Thin Beds: Seismic Analysis workflows to see what is barely resolved

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Abstract

Poor definition of thin beds when approaching the limits of seismic resolution is one problem we are often confronted with when interpreting reflectivity data, particularly when trying to distinguish the stratigraphic relationships between sedimentary packages being imaged.

The loss of higher frequencies due to the filtering effect of the earth (attenuation), and the impossibility to fully recover those frequencies during the processing stages severely affect our ability to vertically separate events in our seismic sections as continuous individual reflectors below the tuning frequency. Seismic resolution is paramount for looking at stratigraphic features that indicate internal bedding geometries, pinch outs and reflector terminations all that often fall close to or below the limit of seismic resolution.

In this paper we illustrate several techniques such as Frequency Analysis, Wavelet Geometry Analysis and Spectral Enhancement, which help identify thin beds and aid the interpretation of their extents in poorly resolved data.

Introduction

High frequency reflections are attenuated by the earth, so their influence in reflectivity data is reduced with depth, resulting in poor definition of thin beds. A thin bed is defined as any bed with thickness of less than $\lambda/8$, with λ being the predominant wavelength for the velocity of the layer (Widess, 1973). Some authors argue that the model used to derive that conclusion was not representative of the majority of real case scenarios, and that the theoretical limits of resolution are better than what Widess' model suggests (Chopra *et al.*, 2006). However, for the purposes of this study, we can continue referring to that definition, and we can add that for bed thicknesses of less than $\lambda/4$ (tuning thickness) we start to have interference between reflections and begin to lose our ability to easily separate these events.

Stratigraphic features such as pinch outs, internal bedding geometries and clinoforms often fall below the level of seismic resolution and this effect worsens as we move to deeper horizons as higher frequency needed to resolve these thin beds decrease with depth. Seismic analysis workflows can help improve vertical resolution and identify thin beds on seismic reflection data, which can in turn lead to more accurate stratigraphic interpretation.

Method

Frequency and Wavelet Geometry Analysis

Frequency Analysis and Wavelet Geometry Analysis can be used to enhance the interpretation of thin beds. Changes in the shape of the wavelet can highlight interference caused by thin and poorly resolved events in the data. Analysis of these changes using the Terrace attribute has been shown to produce trackable events that correspond to previously unresolved events. The Bedform and Instantaneous Frequency attribute can also be combined to identify thin beds

The Terrace attribute identifies thin beds by using a wavelet blocking algorithm which measures wavelet characteristics between zero crossings or inflection points along the wavelet, assigning each voxel between them, the peak amplitude, the thickness or the arc length of the segment between points (Figure 1). This means that interference events which disrupt the wavelet (but do not result in a distinct event) can be separated out as individual events.

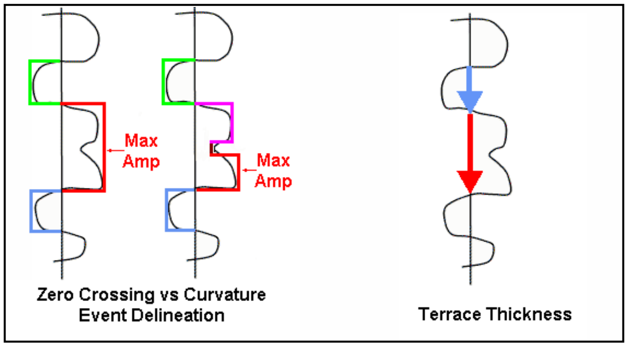

Figure 1 *Event delineation based on the Terrace Attribute.*

These interference events often coincide with the negative values seen in an instantaneous frequency volume which also correspond with events below seismic resolution (Zeng, 2010). These instantaneous frequency spikes can also be used in combination with a Bedform attribute.

The Bedform attribute extracts lineations along the minimum and maximum phase of the data and is therefore independent of both frequency and amplitude. This skeletonises the wavelet and simplifies it enabling the geometries of the facies to be interpreted with greater confidence and ease by making the shapes and geometries of the reflectors more visible. Bedform does not explicitly identify thin beds. However, when combined with the instantaneous frequency spikes the bedforms are extended, letting the location of thin beds and pinch outs to be identified and their geometry and relationships to be studied.

Spectral Enhancement

Spectral Enhancement can be used to improve the vertical resolution of seismic data by boosting the contribution of the high frequency component. Enhancement of frequency in many cases also leads to an increase in noise levels, along with the increase in resolution. We present an approach that selectively enhances the remaining high frequency signal by applying frequency-dependent, structurally-oriented noise filters in order to enhance signal but not noise. This results in improved vertical resolution of the data, and thus better imaging of thin beds.

The vertical resolution and localization accuracy of seismic data are dependent on the frequency content of the seismic signal. High resolution and accurate localization are associated with a high mean frequency and a large frequency bandwidth. The aim of the Spectral Enhancement workflow is to maximize the mean frequency and bandwidth of the seismic data by producing a “white” spectrum, i.e. one in which all frequencies contribute equally to the power in the signal. This is achieved by performing frequency decomposition on the seismic data to extract multiple band limited versions across the full range of the spectrum. Each frequency band undergoes a noise attenuation process specific to that frequency band, ensuring that noise is not enhanced along with the primary signal. Selective weightings are applied to each frequency band to enhance the contribution of the higher frequencies which contain the thin bed information. This results in a whiter frequency spectrum and an output volume that has improved resolution of thin beds.

Results

Example of Terrace and Bedform

The Terrace and Bedform attributes have proved to be particularly effective at highlighting stratigraphic features such as pinch outs and bedding geometries in order to aid in the interpretation of thin beds. Figure 2 shows how the Terrace Thickness attribute helps to identify clinoforms and also permits to interpret a pinching out event which is very hard to discriminate on the original reflectivity. Figure 3 shows how the Terrace Thickness attribute can resolve and extend a reflector which is only partially visible in the input data. Using the thickness measure is particularly effective at highlighting the location of this, and other pinch outs, as the thickness value abruptly changes from low (thin individual reflectors) to high (thicker merged reflectors) at the point of pinch out.

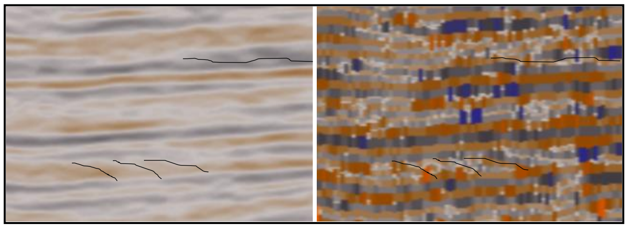

Figure 2 *Terrace Thickness Curvature (right) applied to the original reflectivity (left) data brings out a set of clinoforms and it also helps to clearly identify reflectors pinching out in the upper part of the section.*

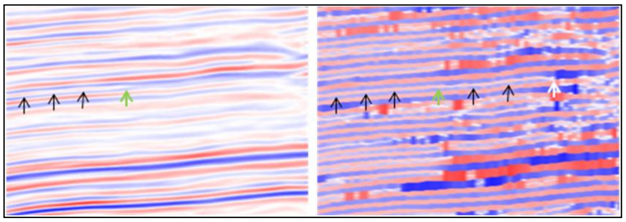

Figure 3 *The effect of the Terrace attribute (right) on the input reflectivity data (left). The black arrows highlight a peak event (red) which pinches out in the original data at the location of the green arrow. In the Terrace attribute the same peak is a continuous event much further along the section until the position of the white arrow.*

The Niobrara Shale from the Teapot Dome in Wyoming, USA is currently a popular exploration target in the Rockies (Figure 3). Like many other shale plays, it consists of a thin target interval and is often analyzed on data that were acquired for other targets. Application of these thin bed workflows can be applied to the post-stack data (no major reprocessing required) and can help resolve these thin reflectors and improve their lateral continuity on the seismic as well. This leads to a more accurate interpretation of the thin target zones.

The Bedform attribute combined with the Instantaneous Frequency can be seen in Figure 4 applied in the same section as in Figure 3. Even though it is not as effective at extending the pinch out as the Terrace attribute, it does help to identify areas where there are doublets or partially resolved features.

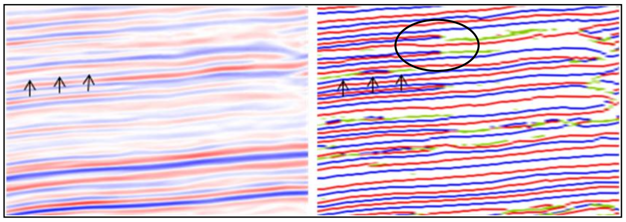

Figure 4 *The Bedform attribute (right) which skeletonises the peaks and troughs (red and blue) and identifies unresolved events (green lineations) by incorporating the instantaneous frequency anomalies. The circles show areas where there appear to be pinch outs, but the negative frequencies help extend the reflectors. This could be used to map locations where the beds reach a critical thickness (tuning).*

Example of Spectral Enhancement

The Spectral Enhancement workflow only enhances what is already in the data and the results can therefore be used with a high level of confidence. The results have been correlated with well data after the enhancement was complete so that the well data did not influence the workflow applied. The results show that the reflectors newly visible due to the increase in vertical resolution show an improvement in the tie with the gamma ray log shown (Figure 5).

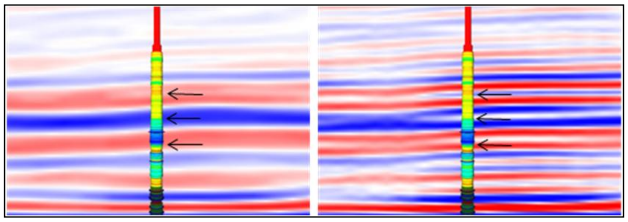

Figure 5 *The seismic reflectivity data before (left) and after (right) application of the Spectral Enhancement workflow. The log data shows the gamma ray response with red indicating low gamma ray and blue indicating high gamma ray. The black arrows indicate areas where reflectors are only visible after the Spectral Enhancement and which correspond to a change in the gamma ray response.*

The interbedded sandstones and shales shown in Figure 5 are from Teapot Dome in Wyoming, USA. The spectrally enhanced data provide a better tie to the gamma ray log data and also produce a clearer picture of the stratigraphic relationships between these beds (note increased complexity at lower left of figure - originally it appears to be one continuous reflector, now seen to include multiple reflectors and possible pinch outs). This can aid in the identification of not only thin beds, but also subtle stratigraphic traps.

Conclusions

With the need to investigate ever more subtle and thin features, the ability to resolve thin beds and to interpret the true extent of pinch outs becomes more important. Attributes are only effective if they can aid or improve an interpretation; the unique attributes presented in this study achieved that goal when applied to the interpretation of thin beds. The Spectral Enhancement and Terrace volumes enabled the interpreter to tie the reflectivity data with the well logs with a greater degree of accuracy. The newly resolved reflectors in both volumes improved the accuracy of interpreted horizons, and enabled auto-trackers to extend the events laterally in a geologically meaningful manner.

The Bedform combined with the Instantaneous Frequency provided additional amplitude-independent information on the extension of thin beds. This technique has been applied successfully to data from many different geological settings and geographical areas, both onshore and offshore, and has proved to be consistent in the quality of the results obtained.

Acknowledgments

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