Follow the Fluid: The Importance of Surgical Interpretation in a DHI Seismic Volume

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Abstract

Nowadays, when quite a lot of modern methods of seismic interpretation come to be assisted by artificial intelligence algorithms, it is necessary to dedicate our attention to interpretive seismic criteria that can hardly be treated with the help of the machine, either supervised or not. In order for any mapping to be successful, It is crucial defining what are the conceptual methods resulting from the experience and learning of the interpreter, which requires his prior knowledge of geological or petrophysical events. In this sense, interpretation can be proceeded by semiautomatic methods, in which the interpreter inserts his knowledge and must select amplitude and phase of the seismic sample that he wishes to spatially correlate. It is a simple logical association of what he knows about a certain seismic phenomenon and how this phenomenon should be tracked, using a spatial search seed, correlating samples, either by similarity or by any other mathematical criterion.

At the 1st Summer School of UFF and UERJ (2021), we launched a type of tracking seismic samples, named Surgical Seismic Interpretation. It aims a semi-automatic tracking, through a manual intervention in the sampling nucleus of the seismic event to be tracked, considering its dominant characteristics of magnitude, frequency and phase, tracking samples according with its spatial continuity and similarity with the original core, or its seed.

The generic concept of semi-automatic seed mapping is not new, having been on the market for more than a decade. Here we present a differential form of an interpretative intervention, which seeks related samples originally associated with a fluid. For this case, tracking does not have individualized stratigraphic or structural characteristics, but rather petrophysical aspects, which are a hybrid scenario between permeability controlled by either sedimentary or structural facies in juxtaposition.

For this hybrid scenario if, for example and by conceptual similarity, we adopt seismic stratigraphy concepts, the most appropriate procedure is the seismic sample tracking through sedimentary sequences, starting at source kitchen, following the secondary migration, and the related accumulations in reservoirs, fitted in each sequence or migrating for a new top or side of a parasequence. Naturally, all of these diagnoses must be carried out on seismic volumes that reflect the best direct indicators of the main elements of a petroleum system, in the traditional way of direct hydrocarbon indicators (DHI). The better, or more representative, be a DHI volume used for seismic samples to be tracked, the better and more realistic the petrophysical response of each mapping carried out.

Here, are exemplified surgical scans for F3 Block Dutch Sector seismic amplitude volume

Introduction

In addition to the geometrical, or structural, mapping of seismic samples that generally generates a surface that represents a mapping, such as top or bottom of a reservoir, or even a lithological unconformity, a salt body, one major objective is the projection on such a surface of the average or instantaneous property of the seismic samples.

Herron (2012) shows that a traditional seismic mapping consists of tracking distinct patterns, which traditionally correlate to geometries, continuities, discontinuities, facies, etc., and for it the interpreter must have specialized knowledge in the sedimentary models that he will be seismically mapping and experience enough to do so.

Dominguez-Colin et al (2017) present an interesting semi-automatic tracking technique, in a segmentation process over seismic images, obtaining sets of binary masks represented by geobodies. This requires knowledge of the local outcrop geology (study area) and wells.

In the oil industry, interpretation is usually done interactively, at a workstation, and the semi-automatic way has an increasingly importance to make available knowing factors for it, being associated to a strong control of the interpreter and to a knowing the geological history of any area to be studied. These factors are important in making high-quality decisions when interpreting seismic data, by the importance on having comprehensible factors that have influenced sedimentation, tectonics and fluid migration in a studied basin.

Classifications of seismic interpretations

Seismic interpretations can be classified by different methods. In general, this happens according to geoscientific objectives, or for their conceptual foundations linked to subjects of structural, stratigraphy, petrophysics, fluid and others. They can also be classified by the effectiveness to which one wishes to map (for carbonates, for salt, for turbidites and for other lithologies) and can be classified by the accuracy and precision of what one wishes to interpret (regional, semi-regional, reservoirs, production zones, etc.).

In terms of styles trace gathering the seismic data, used for mapping, they can be classified as Pre-Stacking (traditional DHIs indicators, anisotropy, common offsets, etc.) and Post-Stacking (DHI, geometry, textures, facies, etc.)

Considering ultimate technologies, a traditional or even modern, seismic interpretation should be analyzed, qualitatively and carefully, related to its practical utility to achieve its objectives, for its effectiveness, for its accuracy and precision for what one wishes to interpret. When any of these factors are not observed, or when they are not analyzed and considered, a strong loss of quality in the seismic interpretation can be generated and bring uncertainties that lead to incalculable financial losses, sometimes intangible, to any geoscientific or engineering project.

Among the most traditional types of mapping, the one related to tectonic styles can provide a broad context for understanding the pattern of faults and folds, which suggests styles of physical construction of sedimentary basins and which can be estimated in large areas of study. Its basic utility is to identify certain geologically formal and basic patterns of deformations that have analogies throughout several geological provinces around the world. Many traditional examples are related to basins with extension, compressive and transform tectonic activities, which define growth faults, structural block boundary faults, rollover anticlines, ridges of structural collapse, synthetic and antithetic faults, reverse and normal faults, fractures, etc.. All their patterns have fundamental roles in the understanding of hydrocarbon secondary migration pathways, as they can be juxta positioned to carrier zones that can be directly connected to source rocks.

Among the seismic interpretation products generated by traditional mapping methods, are those related to the tracking of seismic samples by semiautomatic operation. It uses seeds of magnitude and phase of samples to be tracked, defining how connectivity and similarity between neighboring samples is sought. Such methods preceded several other fully automatic methods using artificial intelligence, which are undergoing rapid and accelerated technological development. Here, a new semiautomatic interpretation method is presented. It differs from traditional methods when applied on DHI cubes. It does not follow straightforward concepts for neither structural nor stratigraphic, but rather a hybrid features array, combined with petrophysical interpretive factors, whose effectiveness, accuracy and precision depend critically on quality of seismic volume adopted as DHI cube.

DHI Anomalies

DHI anomaly cubes are built for obtaining direct seismic evidences of hydrocarbons from conventional Post-Stacking or Pre-Stacking data. It is considered that seismic response from primary wave is able of showing variations in elastic constants that can be associated with the presence of hydrocarbons in the pores of rocks.
Fahmy et al (2008) mention that ExxonMobil DHI-AVO best practices recommends that many factors must be evaluated in order to achieve an understanding of the drill risks, basically involving AVO attribute. In order to obtain such an understanding, the seismic responses from near and far offsets traces 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.
Along the last two decades, many seismic investigations have been done about how to identify and tracking true DHIs.
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.(2000), 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. They also mention that studies have revealed that chimneys can represent a link to deeper hydrocarbon accumulations.
Ligtenberg (2005) presents a workflow dedicated to elucidate fluid migration pathways and faults on seismic data. The method is capable of enhancing patterns in the seismic data amplitudes that are related to fluid migration, combining a set of advanced seismic attributes with neural network technology and is 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, which may provide better insight in the lateral and top seal quality migrate fluids to charge shallow sands, thus indicating the shallow gas drilling hazards and hydrocarbons reaching the seabed, creating mud volcanoes and pockmarks; the occurrence of such features.

Traditional DHIs cubes show anomalies of seismic amplitude that normally occur related to differential presence of hydrocarbons in the rock pore. They happen due to an enough change in the fluid content of the pores, which causes a change 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 hydrocarbon exploration wells, mainly to reduce uncertainty and risks.
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 associated with the accumulation of hydrocarbons. A fluid in the porous

space generating an absolute increase in the reflection coefficient can cause anomalous amplitude variation.

The most common and better described DHI in literature for Post Stacking seismic data is related to Gas Chimneys (Connoly et al, 2021). Many examples are registered and it occurs when a hydrocarbon accumulation escapes from a deeper level in the geographical sense of more remote regions upward, due to any fail from seal element in general, along a fault plane or verticalized fracture zones, and may generate a gas seismic cloud.

Other common DHI from seismic response is Flat Spot, which represent an apparently flat hydrocarbon contact that can be between gas and oil, oil and water or gas and water (sometimes they are not perfectly flat).

Dim Spots, Phase Change and Shadow Effects are the other DHI effects very well described by oil industry literature.

Recognition of any amplitude DHI needs a good quality seismic data.

The Need of High-Quality DHI Cubes

All forms of DHI described before need to be effective in the sense of being valuable for the economic demands they propose, keeping the indispensable precision and accuracy of each information generated, reducing involved seismic uncertainties. Any DHI cube needs to be effective also for a full spatial understanding of the involved petroleum system.

We point that an effective DHI cube is one that, in addition to the direct hydrocarbon indicators mentioned before, should also show seismic evidences for each element of the petroleum system: source, migration, charge, seal, reservoir and retention (Santos et al, 2021). With these evidences, it is possible to follow the fluid path, from sourcing to filling reservoirs. An optimal DHI cube will be one that can show multiple exploration opportunities. Such DHI must clearly distinguish hydrocarbon pockets, from the kitchen, through points of route redistribution (dilatation) and final accumulations (reservoirs). To map such opportunities, a new semi-automatic seismic interpretation method is suggested here, which starts at the deepest part of a seismic data, surgically inserting a seed, which seeks petrophysical responses in the amplitudes, and follows, also surgically , the connectivity of the seismic samples correlated to the desirable fluid for mapping: thus, the surgical amplitude mapping is defined.

Surgical Seismic Interpretation: following the fluid

Here, up till now, we mentioned classic DHIs, which are traditionally interpreted in seismic cubes of primary wave amplitudes, or their spatial relationships, and desirably treated as possible quantitative indicators of the presence of hydrocarbons.

Based on the qualitative concepts of these cubes, a traditional semiautomatic method of interpretation is here used, but now applied to a DHI cube which may indicate the beginning, or the available information about the physical process for fluid secondary migration (gas or oil), surgically identified, tracked and interpreted: Surgical Spatial Interpretation from a DHI cube. The tracking is intended to follow possible fluid expressions (gas or oil) along the sedimentary column in a basin, until it fills certain reservoirs or, undesirably, gets lost on the shallowest surfaces.

Seismic Method to Follow the Fluid

One of the qualities required by modern seismic interpretation, is that it must recognize all possible fluid migration routes, until it reaches and fills reservoirs. In this sense, following the fluid becomes the most fundamental objective of 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 fluids. Considering that reservoir mapping considers concepts of stratigraphy and structural geology, fluid tracking can be considered as a hybrid mechanism between such concepts and is established based on several seismic tracking criteria.

Here, one of these hybrid concepts is presented: a mapping associated with sedimentary sequences with juxtaposition of faults and fractures, and that physically begins with the definition of parameters for seismic samples automatic detection seed, from determined seismic evidence of a source kitchen, or even from a secondary migration sweet spot. From there, DHI events are tracked with a geologically intraformational concept, or within one or more parasequences, constructive logic until the reservoirs be filled.

According to Van Wagoner (1985), a sedimentary parasequence set can be defined as 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 internal layers of a parasequence 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 paleogeographies of parasequences as critical parameter in their definition, 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.

Hydrocarbons indications at the base of the parasequence, possible representing sourcing or a sweet spot for secondary migration, and at its top, under an important fluid seal, are important factors to observe along the tracking. These concepts are important to follow the fluid, as they can indicate regions where vertical stratigraphic barriers exist.

The Importance of an Effective DHI Cube for Block F3 Dutch Sector

In this work, we present approaches to issues related to the fact that many exploration operations do not have a DHI cube that is effective in detecting fluids. Then, questions arise regarding what would happen with such surgical screening. Associated with this analysis, evaluations are carried out of what could represent the volumes detected with the distorted magnitudes then tracked, which amplitudes would not be an effective DHI cube.

Figure 1 illustrates the 3D seismic for F3 Block in Dutch Sector in North Sea Netherlands, whose availability is kindly made 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 characteristics of clastic sedimentation, where the Eridanos delta stands out economically.

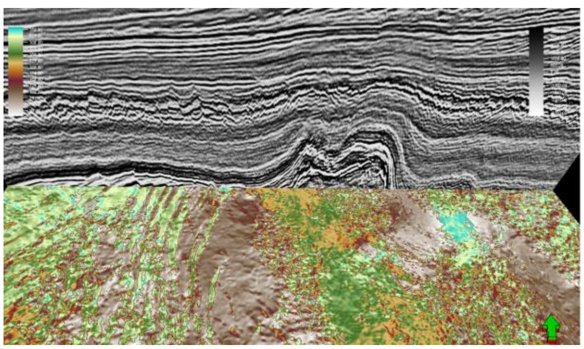

Figure 1 - Example of an Inline of amplitudes in the F3 Dutch Sector block, with clear manifestation of the salt tectonics present in the study area, intercepted by a Time Slice of the seismic azimuths.

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

Figure 2 shows a seismic surface related to the structure that represents the reflection of the deepest layer of the available PSTM data, and that shows the effect of the salt tectonics, with several dome structures. These structures control the spatial distribution of gas pathways in the area.

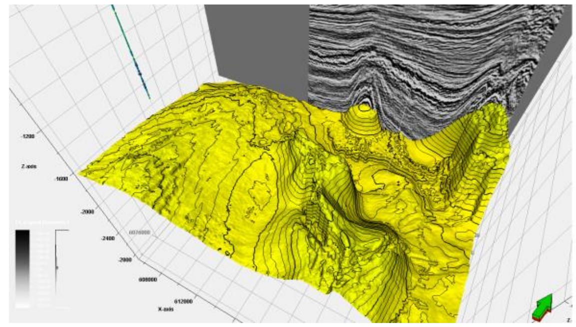

Figure 2 - Seismic surface related to the structure that represents the reflection of the deepest layer of the available PSTM data, with the effect of the salt tectonics that generates several domestic structures.

Figure 3 illustrates a 3D Inline and Time Slice, the deepest available, in the DHI cube used in this work. The greenish tones are related to manifestations of hydrocarbon routes and the blue arrow points to the blue drop of amplitude, indicating the sweet spot adopted as the surgical seed in the mapping practiced here. This point was considered here as the deepest representative of gas migration, in the available data.

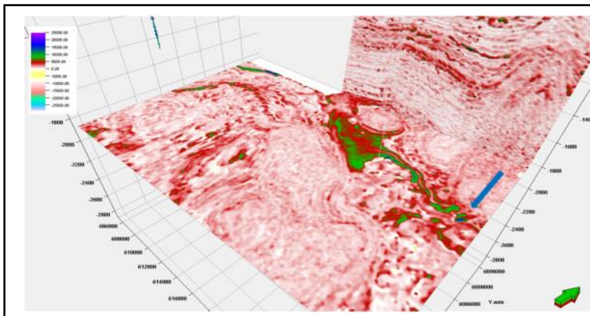

Figure 3 - Inline and Time Slice, the deepest available, in the DHI cube used here in this work. The blue arrow points to the sweet spot for the surgical mapping seed

Figure 4 illuminates 3D response of the surgical mapping that sought the connectivity of all samples similar to the seed provided. The resulting body configuration is the evidence of the fluid pathways for the detected fluid. The greenish hues suggest accumulations of gas, with the highest concentrations represented by the lilac hues, all graphically superimposed on the same Time Slice illustrated in Figure 3.

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

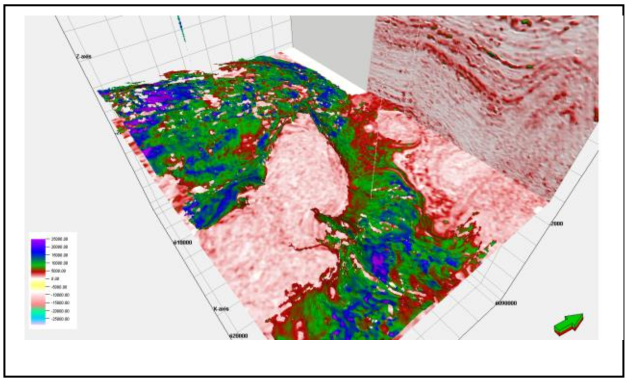

Figure 4 - Inline and Time Slice, the deepest available, in the DHI cube used here with the 3D response of the surgical interpretation that sought the connectivity of all samples similar to the seed provided,

Conclusions

Seismic interpretation is a fundamental step in the reflection method. DHI cubes are critical to follow fluids. New theory and method are presented that allows to seismically trace elements of an oil system, from an effective DHI cube, in post stacking data, defining a surgical seismic interpretation to effectively follow the fluid.

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