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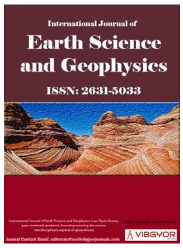

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Spectral Decomposition- A Better Understanding

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Abstract

This article presents a review of the algorithms used in the spectral decomposition of seismic data. This process involves transforming a non-stationary signal in time/space from the time/space domain to the frequency domain. The frequency domain representation reveals many important features that are not evident in the time domain. Over the years, the spectral decomposition of seismic data has evolved from a tool for stratigraphy analysis to a direct hydrocarbon indicator (DHI) technique. Seismic interpreters primarily use this technique. Additionally, as a DHI, it is an excellent tool for minimizing uncertainty and avoiding drilling dry holes.

Introduction

Since the start of this industry, companies have been affected by drilling dry holes. This is very costly to companies each year. It has always been a risk, and it is considered risky for investment. For this reason, the industry updates its technology every year to eliminate and minimize risks and implement success more often.

Some of these techniques and new technologies are considered important steps to exploration and production of hydrocarbons. Such high-end technologies improve all existing methodologies used. One of them is called Spectral Decomposition, which is the motive of this article. The aim is to explain how it works and optimizes its use, as well as providing a comparison of the spectral decomposition methods and their principal transforms with geophysical applications onto Spectral Decomposition (called Specdecomp).

When somebody hears about Specdecomp, they commonly think about mathematics and signals analysis. However, one does not need to be a mathematician to understand this application, only the understanding of a few concepts is required. Before starting with a spectral analysis, a seismic data review is recommended [1]. A technique commonly used is called High Frequency Imaging (HFI), applied to seismic data, a better way to enhance frequencies and extract seismic bandwidth than conventional deconvolution programs (recovers the high-frequency encoded in the lower end of the spectrum). One issue to be considered is that seismic data needs to be processed with amplitude preserving and balancing (i.e., offset varying amplitude balancing, noise attenuation, preserving good S/N ratio, pre-stack Kirchhoff's methods fine migration or common-azimuthal wave form processing, a detailed velocity analysis). This is the new ideal, which was before not possible.

Seismic data is typically limited to about 30 or 50 Hz of usable frequencies. Seismic acquisition and

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migration programs have begun to enhance the spectrum of frequencies, which is a powerful tool for detail in interpretation. Some techniques can yield upwards of 100 Hz of valid data; this process aids in resolving subtle structural and stratigraphic events and obtains better resolution. This allows the identification of very thin strata, as thin as 10-to-15-foot thickness. Once yielded, the interpreter can generate attributes (i.e., such as Relative Acoustic Impedance, Q, RAI, helps to delineate sand bodies and fluids; semblance, instantaneous phase and instantaneous frequency, texture attributes so forth) and determinate which are best to use on any determinate situation for a better interpretation and understanding of reservoir analysis.

Specdecomp, Initially

Spectral decomposition (Specdecomp) was discovered in the 1970s but was introduced to the industry in the late 1990s by Greg Patryka, Castagna, and others [2,3]. Spectral decomposition is now becoming a valuable post-processing and preprocessing technique for investigating complex hydrocarbon plays and stratigraphic characteristics. Typically used in thin-bed stratigraphic details as a hydrocarbon indicator, Specdecomp is based on the concept that a thin-bed reflection has a unique spectral response in the frequency domain. Spectral decomposition algorithms (such as DFT, ST, CWT, TFCWT, Matching Pursuit, etc.) are applied to seismic reflection data to break down the seismic signal into its frequency components (see Figure 1). This technique provides higher resolution at low frequencies and higher time resolution at higher frequencies.

Often, hydrocarbons show low frequencies, and thin beds can be resolved with enhanced time resolution at higher frequencies.

Initially all of these technologies were based on classical Fourier and Cohen transforms which gave the first steps to develop Specdecomp as we know it.

The output is a tuning cube, defined as a series of amplitude or phase maps tuned to specific frequencies. The resulting amplitude spectra can be used to calculate bed thicknesses in the time domain, while phase spectra help to define lateral stratigraphic discontinuities. By examining the amplitude and phase maps at various frequencies (i.e., scrolling through the tuning cube), the interpreter can identify subtle events and anomalies that are not readily visible in the post-stack, pre-stack.

Short Time Fourier Transform (STFT) is a subset of Discrete Fourier Transform, a widely used algorithm that uses a fixed window approach to spectral decomposition. The STFT method is to obtain a frequency spectrum, but the STFT method is seriously limited by choosing a window length. A non-stationary signal, as seismic signals, is conceptually archived by STFT and it produces time-frequency spectrums, which a time-frequency resolution is fixed by choice of time window. Selecting shorter window lengths can help resolve

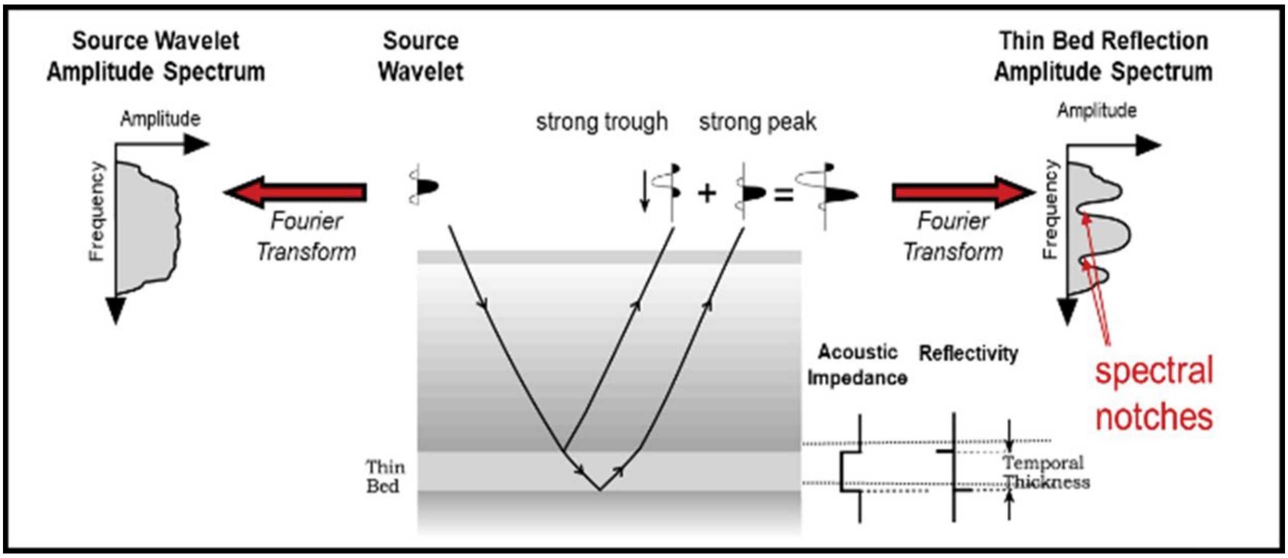

Figure 1: Partyka, Gridley and Lopez [3], The Leading Edge, vol 18, no 3.

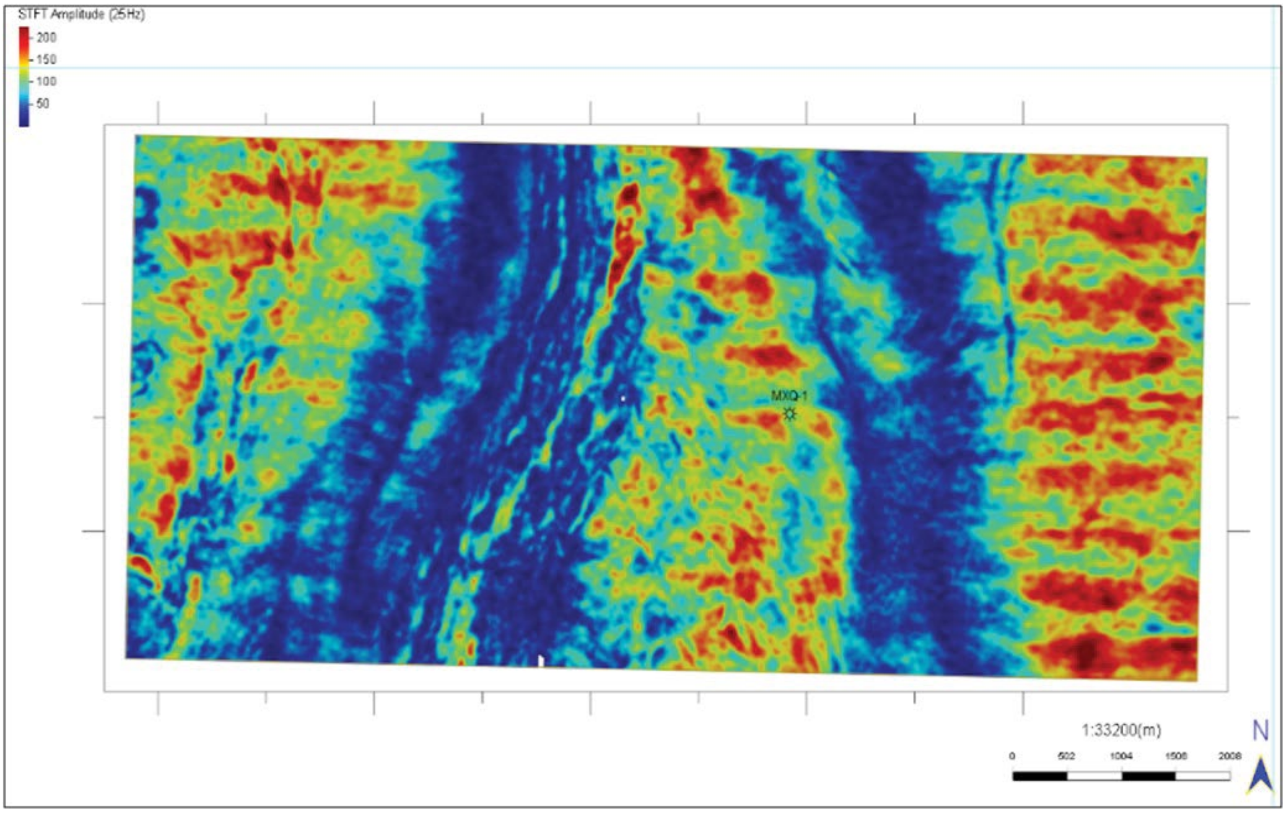

Figure 2: Algorithm STFT map.

high frequency events and separate events with similar or closely spaced dominant frequencies. The STFT shows that in low frequency, components are well resolved and choosing a shorter window length will compromise the frequency resolution to obtain higher time resolution (Figure 2).

The Limitations of STFT include:

- The STFT has a time-frequency resolution limitation.
- The use of finite-length time domain moving windows over which the 1-D Fourier transforms are performed decreases its resolving capability.
- Short windows can resolve high-f events, may overlook low-f events.
- Longer windows 'average' the response, may overlook fine details.

However, the use of these shorter windows can overlook events at lower frequency and the interpretation could be compromised. The downside of this approach is that fine-scale events will not be resolved if the window length is long enough.

Continuous Wavelet Transform (CWT) samples the seismic signal using a moving, scalable time window. In this method, the window size automatically changes with frequency and allows for adaptive sampling of the seismic trace. The resulting spectral maps provide higher temporal resolution at higher frequencies at least better than STFT [4]. The CWT frequency gather shows that CWT is far superior in preserving reflection events than the STFT method for higher frequencies. (i.e., preserves higher frequencies) At lower frequencies, however, CWT cannot adequately resolve events that are closely-spaced in the time domain. This is considered a limitation on this method. The interpreter must be careful to choose the right algorithm for interpretation and needs.

The CWT samples wavelets using a moving, scalable time window and allows for adaptive sampling of the seismic trace. While it provides better frequency resolution at lower frequencies, CWT cannot adequately resolve low frequency events that are closely-spaced in the time domain.

CWT compared with DFT - DFT window is fixed to do short Fourier transform, but CWT, the size of the window will change with frequency. This window

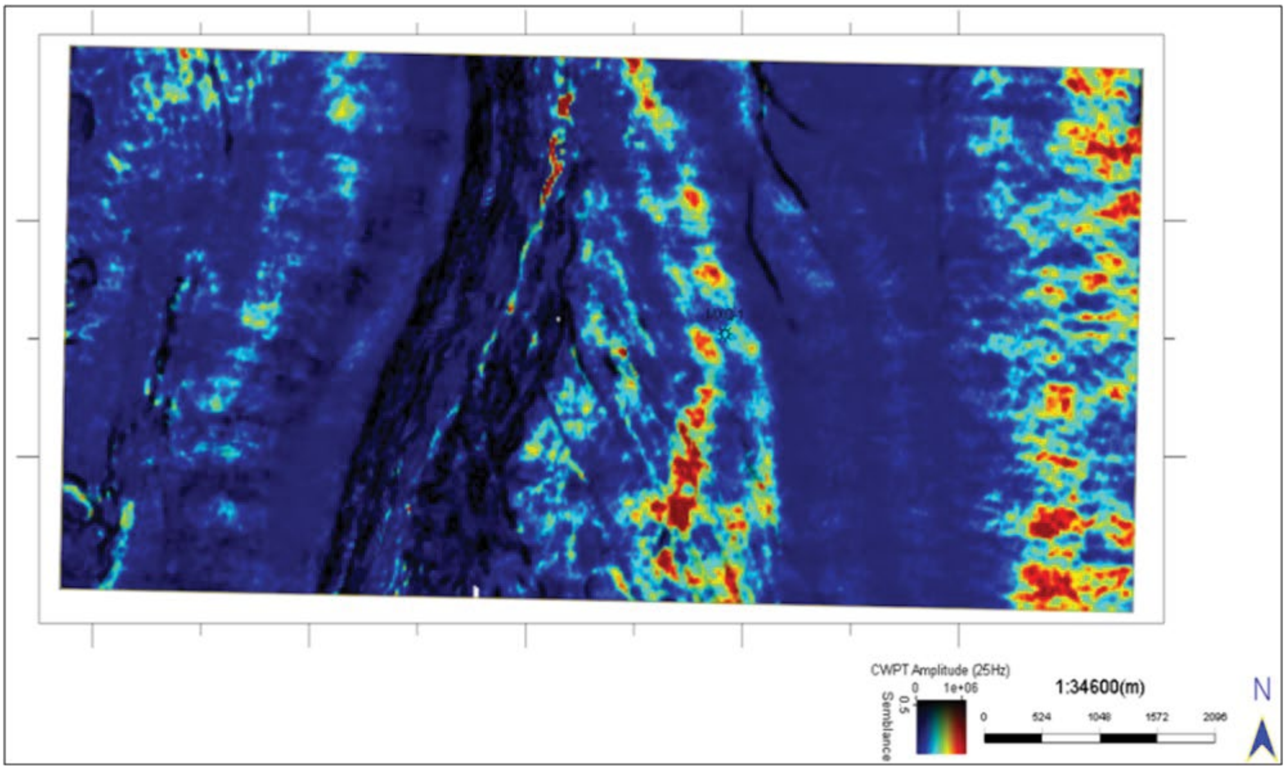

Figure 3: CWPT algorithm Map.

can be long or short. CWT changes achieve higher time resolution at higher frequency.

CWT compare with TFCWT - CWT generates a time-scale map and is then converted to time-scale map using the central frequency.

Some CWT considerations:

- CWT - moving window, where window size automatically changes with frequencies, gives frequencies range (Figure 3).
- CWT creates a map at an optimal frequency, but not exactly at 70 Hz - can be anywhere from 65-75 Hz. Compared to the DFT method, CWT is far superior in preserving reflection events (Figure 4).

Time Frequency Continuous Wavelet Transform (TFCWT) this method overcomes this issue by generating a time-frequency map that displays the exact frequency for any event, considered an advantage. CWT and STFT methods, on the other hand, output maps at a central frequency within a given time window. Like CWT, the TFCWT spectral decomposition method uses a moving window approach, but it does not average neighboring frequencies in the same way as previously mentioned methods. Therefore, TFCWT maps provide higher time-frequency resolution than STFT or CWT (even better than previous methods). Both CWT and TFCWT methods provide high-frequency resolution at low frequencies and high temporal resolution at high frequencies. One disadvantage of TFCWT is that it is computationally intensive, and generating spectral decomposition maps with this method can be time-consuming.

S-Transform (**ST**) generates a real time-frequency map and samples the seismic signal with a moving time window. However, the size of the window in the S-Transform method is frequency-dependent. Because this transform has a more rigorous relationship with the spectra, it can produce Specdecomp maps with fairly high resolution. S Transform is faster to calculate than TFCWT but typically gives similar results.

Like the TFCWT, the ST generates a real time-frequency map and samples the seismic signal with a moving time window. However, the size of the window in the ST method is frequency-dependent.

Because the transform has a more rigorous relationship with the spectra, it can produce spectral decomposition maps with fairly high resolution. An ST is faster to calculate than a TFCWT but can produce similar results and the ST has high stability in noisy conditions [5].

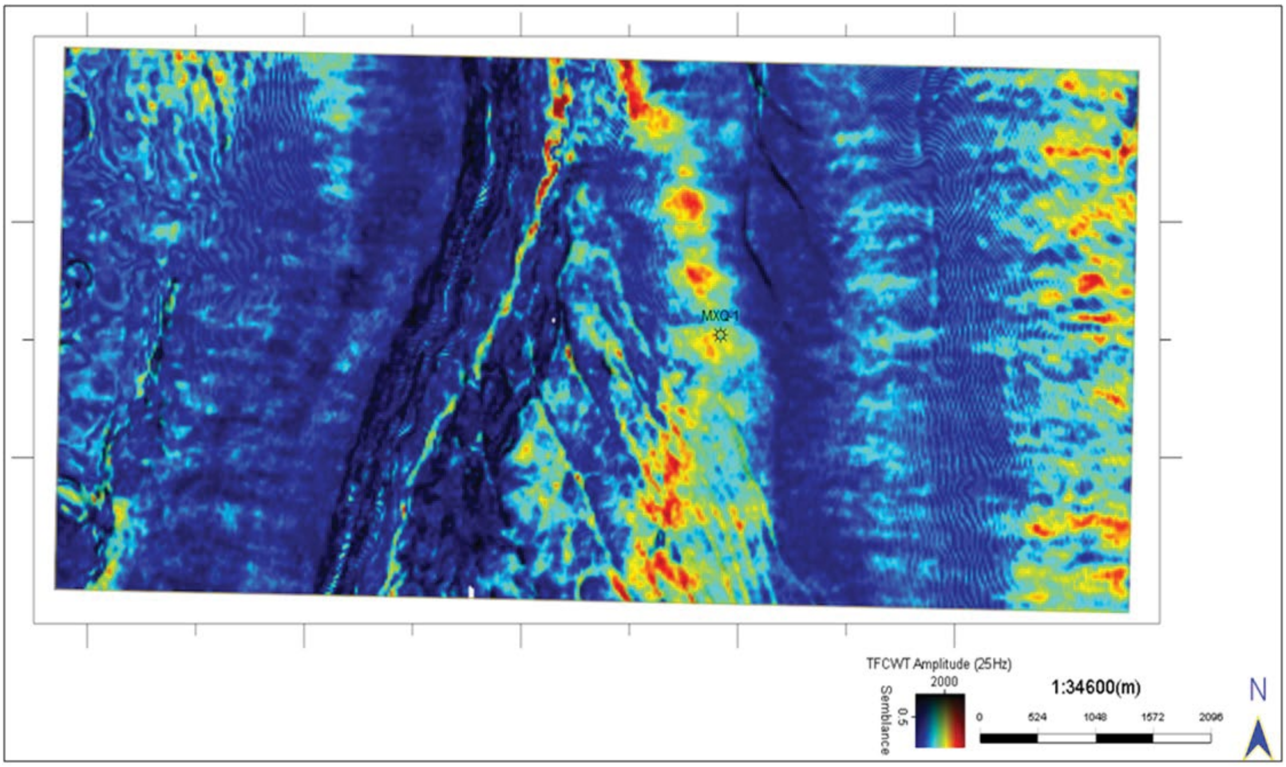

Figure 4: TFCWT algorithm Map.

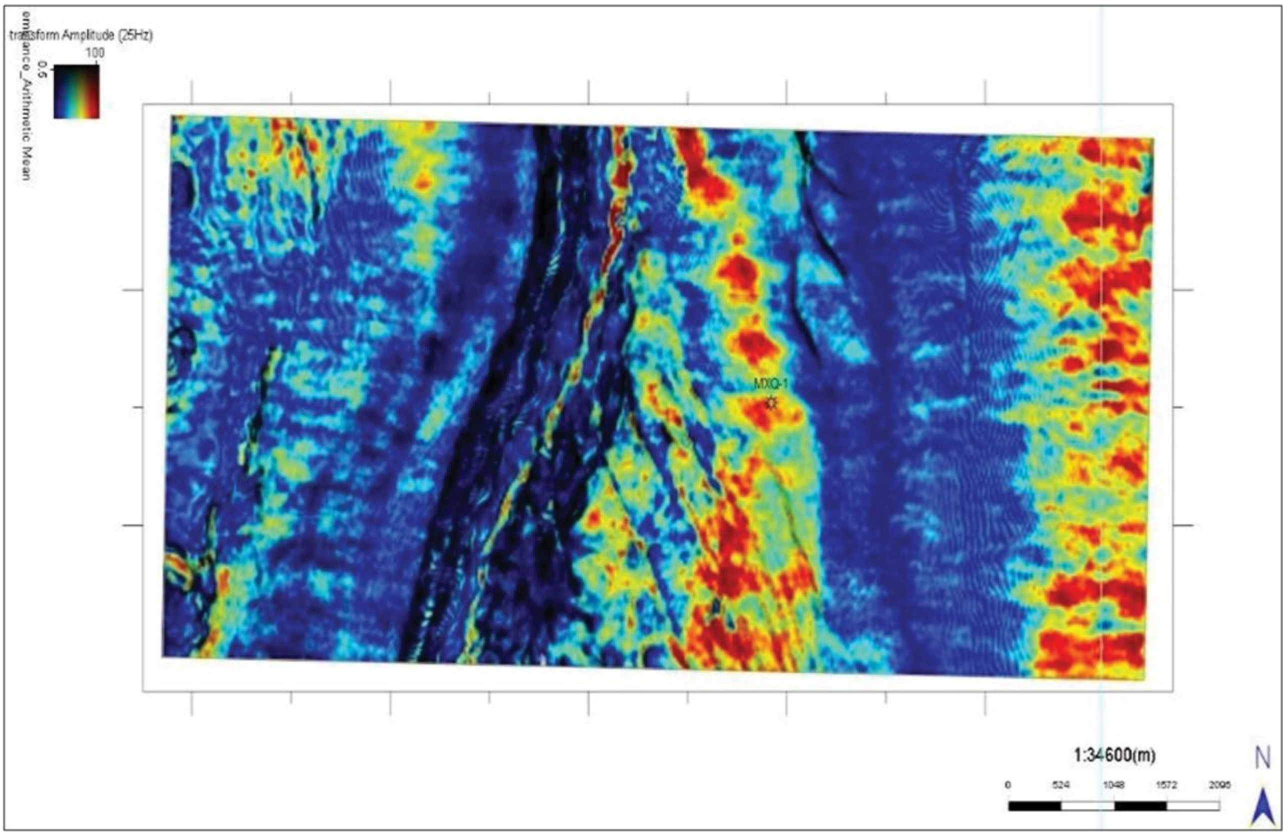

Figure 5: ST algorithm Map.

The similarity between S-transform and STFT is that they are both derived from the Fourier transform of the time series multiplied by a time-shift window. However, unlike STFT, the standard deviation in S-transform is actually a function of frequency. Consequently, the window function is also a function of time and frequency. As the width of the window is dictated by the frequency, it is apparent that the window is wider in the time domain at lower frequencies, which means the window provides good localization in the frequency domain for low frequencies. Due to the low frequency spectrum of surface wave, this aspect makes S-transform more appropriate for further analysis (Figure 5).

S-transform combines progressive resolution with referenced phase information. Therefore, it could estimate the local amplitude spectrum and the local phase spectrum. In addition, it is sampled at the discrete Fourier transform frequencies. Also showing S-transform brings a better imagine than traditional transforms.

Channelized and Braided Fluvial Reservoirs

The hydrocarbon reservoirs typically take place where the porous sands pinch out against impermeable sands or shales. Otherwise, the channel sands can be difficult to differentiate from the adjacent low-permeability strata because the lithology or type-rocks share similar P-wave impedances.

Braided reservoirs that host significant volumes of hydrocarbons almost always have high net/gross ratio, and are often considered to be relatively easy to characterize [1]. When more detail is needed for the reservoir, spectral decomposition could be an innovating tool for this task. It can be applied directly to post-stack and pre-stack amplitude seismic data. However, the industry is updating many technologies as 'strata-grid', (i.e., a package between two or more intervals, volume that has been extracted from the original seismic volume, mostly intervals of interest and stacking into proportional slices).

Sometimes the reservoir can act completely differently from surrounding sand when viewed at discrete frequencies. It acts in a distinctively dynamic way relative to the background as the hydrocarbons have changed the reflectivity of the reservoir.

Maps and seismic cross-section are critical to determine if the features you are seeing are geologically meaningful. When the interpreter is considering a stratigraphic feature that appears fan geometry. At lower frequencies from the "Tuning Cube," the feeder channel of the "fan" is highlighted. At higher frequencies, different lobes of the fan geometry are highlighted. At the highest frequencies available in the seismic data, the thinnest areas are highlighted.

Petrophysical Feasibility

The petrophysical evaluation defines a sequence of channels. Some channels are compact, as identified by the resistivity, density, neutron, and sonic logs. Therefore, it is important to differentiate the seismic attributes associated with compaction from those containing hydrocarbons

The impedance analysis in the reservoir zone identifies the separation by fluids and lithology. The impedance P versus impedance S plot, with effective porosity color coding, shows that shales can be adequately separated from sands (Figure 6).

The VPVS versus density plot, colored by water saturation, identifies how, at a logging level, adequate separation of zones with hydrocarbon presence from water zones can be achieved. Therefore, special processes must achieve a good lithological and fluid differentiation (Figure 7).

Results

All spectral decomposition methods can provide better resolution of the channel morphology in comparison to the post-stack amplitude map, but each offered a different spectral response. Longer window size results are not considered sometimes because structures of interest are only seen at higher frequencies. By sampling the seismic signal with a short window size, it is possible to avoid the averaging effects inherent in the fixed window method as well as obtain better frequency resolution. Generally speaking, thin thickness events appear as high amplitudes at certain higher frequencies in spectral decomposition maps. Therefore, it is possible to observe the spatial variation of the target by viewing spectral maps in succession within the tuning cubes. Sometimes, if channel or bed thickness increases or decreases spatially, it can be observed by scrolling through the frequency slices.

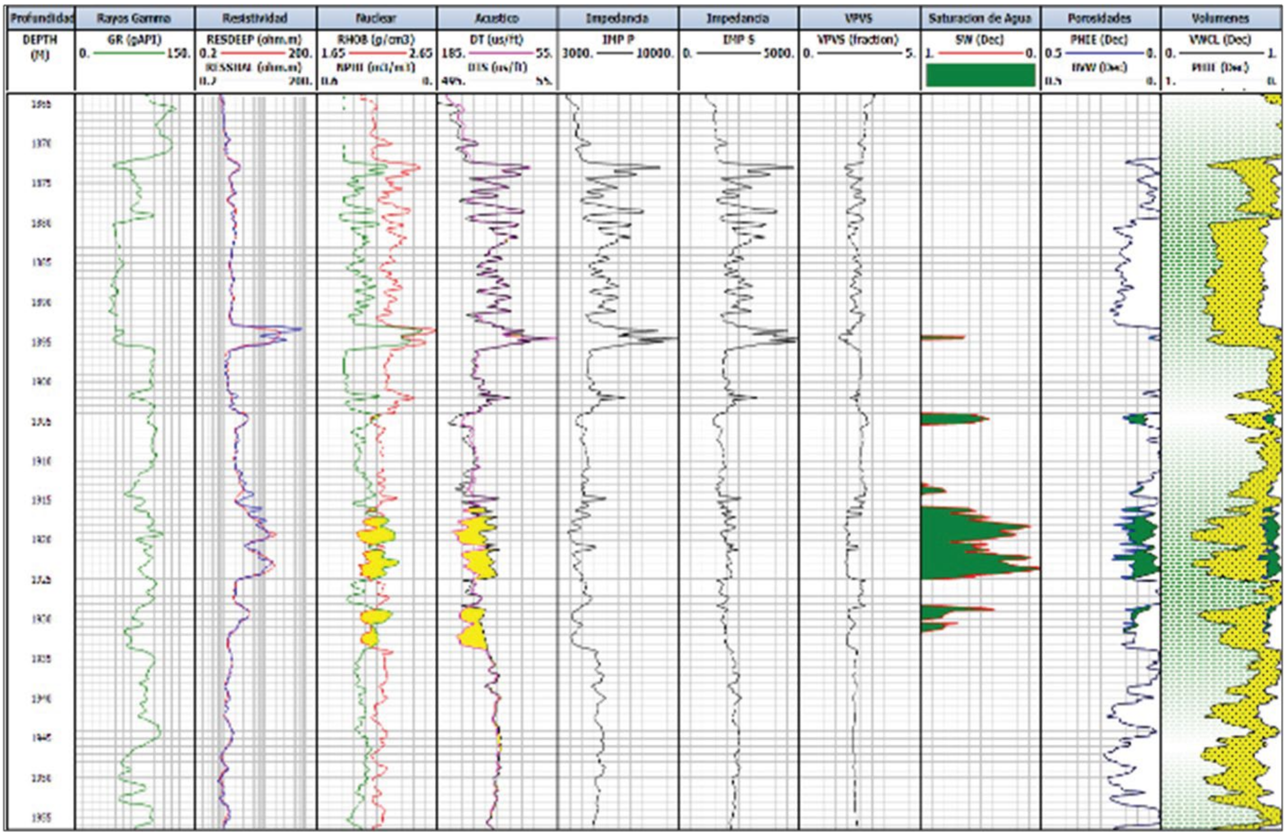

Figure 6: Well-log analized.

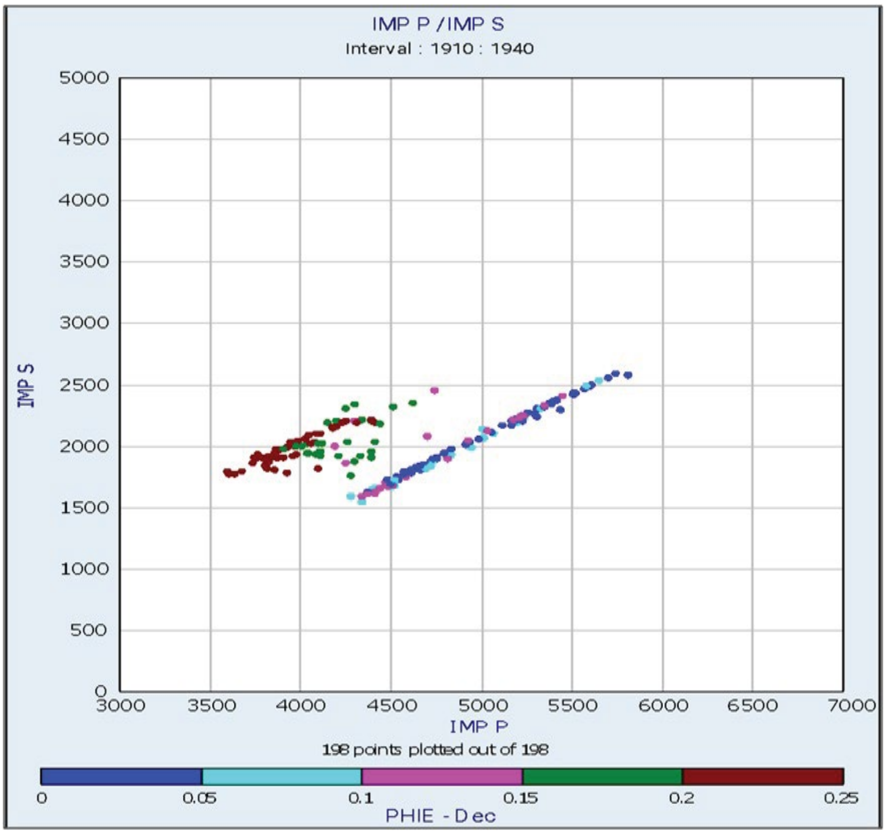

Figure 7: Cross plot Imp P/Imp S.

It is necessary to mention that the conventional seismic attribute RMS or instantaneous amplitude is considered by many interpreters as a point of interest with hydrocarbon content, which is considered very risky and successful in drilling. As a personal recommendation, calibration should be carried out with production of the results of any basic seismic attribute and tied with special processes such as spectral decomposition or seismic inversion.

It is highly recommended to use either seismic pre-stack or seismic post-stack Non-Filter and Non-Gain if you are interested in extraction of conventional seismic attributes or in special processes that are very sensitive to interpretation, a detailed interpretation must be carried out by choosing and keeping the reflector on the entire interpretation. When you use seismic with some type of make-up or filter, you alter the true amplitudes, which can have catastrophic results in your proposals for new well locations, adding to the statistics of new dry wells (Figure 8).

Conclusions

In imaging the Glauconite channel sands, running multiple spectral decomposition methods helped to resolve the channel morphology and bed thickness relationships within the channel facies. While TFCWT spectral decomposition provided the best resolution of all the methods, it also took the longest time to calculate. The S-Transform maps provided similar results to TFCWT and were faster to generate, making the S-Transform method the most efficient technique for resolving the channels in this particular study. Spectral decomposition can greatly improve visualization

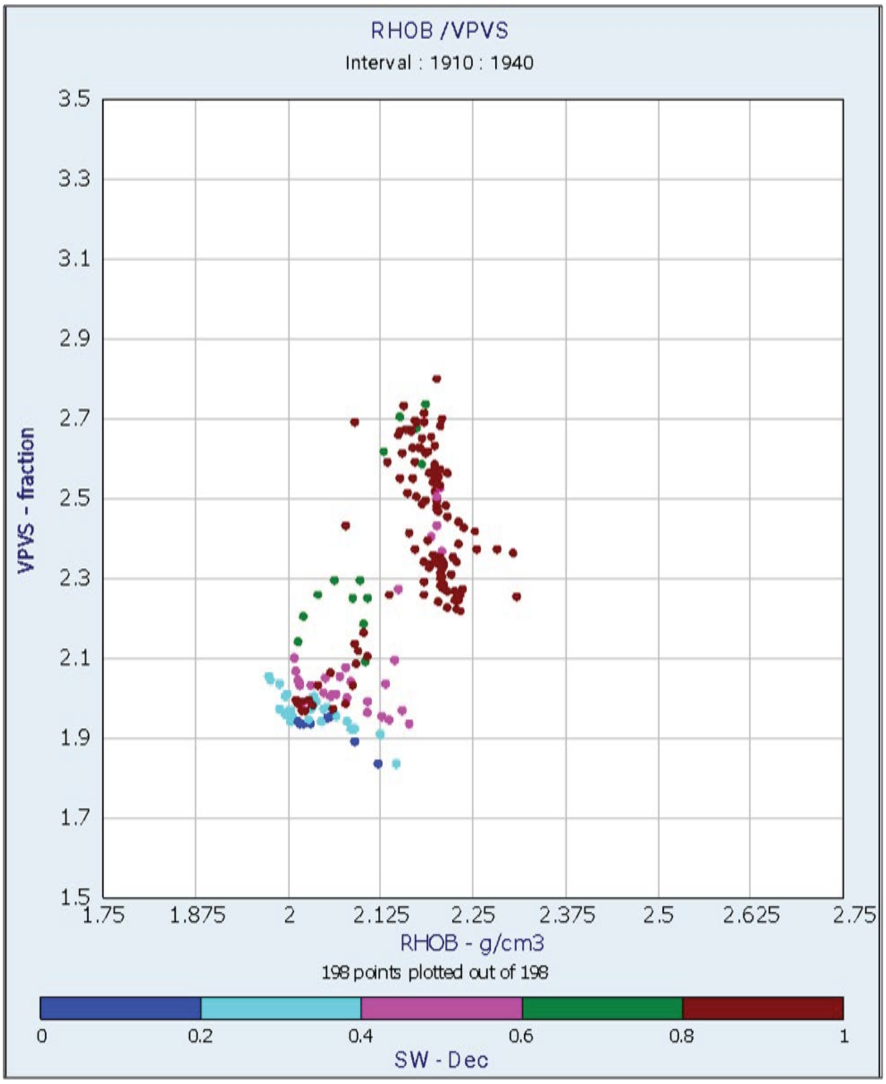

Figure 8: Cross plot RHOB/VPVS.

and interpretation workflows by revealing thin beds, lateral discontinuities and subtle anomalies not readily identified in post-stack seismic data. By correlating the spectral maps back to well logs and attribute relationships, the technique can help the interpreter to better understand complex reservoirs and plan a drilling strategy with greater confidence and considerably reducing risk in success.

Some think that strong amplitude could be an indicator of hydrocarbons, while the other side suggests that amplitude is only a sand indicator. On the other hand it could show nothing about the presence or absence of hydrocarbons. The interpreter must be careful with those indicators and integrate all available data, complementing these results with geophysical techniques such as seismic acoustic inversion, seismic elastic inversion, production data, pressure data, geological data and seismic attributes. Combination of different attributes as an instantaneous amplitude and instantaneous frequency could be used to enhance the continuity of the event. When two seismic events are very close together, it can be difficult to separate one from other on the basis of amplitude; Instantaneous frequency can assist the interpreter determining their relationship between two reflectors.

It is important to consider that well logs show a clear separation of lithology and fluids, which allows for the application of special processes such as spectral decomposition (Specdecomp) or, alternatively, simultaneous or elastic seismic inversion.

Always keep in mind that the objective of any interpretation and/or characterization of a reservoir with production, as well as G&G and productivity studies is to increase or improve hydrocarbon production.

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