Following Fluids using Effective DHI Seismic Volumes

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Abstract

In the oil industry, seismic interpretation is usually done interactively, at a workstation, and semi-automatic methods have had an increasingly use, being associated to a strong control by the interpreter and by consistent geological and geophysical knowledge about an investigated area. These are factors which grant high-quality interpretations by the importance of the understanding about seismic wave propagation effects and aspects that influenced sedimentation, tectonics, and fluid migration along all explored basin rocks. In the interpretation, seismic samples are spatially correlated to a certain conceptual knowledge for each set of elements related to some petroleum system (PS). Generic concepts of seismic semi-automatic mapping by seeds are not new, having been on the market for more than two decades. In the interpretation, seismic samples should be spatially correlated to perceptions of elements combined for some petroleum system (PS). We present concepts for seismic interpretatioin based on direct hydrocarbon indicators (DHI) cubes, strongly related to samples originally associated with a fluid, or concepts to follow a fluid. Samples tracking does not have to individualize stratigraphic or structural characteristics, but rather petrophysical aspects, which build a hybrid scenario for seismic permeability, controlled by both sedimentary and structural facies in juxtaposition, through such DHI cubes.

To describe a hybrid scenario considering conceptual seismic sample similarity, we adopt seismic stratigraphy concepts, here weighed as the most appropriate for fluid seismic tracking through sedimentary sequences. The procedure can start from a sample at near neighborhood of fluid source kitchen or at some sweet-spot related to initial secondary fluid migration. Procedures should be carried out on Effective DHI cubes (EDHI) looking for both, consistent and continuous responses for the any element of a PS. The better, or more effective, be a DHI volume used for tracking samples, the better and more realistic the petrophysical response of each mapping carried out. We propose a seismic semi-automatic mapping, here considered as a surgical method, in which a complete path of secondary fluid migration can be detected. Methods are exemplified for F3 Dutch Sector Block post-stack seismic amplitude data

Introduction

When a seismic interpretation is focused on the role of sedimentary depositional models and tectonic associated to hydrocarbon migration up to the point of feeding a given reservoir, a combination of mathematical, geophysical and geological concepts is necessary for diagnoses about those seismic samples that could effective represent spatial fluid permeability or connected porosity. Post stacking seismic interpretations can be classified from different concepts, according to geoscientific objectives, or from their foundations linked to topics related to structural, stratigraphy, petrophysics geometric patterns and others. They can also be classified by the effectiveness to which one wishes to map (for carbonates, salt, turbidites and other lithology) or still by accuracy and precision (regional, semi-regional, reservoirs, production zones, etc.).

Considering ultimate technologies, seismic interpretation should be analyzed, qualitative and carefully related to its effectiveness. When it is not observed, a meaningful quality miss can be generated, that can bring uncertainties and lead to incalculable economic losses, sometimes intangible, for any geoscientific or engineering project. Among seismic interpretation products generated by traditional mapping methods, are those related to the tracking of seismic amplitude samples by semiautomatic operation. It normally uses seeds of magnitude and phase of samples to be tracked, defining how connectivity and similarity between neighboring samples are understood. Such methods preceded several other fully automatic methods which use artificial neural networks, which are undergoing consistent and accelerated technological development. Here, we present a semiautomatic interpretation method which differs from traditional methods when applied on DHI cubes. It does not follow straightforward concepts for neither structural nor stratigraphic, but rather hybrid features array, combined with petrophysical interpretive factors, whose effectiveness, accuracy and precision depend critically on quality of seismic volume adopted as DHI and its accuracy on defining integrated PS elements.

EDHI for PS Elements

DHI anomaly cubes are built for obtaining direct seismic evidence of hydrocarbons from conventional Post-Stacking data, including angle partial stacks. It is considered that seismic response from primary wave is able to show variations in elastic properties that can be associated with the presence of hydrocarbons. Traditional DHI anomalies happen due to an enough saturation change in the pore fluid content, which causes a sensible variation in the elastic properties of the rock volume, enough to be distinguished by seismic wave. Once distinguished, they have characteristics that can be identified, tracked, and used for studies about locations of exploration wells, mainly to reduce uncertainty and risks. Along the last two decades, many seismic semi-automatic mapping have been done to identify and tracking true DHIs helping, for example, on the traditional AVO diagnoses and others

Meldahl et al (1999) present a method for semi-automated detection of seismic objects, including chimneys, to increase the detectability and mapping efficiency of the desired objects adopting an iterative process comprising at least two steps: contrasting (ie texture enhancement) followed by object recognition. Mapping is performed by extracting several attributes from multiple windows and feeding these to either a supervised, or an unsupervised neural network. Size, shape, and direction of the extraction windows as well as the attributes, are chosen in relation to the objects one wishes to detect.

Heggland et al. (2002), describe a semi-automated detection of seismic chimneys, applied to several 3D data sets from the Norwegian shelf and the Gulf of Mexico. They mention that columnar distortions in seismic data usually termed seismic chimneys have been observed to tie in to features associated with gas (frequently interpreted as free gas in the sediments), either as small accumulations captured in the shales, or as upward migrating free gas.

Ligtenberg (2005) presents a workflow dedicated to elucidating fluid migration pathways and faults on seismic data. The method can enhance amplitude patterns related to fluid migration, combining a set of seismic attributes with neural network technology, being able to highlight even very subtle fluid flow features that remain hidden when only single seismic attribute is used. The author mentions that pathways can be also related to leakage from potential reservoirs, and the method may provide better insight about lateral and top seal quality.

Fahmy et al (2008) mention that ExxonMobil DHI-AVO best practices recommends that many factors must be evaluated to achieve an understanding of the drill risks, basically involving AVO attribute. To obtain such an understanding, the seismic responses from near and far offsets traces, from partial stacks need to have their wavelet's properties similar to each other, where the balance parameters of the frequency band are critical, with such balance being subjective aspect.

The most traditional DHI is the Bright Spot that is a seismic response to a geographic region in depth with a local increase in the absolute amplitude is associated with the accumulation of hydrocarbons. In this sense, a fluid in the porous space can generate an increase in the absolute value of reflection coefficient, causing anomalous amplitude variation.

The most common and better described DHI in literature for Post Stacking seismic data, is related to gas chimneys. Many examples are registered, and it occurs when a hydrocarbon accumulation escapes upward, due to any fail from seal element, along a fault plane or vertical fracture zones, and may generate a gas seismic cloud.

It is valid to mention others common DHI from seismic response, like flat spot, dim spots, phase change and shadow effects are the other DHI effects very well described by oil industry literature.

Here, we propose that, whatever the DHI cube it should also be an effective indicator for all PS elements, where seismic response can be given in part by the fluid factor saturating and part by the rock stiffness factor, as described by Bortfeld (1961) who adapted Zoeppritz equations. He simplifies factors for P wave reflectivity equation of a saturated rock, in response to the incident wave as:

P-wave Reflectivity = Fluid Factor + Rigidity Factor (1)

To conciliate DHI concepts with effective PS elements, we adopted genetic classification concepts of Demaison and Huizinga (1991) to describe and predict the potential of a PS and, consequently, identifying exploratory segments to locate areas of occurrence of petroleum or plays. In this sense, we propose that a DHI cube should expand their basic concepts to understand seismic responses for all elements of each investigated PS. Thus, the genetic classification of such authors, using parameters related to the charge factor (super charged, normally charged, and under charged); migration drainage style (vertical or lateral) and trapping style itself (low and high impedances), can be extended, making it possible to seismically characterize PS elements according to the following concepts:

Effective Kitchen - related to regions in the spatial vicinity of a fluid source, which indicate the beginning of secondary migration, where the total length of each recorded seismic trace length be enough to reach depths in such regions. In this concept, there should be a weighted analysis of the fluid and rigidity factor for the rock source in equation (1).

Effective Secondary Migration - with pathways of carrying areas, pervasive, stratigraphic or due to faults and fractures, must be diagnosed by the fluid factor of equation (1)

Effective Seal - describes the level of sealing resistance to fluid pressures by overlying rocks (impedance that works against the dispersion of the petroleum charge). In this case, the rock stiffness factor and its physical and hydraulic resistance to trapping and the pressure would give the reflectivity in equation (1) predominantly by underlying fluid.

Effective Reservoir - would be one classified as high impedance for those regions that contain hydrocarbons, causing significant variations in the fluid factor of equation (1), and the one with low impedance, that has dry regions in terms of hydrocarbons, whose variations would be of very small magnitude, associated only with the rigidity factor in equation (1).

As any other seismic interpretation, ambiguities can happen, like individualized by low impedance but dry layers, residual fluid (differential diagenesis) along past fluid migration paths and others less common.

Thus, whichever DHI cube be proposed as effective in detecting or suggesting presence of hydrocarbon accumulations, it should be a direct and effective indicator also for all the factors described by equation (1), or by any other equation derived from Zoeppritz equations or similar ones.

Seismic Qualifying for High-Quality DHI Cubes

As described before, all DHI should be effective in the sense of being valuable for the economic demands they propose, keeping the indispensable precision and accuracy for each derived information, reducing involved seismic uncertainties. Any DHI cube needs to be effective also for a full spatial understanding of the involved PS.

Santos et al (2019) show that a large amount of amplitude samples with low magnitudes, related to important geologic targets, has been underestimated and poorly understood due important, and always present, contamination by high-amplitude of coherent noises and other signals. They show the importance of the understanding effects from both types of common seismic wave attenuation, intrinsic and apparent. They present a post-stack data attenuation process named seismic qualifying which main target is attenuation of high-energy noises and “undesirable” signals to enhance primary wave events with low amplitudes, straight related to weak reflectivity. They conclude that a geoscientific interpretation after data qualifying expands chances of success for seismic detection of gentle heterogeneities like those related to subtle structural, stratigraphic and petrophysical variations for signal with their low-amplitudes only mixed with white noises. Robinson and Treitel (1980) show that to detect signal immersed in white noise is possible when S/N is from 2.0 to 0.25.

With seismic qualifying, we look for the generation of high-quality DHI cubes able to reveal seismic evidences for each element of the PS: source, migration, charge, seal, reservoir and retention. These evidences help to increase the possibility of following fluid pathways, from sourcing to reservoir filling. An optimal DHI cube will be able to show multiple exploration opportunities, here nominated effective DHI cubes. They should be able to distinguish hydrocarbon pockets, from the kitchen, through points of route redistribution (dilatation) to the final accumulations (reservoirs).

Surgical Seismic Interpretation: following the fluid

One of the qualities required by modern seismic interpretation for fluids, is that which searches for all possible migration routes, until they reach and fill reservoirs. In this sense, following the fluid becomes a fundamental objective for any economical mapping. This objective goes beyond simple concepts of reservoir mapping, and establishes the tracking focus on the double simultaneous concept: reservoirs but filled with economical fluids.

To map fluid accumulation opportunities, we propose a new semi-automatic seismic interpretation method. It can start at the deepest part of a seismic data, possibly related to a source kitchen or at any sweet spot firmly associated to a secondary fluid migration. Then, surgically inserted seeds seeks petrophysical-related amplitude responses, tracking connectivity of the seismic samples correlated to the desirable fluid mapping. Based on the concepts of EDHI cubes, the tracking intends to follow possible fluid expressions (gas or oil) along a sedimentary column in a basin, until that point where they fill existent reservoirs or, undesirably, gets lost on the shallowest regions.

While conventional reservoir mapping uses concepts of stratigraphy and structural geology, fluid tracking should be considered as a hybrid mechanism between such concepts and it is established based on several seismic tracking criteria. Here, we present one of these hybrid concepts: volumetric mapping associated with sedimentary sequences with juxtaposition of faults and fractures. It physically can start with the definition of parameters for a specified seismic seed during automatic detection, within any geologically intra-formation concept, like a set of sedimentary layers, building a parasequence.

According to Van Wagoner (1985), a sedimentary parasequence set is a succession of relatively conformable layers, genetically related and spatially limited by flooding surfaces and by their stratigraphically correlated surfaces. Because layers are conformable, they may include brief interruptions in sedimentary deposition (diastem) and do not have substantial periods of erosion or non-deposition (hiatus). Being genetically related, means that all the parasequence internal layers were deposited with lateral continuity in relation to the others: Walther's Law is valid. These concepts are very important to follow the fluid, as they can indicate the position of lateral stratigraphic barriers. Limited by flooding surfaces specify paleogeography of parasequences as critical parameter, once they form striking contacts that separate shallow water facies, underlying deeper water facies, and it is then possible to point out regions where a new genetic cycle would begin. Hydrocarbon tracking can start at the base of a parasequence, possible representing sourcing or a sweet spot for secondary migration, with important fluid seal at its top. These concepts are important to follow the fluid, as they can indicate regions where lateral and vertical petrophysical barriers exist trough one or several parasequences.

Tracking EDHI Cube in F3 Dutch Sector Block

In this work, we present approaches related to evidences that many exploration studies do not have a DHI cube that could be effective in detecting fluids. Then, questions arise regarding to what would happen with such proposed surgical tracking for these cases. Besides, evaluations would be carried out with doubts about what could represent the volumes derived from samples with distorted magnitudes, whose would not represent effectiveness for DHI.

Figure 1 illustrates the 3D seismic for F3 Block in Dutch Sector in North Sea, Netherlands, whose availability is kindly done by DGB Earth Sciences. It is a Post Stack Time Migration (PSTM) with a very good quality for Cenozoic layers greatly affected by salt tectonics and by depositional features of clastic sedimentation, where the Eridanos delta stands out economically due gas accumulations.

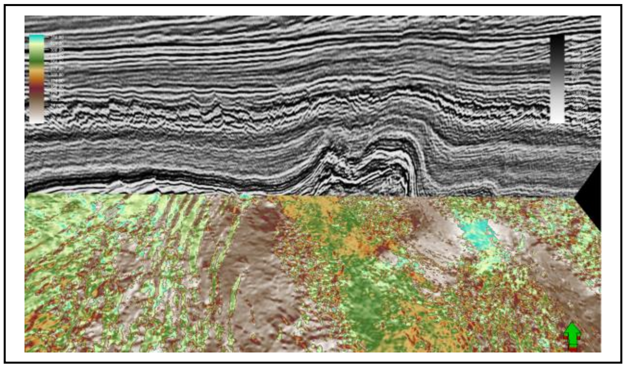

Figure 1 - Example of an Inline of amplitudes in the F3 Dutch Sector block, with clear manifestation of the salt tectonics present in the study area, intercepted by a Time Slice of the seismic layer azimuths.

A common type of DHI evident in F3 Block is related to gas chimneys, flat spots and shadow effects, caused by different seismic wave propagation effects that are manifested through distortions in the seismic response related to gas upward movement and residual accumulations, causing reduction of bulk elastic properties, and generating wave scattering with image defocusing of the reflected energy.

Figure 2 shows a seismic surface related to the structure that represents the reflection of the deepest layer integrally available on PSTM data, showing effects of salt tectonics, with several dome structures which control the spatial distribution of gas pathways in the area as shown later.

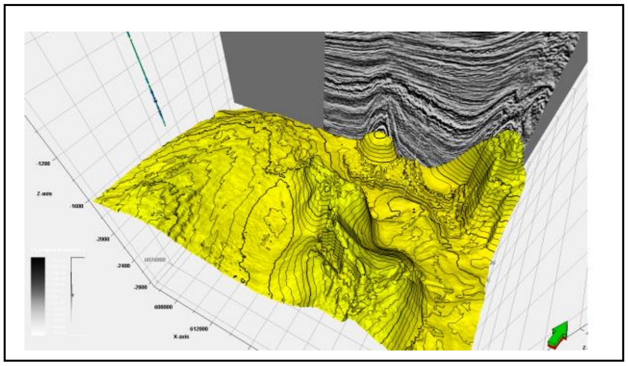

Figure 2 - Seismic surface related to the structure that represents the reflection of the deepest layer of the available PSTM data, with the effect of the salt tectonics that generates several dome structures.

Figure 3 illustrates a 3D Inline and the deepest available Time Slice, from an EDHI cube used in this work. The greenish tones look indicate possible manifestations of hydrocarbon routes and the blue arrow points to the blue drop of magnitude, related to an indication of a sweet spot adopted as the surgical seed for the tracking practiced here. This point was considered as the deepest representation of gas migration, in the available data.

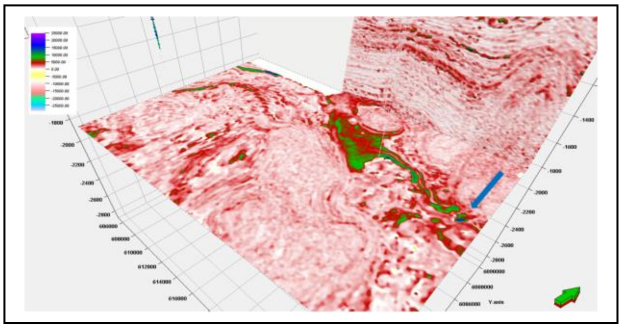

Figure 3 – EDHI cube with Inline and the deepest available Time Slice. The blue arrow points to the sweet spot for the applied surgical mapping seed

Figure 4 illustrate 3D response of the surgical mapping that sought connectivity around samples similar to the provided seed. Resulting seismic body configuration suggest an evidence of fluid pathways. The greenish hues suggest fluid accumulations, with the highest concentrations represented by the lilac hues, all graphically intersected by the same Time Slice illustrated in Figure 3.

All tracking resources applied in this work are conventional components of the Seismic Interpretation module contained in Petrel - Schlumberger.

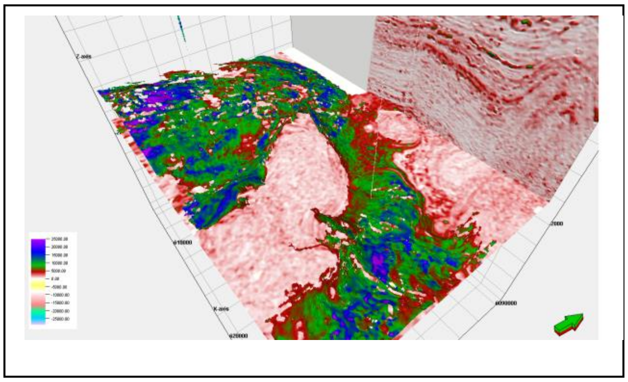

Figure 4 - Inline and Time Slice, the deepest available, in the EDHI cube used here with the 3D response of the surgical interpretation that sought the connectivity of all samples similar to the provided seed,

All EDHI here presented are illustrations for interpretative concepts and then subject to further and integrated analysis.

Conclusions

Seismic interpretation is a fundamental step in the reflection method. DHI cubes are critical to follow fluids. New theory and methods are presented to allow to seismically tracking elements of an petroleum system, derived from concepts of Effective DHI cube. We look for indications of fluid source, secondary migration, seal, charge, retention, and reservoir filling, using qualified post stacking data, designing surgical seismic interpretation to effectively follow a fluid path. Results has shown enhancements of the DHI role as important tool for seismic exploration.

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