Subtle Fluid Seismic Facies indicated by Weak Reflectivity in Santos and Campos Basins - Brazil

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Abstract

Seismic reflectivity derived from compressional waves, commonly used in the oil industry, has not only geology-related signals but also events referring to coherent and random noise. These noises affect primary wave responses, contaminating mainly those related to background amplitudes. This work seeks to follow two strands: Interpret data to build an optimum seismic qualification, providing a more balanced amplitude spectrum of for all frequencies, and perform deconvolution filters to derive subtle reflectivities that can be correlated to desirable fluid responses. The main objective is highlighting events correlated to weak reflectivities that can differentiate fluids from rocks and all elements of a petroleum system. These concepts were applied in Campos and Santos Basin, for post-stack 3D seismic data.

Introduction

One of the great economic motivations of seismic interpretation for major oil industry targets is the possible response of the recorded signal as a hydrocarbons direct indicator (DHI). In this sense, several seismic methods have been developed and applied with a significant success rate from pre-stacked seismic reflection data, such as traditional workflows for amplitude versus offset analysis (AVO). However, many pitfalls and ambiguities have been observed and failures have occurred due to the existence of factors not very well understood in the propagation of the seismic wave and not corrected with the acquisition and/or processing parameters applied to input data. Factors such as lack of long offsets, anisotropy effects, velocity models, rigorous muting in the amplitudes of the long offsets, phase mixing in the signal response and others more associated with geological factors, such as coherent noise intrinsically generated by sediments layering, have been reported as major causes of loss of efficiency in success rates.

Based on the theoretical hard premise that every primary seismic event that appears as anomalous in pre-stacking data must be duly preserved in post-stacking data, the possibility of analyzing amplitude anomalies also in the latter is expanded. Anomalies are treated here as all those associated with values that deviate significantly from the local mean, in any sense of a histogram of distribution of amplitudes (positive or negative). Among all anomalies of a rock-fluid system that may stand out in a seismic reflection data, those associated with fluids are of greater interest, which form the target of important research and exploration studies by oil industry and, more recently, also for understanding spatial distribution of contaminants in sedimentary basins. Fawad et al (2020) present an important review of methods for detecting seismic response anomalies that indicate the presence of hydrocarbons. They register after 1970s, there was a growing search for quantitative analyses for petrophysical and elastic parameters, mainly using approximations of Zoeppritz equations. Based on these equations, Bortfeld (1961) described the influence of fluids and stiffness in the seismic response derived from a set of earth reflectivities. These works may be considered as starting points for the vertiginous growth of scientific research dedicated to seismic inversion processes in the search for direct quantification of hydrocarbons.

In this important and historic scientific race for the quantification of fluid saturations, little relevance was given to the geological and petrophysical role or meaning of primary reflectivity when it is estimated directly from seismic data without wells, as needed in regional exploration context for petroleum system modeling.

When a geophysical investigation for hydrocarbon focuses exclusively on the pair reservoir and host rocks, a great potential of seismic information is neglected, ignoring indications for all other elements of a petroleum system and their spatial configurations. Elements that are fundamental in determining the existence of hydrocarbon fluidic mass systems, from the beginning of secondary migration, adjacent to any fluid sourcing facies, up to the arrival of fluid in traps and possible reservoir filling, including the final and necessary analysis about possible leaking windows.

All this demands seismic information that spatially covers completely, or in a large part, analyzed sedimentary basin fluidic system. Information which makes possible visualizing or detecting migration paths which lead fluids to reservoir rocks, indicated by seismic reflectivity, has increased its exploration importance. Such reflectivity should be selectively associated to petroleum system elements, obtained after some treatment of the seismic signal to maximize attenuation of coherent noise, generally remaining in any seismic data, stacked or not, as specified in seismic qualifying processes in Santos et al (2019).

Liner (2012) presents a set of seismic events associated with factors that cause primary waves apparent attenuation. In it, there is no transformation of kinetic energy, as occurs in intrinsic attenuation, being fully conserved when several sets of secondary waves are generated from different impedance contrasts, which can be erroneously modeled as geological layers and/or petrophysical heterogeneities. Many types of secondary waves are grouped in this context such as internal multiples, converted waves, and those derived from P-wave transmission effects, generating remaining coherent noise in pre, and post stacked data.

Such secondary events, when propagating to deeper regions of a given sedimentary basin, will always distort, or even completely hide, subtle primary amplitudes that may be derived to indicate different fluidic masses permeability. In general, such masses are related to weak reflectivity and generate amplitudes with very small magnitudes, basically modeled as subtle seismic facies. In general, these small amplitudes are under the level of secondary waves derived from apparent attenuation effects and cannot be dealt using conventional seismic data processing like Wiener deconvolution algorithms, which assume seismic time series as stationary in their convolutional models.

Margrave et al (2011) extended the method of stationary spiking Wiener deconvolution of seismic data to the context of nonstationary signals in which the nonstationarity can be considered as due to attenuation processes. As a statistical or blind deconvolution, they assumed a statistically white reflectivity and a minimum-phase source and attenuation process. They show that a set of secondary waves can be considered as composed of stationary events and thus could be attenuated by efficient conventional deconvolution processes, effective for this purpose, such as the Wiener type extended to non-stationary processes, showing subtle enhancement of detail and robustness in the presence of coherent noise.

Here we show how efficient 1D seismic deconvolution can satisfactorily recover primary reflectivity responses of a petroleum system, in all spatial conception, which makes possible understand and indicate mass fluid permeability even in stacked seismic data (like full PSDM data). It is possible indicate existence and effectiveness of elements of permeability in the control of migration paths, seals, fluid charge and retention and, with a final and desirable focus, hydrocarbon reservoirs. Such indicators are here exemplified with cases in sediments from Brazilian basins, in the post-salt and in the pre-salt scenarios, with the use of synthetic and reflectivity responses derived from deconvolution of data volumes, respectively in the Campos Basin (Campos Seismic Deconvolution - CSD) and in the Santos Basin (Santos Seismic Deconvolution - SSD).

Research trends

One of the major objectives of seismic interpretation for oil is the investigation of DHI in a sedimentary basin. The most efficient and widespread method worldwide is through AVO analysis. In the recent history of this interpretation many unclear ambiguities have been reported and failures have occurred due to coherent noise. Such noise may often not be properly considered as a negative quality factor for any DHI.

Among amplitude anomalies that may exist in a seismic reflection data used to describe a rock-petroleum fluid system, some may be correlated to the presence of fluids and their quantification stand out. In recent decades, they have been objects of intense geoscientific research for reservoirs seismic analysis. DHI method focusing only the context of reservoirs and their local host rocks and it should be complemented by other seismic methods to describe spatial behavior of the fluid factors to effectively indicate spatial configurations for all other elements of any petroleum system. Such elements here considered since the beginning of the secondary migration at great depths, in paleogeography adjacent to some sedimentary facies including hydrocarbon source, to the arrival at traps and filling reservoirs, with the necessary analysis of possible leak regions.

In the oil industry there is a growing demand for the use of all available seismic information, and not only those strongly anomalous, specially including amplitudes contained in the range of low magnitudes grouped and classified as background amplitudes. One important question about investigative motivations for using all seismic amplitudes present in a reflection data for petroleum is: Is it possible detect a seismic variation due to different fluid masses permeability, associated for example with different viscosities, GOR and API degree, in blends or in single phases? Starting answers can be established analyzing small-magnitude amplitudes and their relationships with those strong amplitudes derived from purely geological components with higher impedances.

Strong amplitudes in the final interpretation images are mainly derived from reflected waves in materials that present great lithological contrasts between rocks (some unconformities, hiatuses, top of reservoirs, salt, volcanic, carbonates, etc..), but they can also be related to unbalanced processes for wave attenuation recovering amplitudes which can enhance important coherent noises. Such noises can crucially inhibit small amplitudes, which could indicate fluid masses behavior.

Here we show how any optimized deconvolution process can reduce the magnitude of coherent noises and relatively enhance small-magnitude amplitudes, which can be related to fluid factors.

Method

Attenuation of coherent noises that propagate through a sedimentary column until reaching great depths contaminating and distorting signals that can emerge from weak reflection coefficients (primary low amplitudes) is an important step for any seismic processing workflow. It can critically collaborate to differentiate fluidic masses behavior in a basin space by its capacity to enhance differential permeability-related seismic facies. Weak reflectivity values build an important part of impedance contrasts related to rock-fluid systems, which are investigated by the P-waves normally manifested by subtle magnitudes.

Such impedance contrasts can be effectively differentiated in post-stack data, by attenuating greater amplitudes present in the traces, using effective deconvolution processes, in which a simple and efficient wavelet extraction can offer information and visualization of scenarios that point out direct indicators of all the elements of any petroleum system involved. Filtering technique here exemplified seeks direct indicators of hydrocarbons and increases chances of success in direct indication of all petroleum system elements, since the condition of stationarity of coherent noise, providing optimized performance for deconvolution processes.

It is necessary to point out that all ambiguities inherent to the seismic method will always exist, even though the deconvolution process be quite effective. Any interpretive methodology must always consider them. Figure 1 shows a resumed workflow involving the methodology here applied.

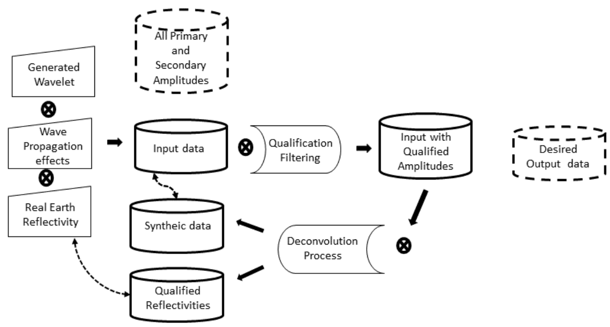

Figure 1 - Resumed workflow involving qualifying filtering and deconvolution processes

Input data can be modeled as a wavelet convolved with real reflectivity series and also convolved with secondary waves intrinsically derived from primary wave propagation. After a process of seismic qualifying, a desired output volume is generated, which is considered a reference for any further deconvolution process. Final volumes can be a synthetic to be compared with input data and a derived seismic reflectivity volume to be used in any subsequent interpretative process, both generated to strategically reduce uncertainties related to any present ambiguity. Each ambiguity can be understood and solved through non-traditional methods of investigation of seismic data for oil, in which the hydraulic behavior of possible fluids is valued, and can be conceptualized through most of the theories of hydro stratigraphy. Differently, in this interpretative way, there are no individual hard links to stratigraphic and/or structural facies, for each identified exploration opportunity, or for a given reservoir, since the method is based on the tracking of migration routes that will always be a juxtaposition of all heterogeneities indicated in a seismic data, more related to Petrophysical factors like permeability. The method follows the main objective of this work in showing the feasibility of conventional stacked data (PSDM or PSTM) to differentiate weak reflectivity that can be attributed to fluid movements relative anomalies. The workflow here suggested seeks adding information for geoscientific studies about petroleum system elements, involving some analytical potential benefits such as those following described:

- Enhancement details of structural and stratigraphic geometries in fluid reservoirs
- Understanding of physical terminations of seismic bodies associated with sedimentary bodies and tectonic blocks
- Subtle variations of sedimentary facies
- Definition of zones with higher fracture density of and subtle faults
- Indication of subtle Petrophysical variations
- Perception of DHI amplitude fluctuations in the background
- Possible identification of polarity inversions
- Non-trivial indicators of fluid contacts
- Indicators of possible differential permeability zones for fluidic masses
- Variations of permeability barriers and seals
- Existence of structural permeability belts
- Recognition of volcanic and carbonates
- Recognition of possible paths of contaminants, hydrogen and geothermal processes

Some of these benefits are here exemplified, illustrating the potential and interpretative differential for deconvolution techniques developed by UFF.

Results from Campos and Santos Basins

When describing the CSD (post-salt) processes it is important to mention that it is designed to enhance subtle amplitudes and geometries associated to higher relative frequencies in the input data, when compared to the dominant frequency in the Pre-Salt layers. This type of deconvolution is mostly applied to siliciclastic sediment packages from the drift tectonic phase during the basin formation. In this package primary wave responses are contaminated by coherent noise derived from Neogene and Paleogene intralayer secondary waves that can be considered as the stationary part of an extended Wiener deconvolution process (Margrave et al, 2011). Figure 2 shows a 3D inline from qualified amplitudes (desired output for a deconvolution) and a reservoir layer model extracting values from derived seismic reflectivity volume. Lower absolute reflectivity values indicate lower permeability regions. Better description of these applications can be found in Cunha (2022).

For the SSD processes, subtle signals with increasingly lower frequencies in the signal spectrum as the depth of investigation increases, are generally associated with the definition of carbonate reservoirs under thick layers of salt and pre–salt sedimentary section. In this geological scenario, downgoing primary waves are reflected at pre-salt carbonates, generally located immediately below the base of the salt and deeper, generating upgoing primary waves.

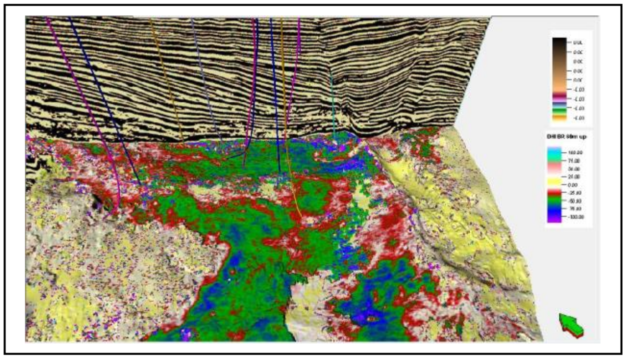

Figure 2. Lower absolute values indicate lower permeability regions (yellow textures). Green and blue facies indicate better fluid accumulations or fluid transmission along heterogeneities, normally truncated by low permeability facies. These upgoing waves are reflected once again in the base of the salt generating secondary downgoing waves that will contribute to coherent noises contaminating the primary response from all signals coming from the pre-salt carbonates and other rocks. This process is repeated for every sedimentary layer in pre-salt package. In this geologic scenario, we can consider almost perfect stationarity for a wave propagation process in the interior of homogeneous salt bodies and in the interior of basement rocks, showing no relevant residual secondary waves after deconvolution. Figure 3 illustrates seismic reflectivities after deconvolution processes for an inline and a depth slice at 6420m in Santos Basin. Lila, dark blue and green textures indicate greater probability of fluid retention and transmission, bordering sealing bodies and along structural discontinuities. Better description of these applications can be found in Quintes (2022).

Conclusions

Seismic reflectivities are important tool for recognizing textures associated to key elements of a petroleum system, including fluids. They are strategic to help exploration studies where no wells have been drilled. Deconvolutions in post-stack data play very important role in scenarios for both, siliciclastic post-salt reservoirs and pre-salt carbonates in Campos and Santos basin.

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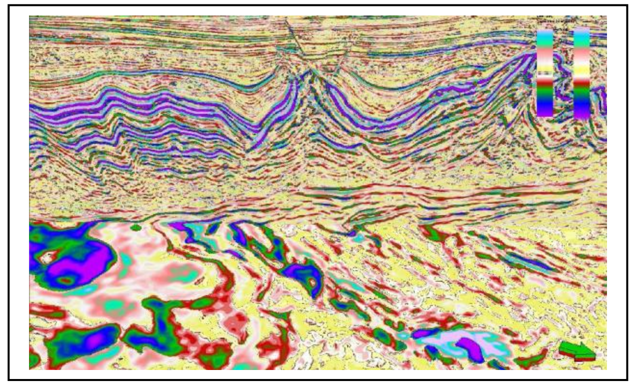

Figure 3 - Seismic reflectivities after deconvolution processes for an inline a depth slice at 6420m in Santos Basin

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