[GC]Advances in Spectral Decomposition and Reflectivity Modeling in the Frio Formation of the Gulf Coast*

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General Statement

The seismic interpreter now has the use of a simple tool to aid in the search for hydrocarbons by allowing individual target reflection events to be spectrally analyzed and compared to gas response modeled from well logs with and without pay. The seismic reflection is then decomposed to spot a positive gas response.

Until now, spectral decomposition techniques have used windowing methods to decompose the seismic trace into its constituent frequencies -- but these methods:
- Mix reflection events and introduce unwanted artifacts into the data.
- Restrict the usefulness of spectral decomposition to the inspection of single-frequency maps to try to relate amplitude maxima to geologic events.

Recent advances in techniques have yielded a method that does not use windowing to decompose the trace: The Instantaneous Spectral Analysis (ISA) method uses a wavelet transform technique to produce single-frequency reflection events that are accurately localized in time. Each full-spectrum reflection can be visualized and analyzed at its uncontaminated single-frequency equivalents.

Frio Seismic Bright Spot

Figure 1 shows a high amplitude reflection characterizing a Frio reservoir in which gas is trapped stratigraphically due to a sand pinchout. The Frio sand, which is about 68 feet thick, is shown in Figure 2, with the well log synthetic seismogram tie. Notice that the gas pay has a low velocity compared to the brine-filled part of the sand at the base. This adds significant strength to the reflectivity of the sand body, causing it to be seen as a high amplitude reflection, the classic bright spot.
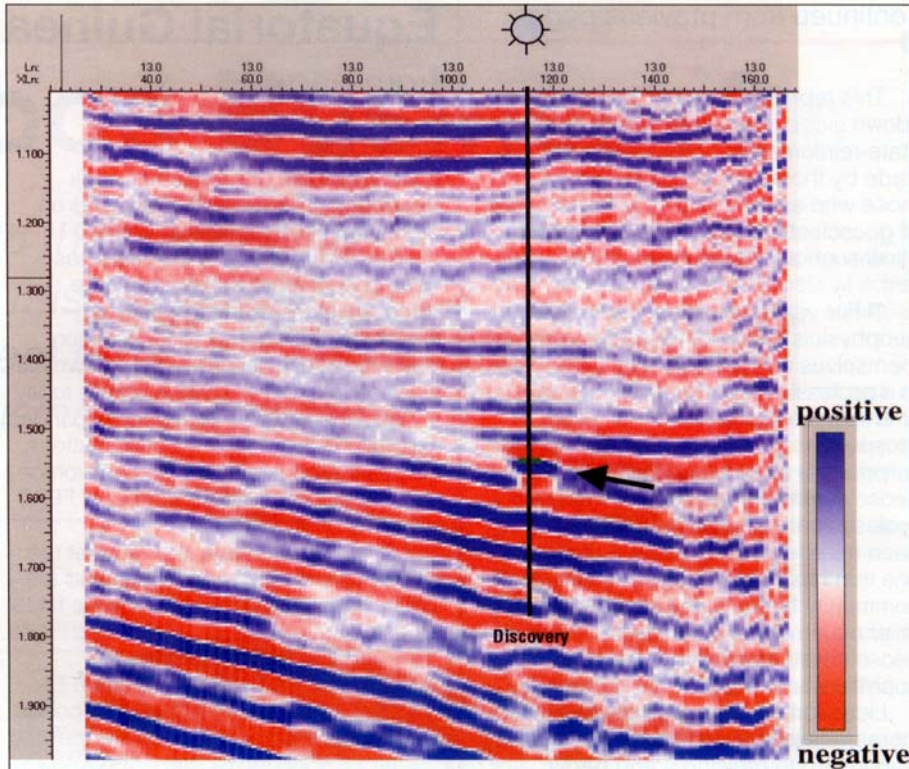
Figure 1. A Frio reservoir in the Gulf Coast. Bright spot pay sand shown by high amplitude at arrow.
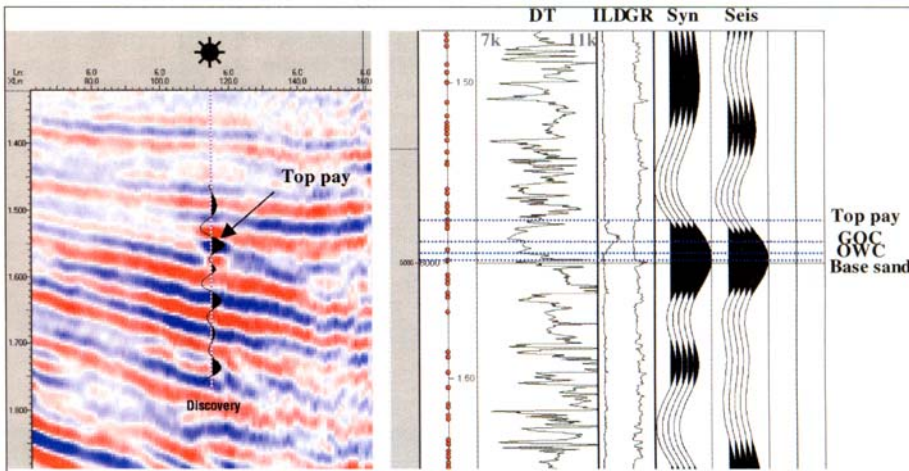

Figure 2. The synthetic tie to the seismic and the log data showing the Frio pay sand.

What cannot be seen is the behavior of the individual seismic frequencies; i.e., what effect does the hydrocarbon charge make on the amplitudes of each discrete frequency. Because the ISA technique allows uncombined reflectivity to be examined, as no windowing is used during the calculation, the pay reflectivity can be isolated and studied. This new approach allows one to show the reflection's response to the hydrocarbon charge at various frequencies via a "frequency gather," as shown in Figure 3a.The display shows increasing frequency to the right with the strongest amplitudes in warm colors.

This is very similar to the familiar AVO gather -- except where adjacent traces represent the reflection's response to changing offset in the AVO gather. Here each trace represents the reflection's amplitude at a single frequency, or amplitude versus frequency (AVF). The anomalous response caused by the pay clearly can be seen as a very high amplitude with a peak frequency that is shifted toward the high end of the useable bandwidth. When the process is run on the entire seismic line, single-frequency panels are produced, as shown in Figure 3b and 3c. Note that at 10 Hz, the pay does not exhibit high amplitude, while at 36 Hz, it is one of the brightest events on the section. The Frio bright spot on the 36 Hz seismic line in Figure 3c agrees with the frequency gather shown in Figure 3a. The pay has relatively little energy at 10 Hz, but at 36 Hz, it is one of the few remaining events to have high reflection strength. This is in contrast to the strong events centered between 2.0 and 2.1 seconds at the wellbore. They have visually lower frequency and their strongest reflection amplitudes are closer to 10 Hz. When viewed as a frequency panel movie, the changing contrast becomes very striking.
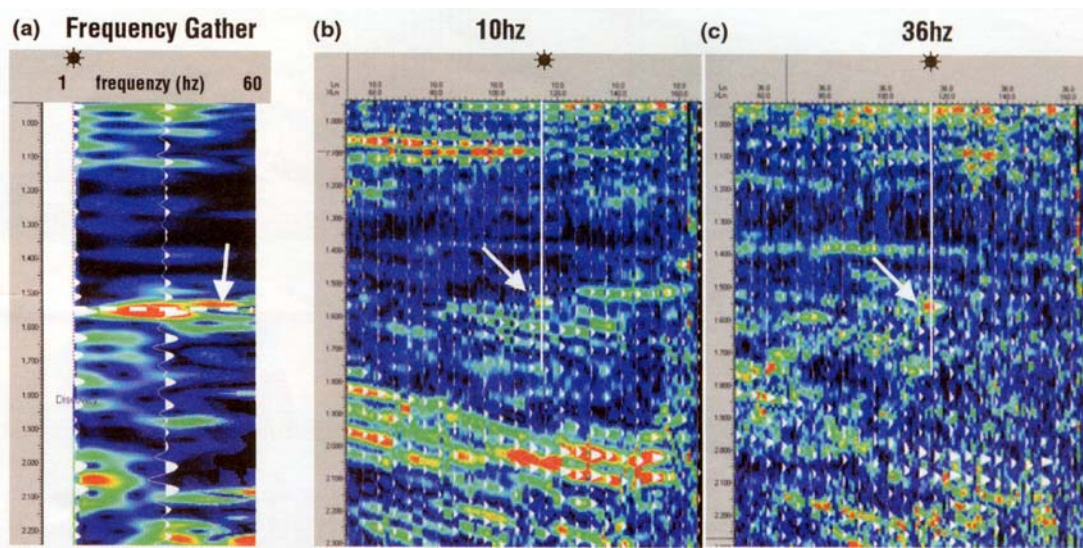

Figure 3a. Frequency gather at the wellbore with the full-spectrum trace as an overlay. The gather shows increasing frequency to the right with warm colors for higher amplitude. Frequency normalization has been used to remove the seismic wavelet. Top of pay zone shown at the dotted white line. Figure 3b and 3c. Frequency panels of the seismic line shown in Figure 1 at 10 Hz and 36 Hz.

3-Dimensional Map Displays

When the ISA process is applied to cubes of seismic data, the results are a series of single-frequency cubes that are loaded onto the workstation and interpreted. Figure 4 shows four slices from the frequency cubes on the pay horizon:
- The first is at 24 Hz, that frequency which has a minimum amplitude response for the area surrounding the pay on strike (indicated by the arrows).
- The second is at 32 Hz, or near the maximum of the amplitude response at the pay.

- The third is at 47 Hz, which shows a minimum in the amplitude spectra of the pay as seen on the frequency gather at the arrow.
- The fourth at 58 Hz shows the reflectivity of the pay close to background.

As Figure 4 shows, the pay is acting completely different than the surrounding sand when viewed at discrete frequencies. This is even more apparent when all the frequency maps are viewed as a movie. The pay has a distinctly different dynamic frequency response than the background because the hydrocarbons have changed the reflectivity of the reservoir.
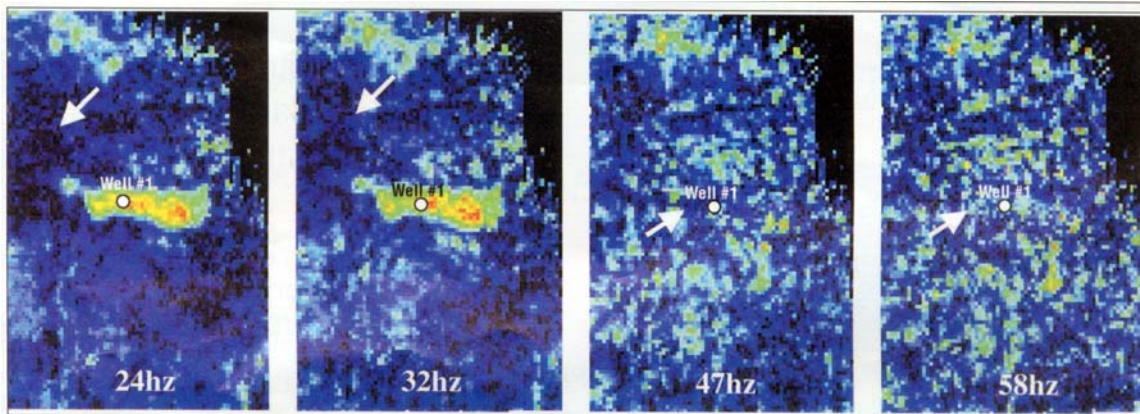

Figure 4. Horizon amplitude maps at four frequencies. Subtle amplitude changes can be seen between 47 and 58 Hz at the arrows. Note the amplitude shadow at 47 Hz associated with the bright amplitude at 32 Hz due to gas pay. This is part of the reflectivity signature of the hydrocarbons. The amplitude shadow at 24 Hz at the arrows is indicative of sand with no hydrocarbons.

Well Log Modeling Confirms Frequency Response

To understand the seismic response, let us examine the detailed reflectivity obtained from well logs. Figure 5, which shows the modeled response using sonic and reflectivity logs, explains this difference in dynamic behavior. The only change between the two curves is that the velocity of the Frio pay zone has been replaced by a brine-filled sand velocity. The local reflectivity of both cases has been analyzed for spectral content and is shown in the graph of amplitude vs. frequency. One can clearly see that the hydrocarbons are responsible for the high amplitudes at and around 32 Hz and the associated dimming at 47 Hz. They also are responsible for subtle changes in reflectivity at other frequencies. Similarly, the amplitude low at 24 Hz in the curve with no hydrocarbons can be seen in the maps in the area surrounding the reservoir.

Spectral Results

The sand that produces in this Frio field is present along strike, pinches out updip, and is not present downdip. If the observed anomalous reflectivity were due to the sand thinning, then sequential frequency maps should show a feature "walking" away from the

field; this is not seen. The amplitude maxima of the reservoir at 32 Hz and the following minima at 47 Hz, plus the amplitude minima at 24 Hz in the brine-filled area adjacent to the reservoir observed in the maps, are explained by the spectral modeling.
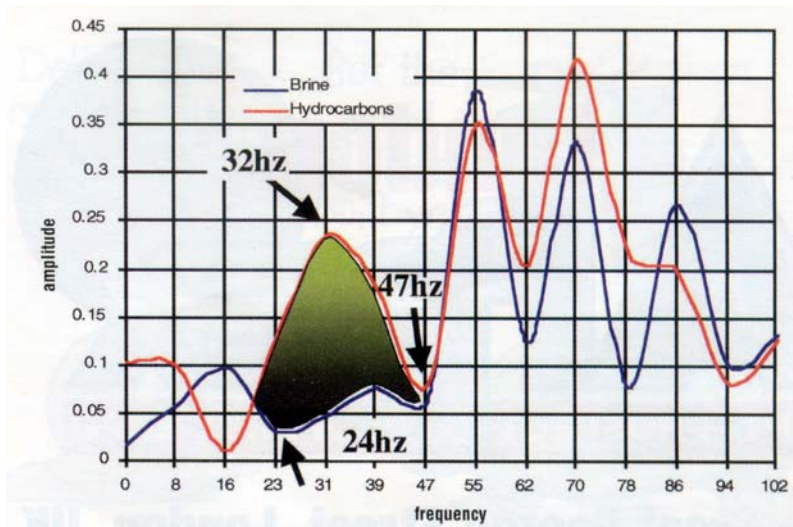

Figure 5. Simple fluid substitution via velocity showing reflectivity below 50 Hz is dominated by the presence of hydrocarbons. Hydrocarbon reflectivity shown in shaded area and exhibited at 32 and 47 Hz (see Figure 4).

There could be other geologic conditions that would cause the reflectivity of this reservoir to more closely resemble the brine case. A decrease in porosity, for example, would bring the reservoir velocity closer to that of a brine-filled sand. In the case of very low porosity, the velocity of the brine and hydrocarbon-filled sand would be much closer, and the difference in reflectivity would be much smaller. Thus, the pay would be harder to discriminate spectrally.

The technique illustrated here will work best in sands with high porosity and permeability, but it has been employed successfully in consolidated sands and carbonates in a variety of depositional environments and depths. Others uses include:
- The display of attenuation and low-frequency shadows for direct hydrocarbon indication.
- The analysis of subtle thickness or porosity changes, which result in tuning frequency changes.

Because the input to this process is simply the migrated data, the better the data quality, the more accurate the results of this method.

Conclusion

A new type of spectral decomposition has been shown to be useful as a simple tool to isolate the reflectivity of hydrocarbons in a Frio sand reservoir using migrated data. By viewing frequency maps as a movie, subtle changes in frequency become dynamically visible. The observed unique reflectivity of the reservoir due to the presence of hydrocarbons has been confirmed with its theoretical reflectivity calculated from well logs. The ISA method of spectral decomposition does not mix the reflections in time, thus allowing the investigation of reflectivity from individual seismic events.

This method shows great promise to become another valuable seismic detection tool in the search for hydrocarbons.