

Seismic Resolution: Thinner than first believed

Thomas A. Pierle* Schlumberger

Summary

Ever since the time of Widess(1973), seismic resolution of thin layers was limited to measuring the length of the wavelet. The idea that the waveform remains stable within less than a $\frac{1}{4}$ wavelength has been apart of the seismic literature since 1973. Building on these foundations, Greg Partyka(1999) furthered our understanding by incorporating discrete Fourier transforms (DFT). This process inferred below these limits by using the tuning affect of frequency. Most of today's geophysicists believe a $\frac{1}{4}$ wavelength is a barrier and thickness of sediment cannot be determined below this limit but inferred. The ideas contained in this paper state we can go beyond this barrier. We can determine the thickness of these two interfaces by analyzing changes of the slope on the wavelet's side lobes when the wavelets of these two interfaces merge, and bringing us much closer then we ever considered before.

Introduction

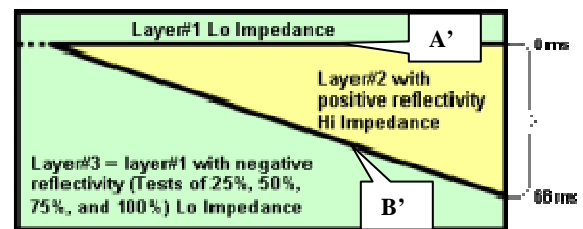
Prior industry belief purported in M. B. Widess (1973) stated that $\frac{1}{4}$ wavelength was as close as we could get to determining "How thin is a thin bed". It was and still is today a geophysical principle regarding the limiting resolution we can expect in determining how thin we can resolve bedding layers from seismic. Many of us believe this to be true as it is evident in most of the present day literature that quotes Widess(1973) and permeates the research houses of academia and the seismic interpretation industry. There is a problem with the premise that the seismic measurement of wavelength is key to measuring seismic resolution and that the limit of resolution is a $\frac{1}{4}$ wavelength. Partyka's(1999) ideas hinted at the possibility that we might be able to go beyond this limitation. He focused in on frequency's ability to tune in on the layer thickness. The tuning affect brought about changes to the amplitude and thus inferring a layers thickness in conjunction with the frequency that detected it. There are other tuning affects on the wavelet that help use determine the thickness of the bedding.

There is a change to the wavelet that is revealed by measuring the slopes on either side of the maximum lobe. These changes can be seen by using a simple derivative or directly measuring the maximum changes of the slopes between 2 samples or data points. The derivative is used in this paper to measure these slopes and demonstrates that a $\frac{1}{4}$ wavelength is not the limiting factor. The form of the wavelet continues to change below a quarter wavelength threshold, but only the wave length remains constant. The

measurements of the slopes reveal that the waveform does not stabilize but continues to deform the slopes up to the very last sample or data point. This presents to the geophysicist a method to see beyond the previous resolution limits predicted by Widess(1973). Using this methodology the interpreter can now detect hydrocarbon deposits that may be contained in thin bedding layers whose thickness is less than the one quarter wavelength threshold. A geophysicist can now see with greater clarity the refining upward and downward sequences where oil dominated stratigraphic layers are hidden away; (i.e. channels, splays, talus slopes on reefs, eolian, turbidite deposits, etc). Here is the opportunity for the interpreter to discover and detect economically important formations by utilizing this methodology in the areas of software, processing, and interpretation of the seismic data.

Theory and Methods

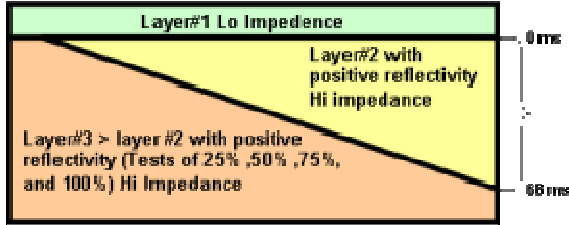
In revisiting Widess(1973) we start by using his example. (Model 1) is the Widess wedge which is a positive reflection boundary A' being joined by a negative reflection boundary B'. The process begins with applying a zero phase 20 hertz Ricker wavelet to each of the reflectors. The first application of the wavelet begins at the far right side of the graph where the reflectors are at their maximum separation of 68 milliseconds, Every 2 milliseconds of separation the wavelets are applied until the two wavelets merge together on the left and vanish at the tip of the triangular wedge. Further study included a modification of the layer#3 below the wedge by varying the strength of the reflective boundary B' by -25%, -50%, -75%, and -100% of the wedges reflectivity. The addition of these changes only strengthened the final conclusions.



Model 1: Widess Wedge: The convergence of a positive reflector A' and a negative reflector B' over a 68 ms interval at 2ms steps

Seismic Resolution

There are two models used in this study. The second (model 2) which is not discussed in depth in this abstract was also used in the study. The model contains the confluence of two positive reflectors A' and B' as they approach each other until the lower one is truncated against the other. The layer#3 varies its positive reflective boundary by similar increments of +25%, +50%, +75%, and +100%.



Model 2: The convergence of two positive reflectors over a 68 ms interval at 2ms steps

Measure the Slope:

The following details the results of using (model 1) to demonstrate the changes in the slope, which come from either side of the primary lobe. The process examines the interference occurring between the secondary reflector B' as it approaches the primary reflector A'. Using the derivative we can measure the slope and not only infer thickness but measure it. In this case the limiting factor is the sample rates not the frequency, amplitude, or wavelength. In order to evaluate this method the user will need to extract a known wavelet from the seismic to compare its slope, time at a slope, or amplitude at a slope from simple modeled responses to the seismic section.

We return to the Widess wedge model, and compare the results of the changes in slope on either side of the primary lobe of a wavelet (Ricker). In Figure below from Sheriff we have a standard definition of the Ricker wavelet used.

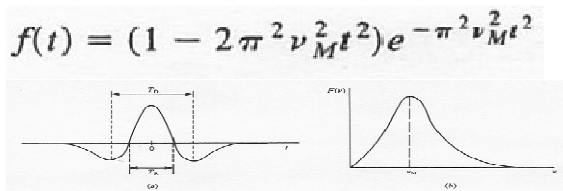


Figure 1: Ricker wavelet equation

Applying a derivative of the equation above will help us obtain the slopes we need at the slope position on the Ricker wavelet in (Figure 2). It is these changes in slope

that allow us to come far closer to the resolution than the accepted wisdom of today.

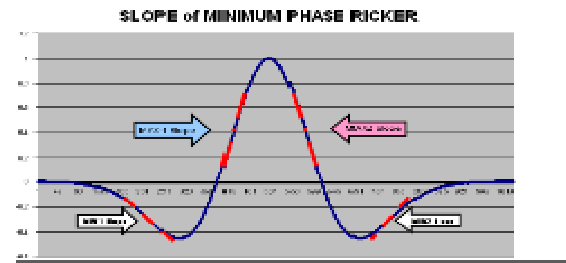


Figure 2: Ricker Wavelet with the slopes marked

The method is to find the derivative of the Ricker wavelet represented in pink in (figure 3) and see what happens to the slopes of the primary wavelet as the secondary wavelet begins to constructively interfere with the primary waveform

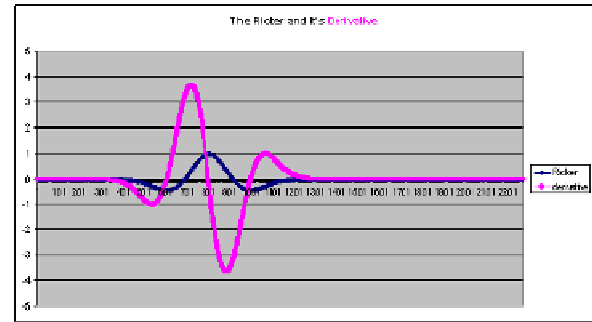


Figure 3: Graph of Derivative of the Ricker and the Ricker Wavelet. Note: For Graphing purposes the Derivative is 1/3 its real value.

In the (figure 4) below is a graph of the Ricker equation (Dark Blue) used on two reflectors in (Model 1). In the figure the two reflection coefficients of A' and B' (Noted in Model 1) and their resulting 20 hertz wavelets are progressing from a distance of 68 milliseconds at 4 milliseconds intervals until they converge.

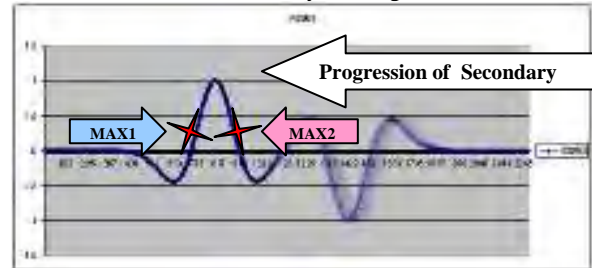


Figure 4: Progression from Right to Left of the Ricker

When they begin to interfere constructively with each other a dramatic change will occur to the two opposite slopes of

Seismic Resolution

the primary waveform. The first changes begin with MAX2 and then MAX1 as these two wavelets become closer and the interface narrows. These changes continue to occur beyond Widess $\frac{1}{4}$ Wavelength. Looking at the Ricker alone will not dramatically reveal these changes because the changes are subtle. The use of the derivative easily exposes these changes in slope, but the direct measurement of slope from samples or data points also show a dramatic affect.

(Figure 5) represents the changes to the slopes as the wavelets approach each other from the right to the left side of the graph. The dark blue curve is the Ricker wavelet and the pink curve is the derivative. By examining the derivative the positively sloping side of the wavelet starts to diminish at a slower rate than the negatively sloping side. The dramatic change to the negatively sloping side is due to the two reflections coefficients and their respective wavelets coalescing.

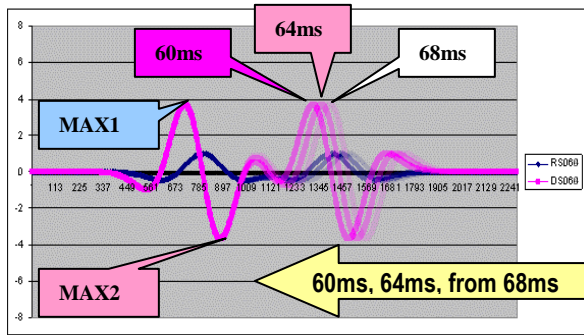


Figure 5: Movement of B' toward A'

The Change Begins

The closer the secondary reflection moves past the Widess point the greater the change is evident. The two slopes in the (figure 6) begin these changes starting at 32ms, 28ms, and 24ms of separation as the reflections progress toward each other.

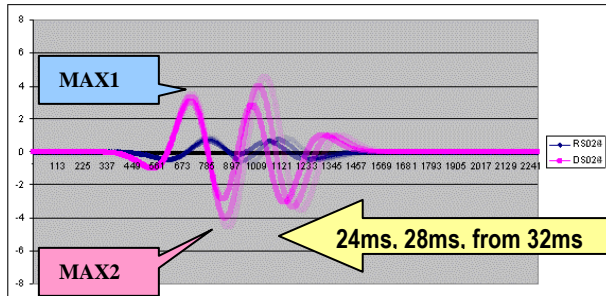


Figure 6: Changes occur with MAX2

In the (figure 7) at 20ms, 16ms, and 12ms the slopes begin to demonstrate the changes that surround the Widess Limit. These measurements are from the slopes approaching the 12.5 millisecond limit, which is a $\frac{1}{4}$ wavelength of the 20 hertz Ricker wavelet. The last set of slopes reveals change not only in the slope but its relative position in time.

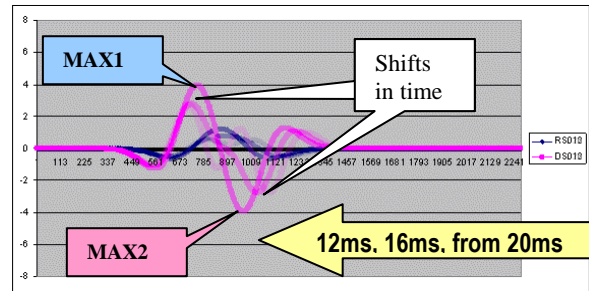


Figure 7: Changes at Widess 12.5 ms

Changes after the Widess Limit

In the last few milliseconds the greatest changes to slope take place after the Widess boundary of 12 milliseconds is breached.

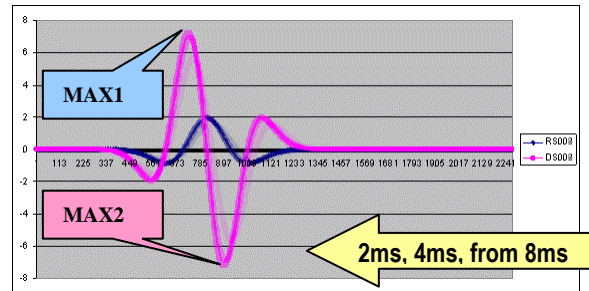


Figure 8: Changes After a quarter wavelength

In (figure 8) at 8ms, 4ms, and 2ms the slopes begin their greatest change after the Widess boundary of 12.5 milliseconds. The pink curve that represents the derivative of the wavelets as they converge demonstrates this dramatic change up to the point of merger. This can also be seen using a positive secondary reflector that was in another part of this study and alluded to with (Model 1).

In (figure 9) is a measurement of each of these changes in slope. The light dashed horizontal blue line and the dashed horizontal red line represent the wavelet with no influence from the other reflector. The dark blue solid line of Max1 and the pink solid line of Max2 show changes up to and including the last sample before merger. In the far right is the 68 millisecond separation in the model. Each data point to the left represent a slope measurement as the two

Seismic Resolution

Phone: 86 10 5884 6160

reflectors approach each other in 2 millisecond intervals; at the far right the two reflectors join together. Notice how changes still occur to the slope of the wavelet even past the Widess $\frac{1}{4}$ wavelength of 12.5 milliseconds.

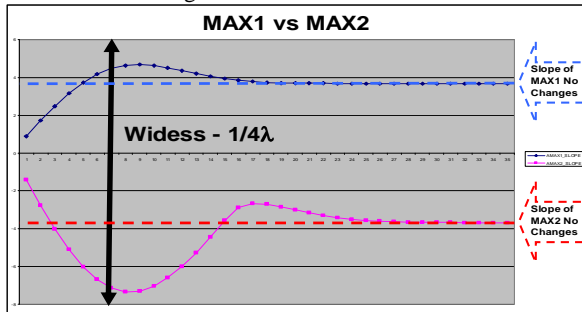


Figure 9: Graphed changes to slope MAX1 and MAX2

Conclusions

The ability to recognize this fine a detail changes how we view seismic resolution from now on. The geophysicist now has the potential to discover thin beds below the resolution predicted by Widess. Interpreters can map the fining upward and downward sediments generated by streams, rivers, and bay deposits, turbiditic flows, and the fragmented remains of talus slopes generated by wave action against reefs. All these geologic processes produce this kind of signature response which is hard to detect by today's algorithms. For the oil industry this is where most of the remaining oil and gas reserves are to be found. The process of examining the changes in slope allows the interpreter to see closer than ever before to the finer details of the reservoir and the stratigraphic nature of the interface.

Acknowledgements

It is hard to stand on the shoulders of giants like Widess, Pradyka, and Sheriff; their inspirational writings cannot be mentioned enough.

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Walter E. Brown, PH.D. Project Engineer IESX Interpretation Schlumberger/GeoQuest Houston, TX. Phone: 713-513-2125

William D. Randolph Principle SW. Consultant Schlumberger/GeoQuest Houston, TX. Phone: 713 513 2275

Randoph E.F. Pepper Geoscience Advisor Schlumberger Beijing, China

Seismic Resolution

EDITED REFERENCES

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