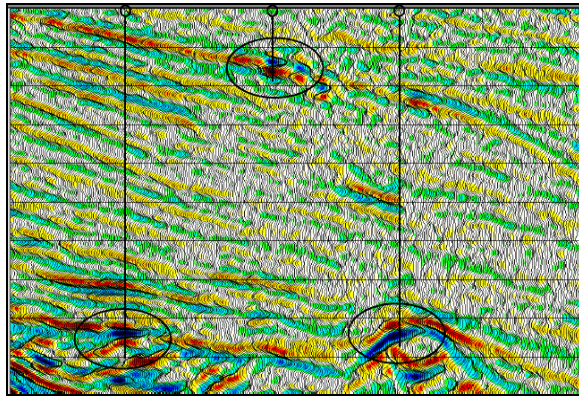


Figure 6. Normal seismic section (left) and HFI processed seismic section (right) shown with and without fault interpretation. Faults are seen visible even on normal section after a look on HFI section (right).

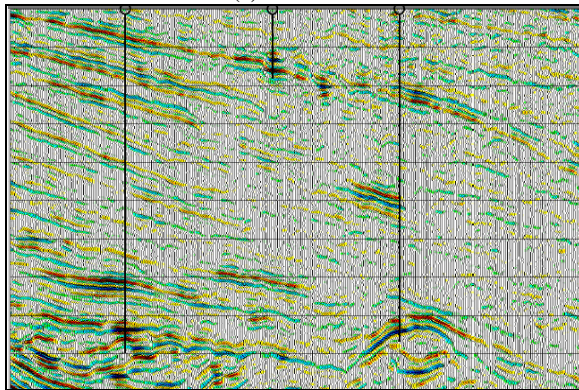
The high frequency imaging also helps in the areas of discrete and stacked reservoir bodies. As shown in the Figure 8(a), a well drilled up-dip in a producing reservoir resulted as a dry hole. High Frequency Processing helped in finding not only the limit of reservoir sand but also in locating additional a deeper pay sand that was confirmed there after. (Figure 8 (b) & 8 (c)).



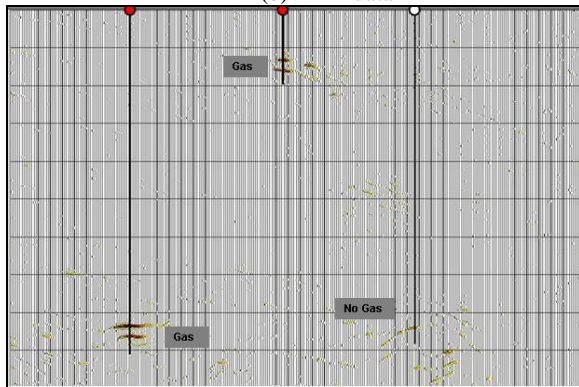
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(a) Normal data.

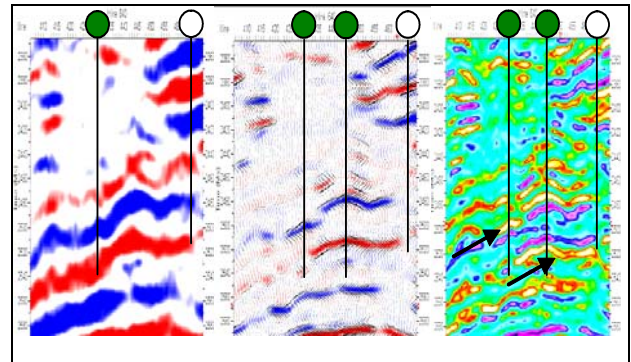


(b) HFI data



(c) AVO Attribute computed on HFI data

Figure 7 Input Seismic section (a), HFI section (b) and AVO attribute computed on HFI data(c).



(a) (b) (c)

Figure 8 An example of High Frequency processing with seismic inversion helps in identifying discontinuous pays and their limits.

### Conclusions

The new seismic processing technique used to enhance the frequency of the seismic is of paramount importance in the exploration and development of thin reservoirs. These reservoirs have been seen in numerous discoveries in many basins both onshore and offshore. If the seismic data has been acquired and processed correctly and there is sufficient well control to verify the results, then higher frequencies can be used to help resolve thin beds, small faults and detailed stratigraphy. High Frequency Imaging may not be as effective, however, in areas where existing seismic is noisy, with a poor signal to noise ratio and in areas with limited well control. As with most seismic processing methods, there is no one "silver bullet" that will achieve all goals, but this is yet another weapon in the seismic arsenal worth trying.

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#### **Acknowledgments**

The authors would like to express their gratitude to Reliance Industries Limited for providing this opportunity to present the paper. We are thankful to M/S Geotrace Technologies Ltd, for their processing support and for providing HFI results and images. Thanks are also due to all the colleagues who provided active support in preparing this paper.