PS Seismic Attenuation Workflow for Lithology and Fluid Interpretation*

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Abstract

A seismic interpretation workflow was developed by using well log information, rock physics modeling and seismic attenuation analysis. From the well log information, rock physics modeling was performed to calculate the seismic attenuation within the lithological facies of interest. The workflow starts by using rock physics diagnostic and template tools in order to establish the theoretical model that best represents the lithological facies. Moreover, the Dutta-Odé (1979) patchy saturation model is used to determine the attenuation values by changing the gas saturation. From this, with an equivalent viscoelastic standard model (Zener, 1965) and by the knowledge of the high and low frequency limits of the complex modulus, a constant Q (quality factor) can be obtained (Dvorkin-Mavko, 2006). The rock physics templates address the seismic relations of velocities, acoustic impedance and attenuation with respect to diagenesis, compaction and saturation trends. These elements constrain the seismic properties to guide for prospective hydrocarbon areas.

The attenuation estimations from rock physics modeling were used to generate synthetic seismograms to assess the attenuation impact in the seismic response for interpreting the field seismic information. Few methods for calculating attenuation were tested in the controlled synthetic seismograms to find out which method could be the most stable in the real seismic data. For instance, in the seismic modeling, the bandwidth was varied to see the impact that high and low frequencies might generate on the seismogram and understand how that could affect the method for calculating attenuation in real seismic information. Seismic models with different scenarios were created to analyze what to expect when calculating attenuation, e.g., ranging below 1 Hz. The results of the estimated attenuation in real seismic traces around the well were compared to those modeled by rock physics and seismic modeling.

Application of the workflow for a gas reservoir in the Gulf of Mexico is discussed.

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1) Facies characterization from logs.

The clastic reservoir shown here is composed of lithic sandstones of the lower Miocene with a fine to medium grain texture with variable distribution of clay content. The porosity ranges from 15 to 20% with some gas saturation up to 40%. Cores and well log analysis provide quantification of the mineral fractions, porosity, saturation, effective pressure, elastic properties, etc. for each facies within a depth interval of interest. In order to apply a deterministic rock physics model at reservoir conditions, it is also important to consider the corresponding fluid properties.

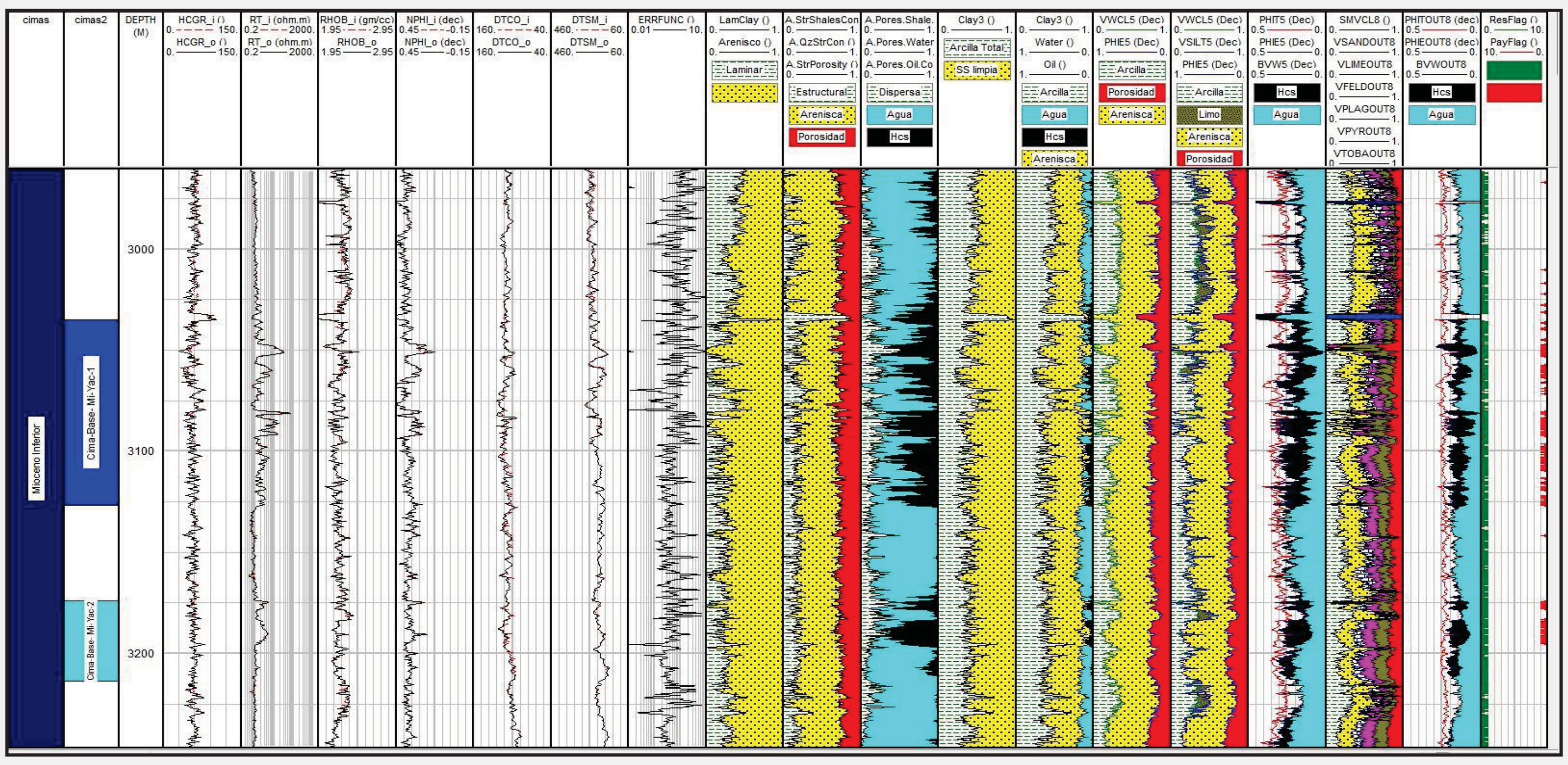


Fig. 1 Determination of the lithological, petrophysical and elastic properties from the well logs and cores available in the depth interval of the reservoir.

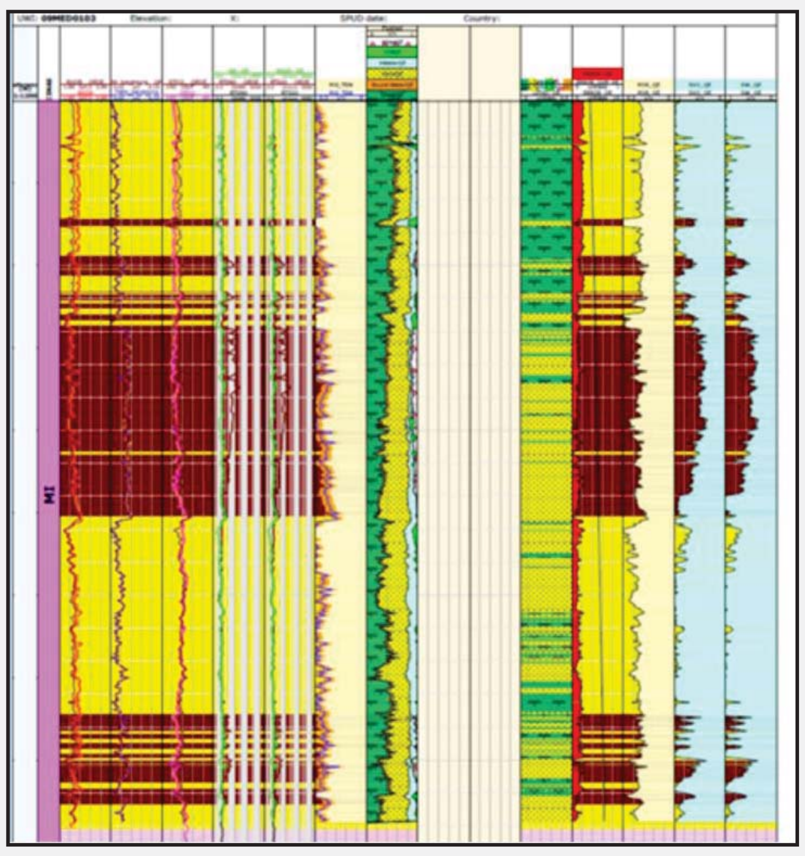


Fig. 2 Depth interval (2800 to 3250 m). Red brown color shows the gas-saturated facies.

2) Rock physics modelling of the reservoir

By taking into account the sedimentology, well log analysis and rock physics diagnostics (e.g., Avseth, et al., 2010; Dvorkin et al., 2014), the theoretical model that best represent the reservoir in this case is the soft-sand model (Dvorkin & Nur, 1996).

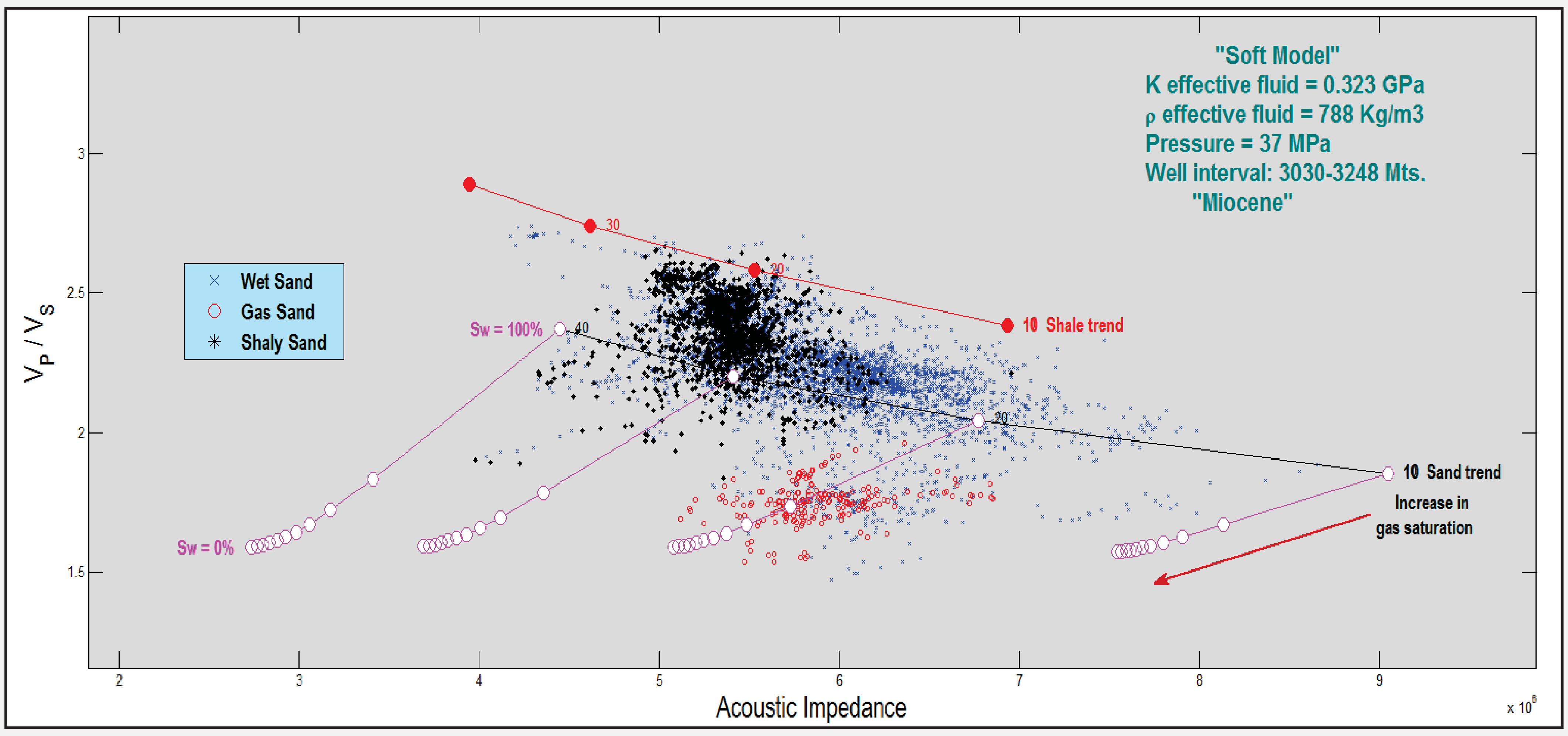


Fig. 3 The rock physics template for this clastic reservoir. The data in black is shaly sand, blue is wet sand and red is gas-saturated sand.

3) Calculating the inverse quality factors

The patchy saturation model by Dutta & Odé (1979) was used to determine the seismic attenuation effects by changing the gas saturation. One starts using the parameters of the soft-sand model that best represents the reservoir with additional information needed in the poroelastic model, such as permeability, fluid viscosity and a “critical size” parameter, below which the patch is relaxed from the wave excitation. In practice, this characteristic scale of heterogeneity is difficult to establish.

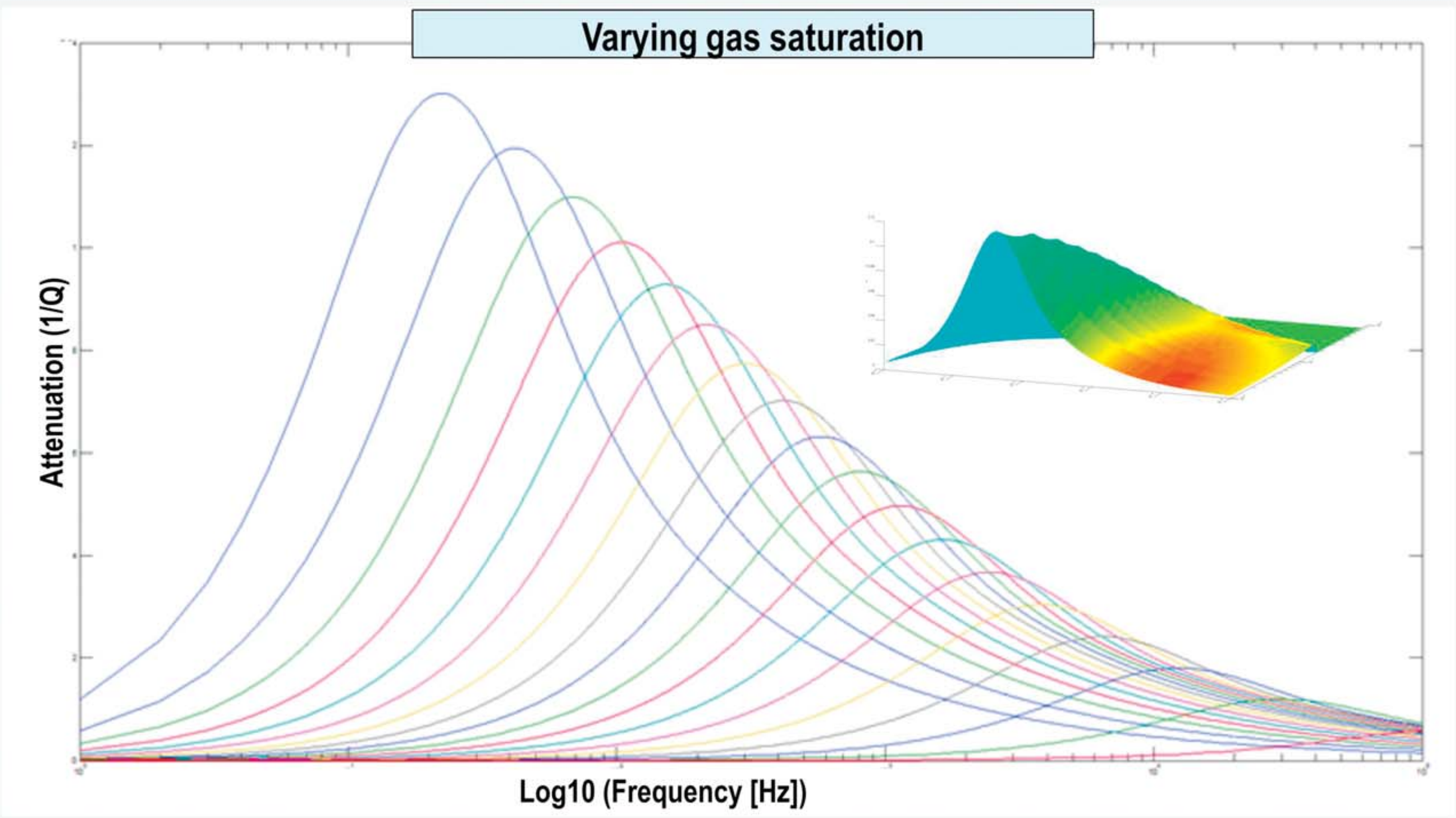


Fig. 4 Example of the patchy saturation model. Attenuation is frequency dependent. By changing the gas saturation, the maximum attenuation deviates to a higher frequency and reduces to a smaller value. In fact, the maximum attenuation value in each case is associated to about 87% of water saturation (see Fig. 5). So areas of larger gas will have lower attenuation (but yet observable) than areas of almost fully water saturation.

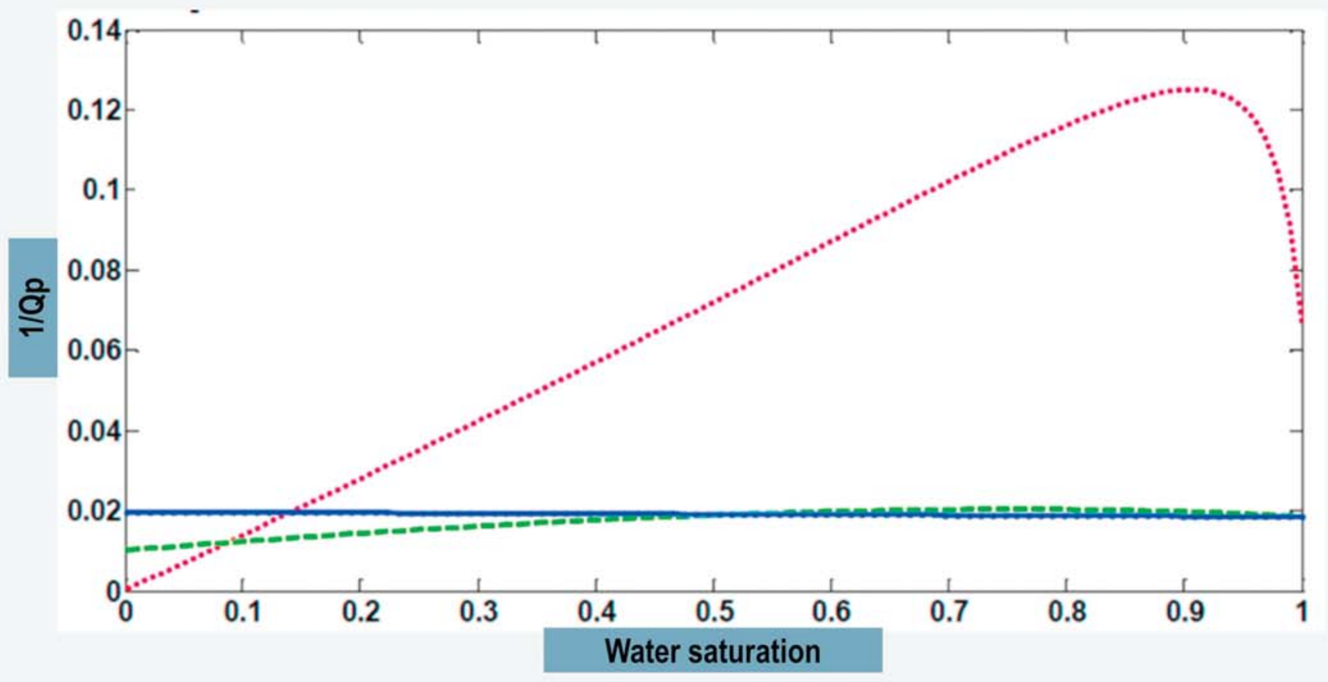


Fig. 5 Attenuation vs Saturation. Red line is water saturation against gas saturation. Maximum value around 87%. Blue line is water substituted by itself. Green is by substituting to oil. How can we relate frequency dependent attenuation to gas saturation?

The frequency dependent modulus dispersion is characterized by a relaxed low frequency limit, by an unrelaxed high frequency limit and by a characteristic frequency at maximum inflection where attenuation is at maximum. So according to the standard linear solid (SLS; Zener, 1965), the maximum inverse quality factor is at the critical frequency, taking the corresponding relaxation limits into account. In order to obtain the attenuation logs, the Dvorkin & Mavko (2006) theory was used for calculating the P and S inverse quality factors at partial and full saturation that is based on the SLS model.

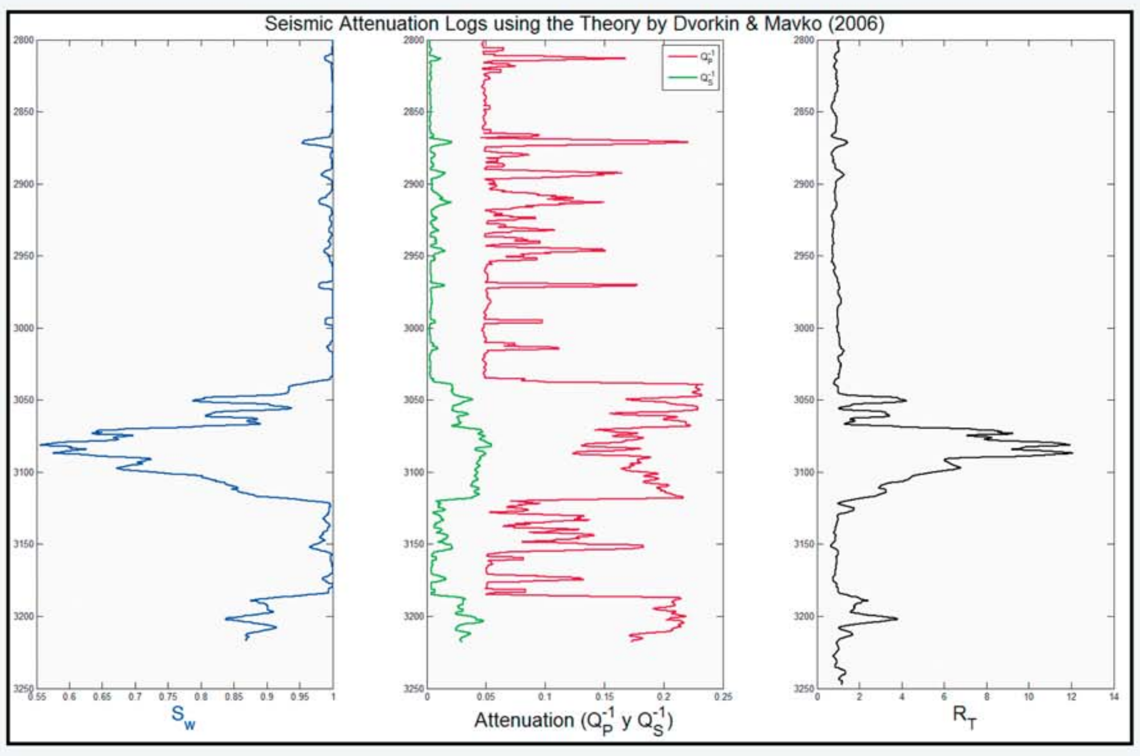


Fig. 6 Attenuation results for the 2800-3220 m depth interval. Notice in the gas saturated that for higher gas saturation smaller the attenuation is, however perceptible.

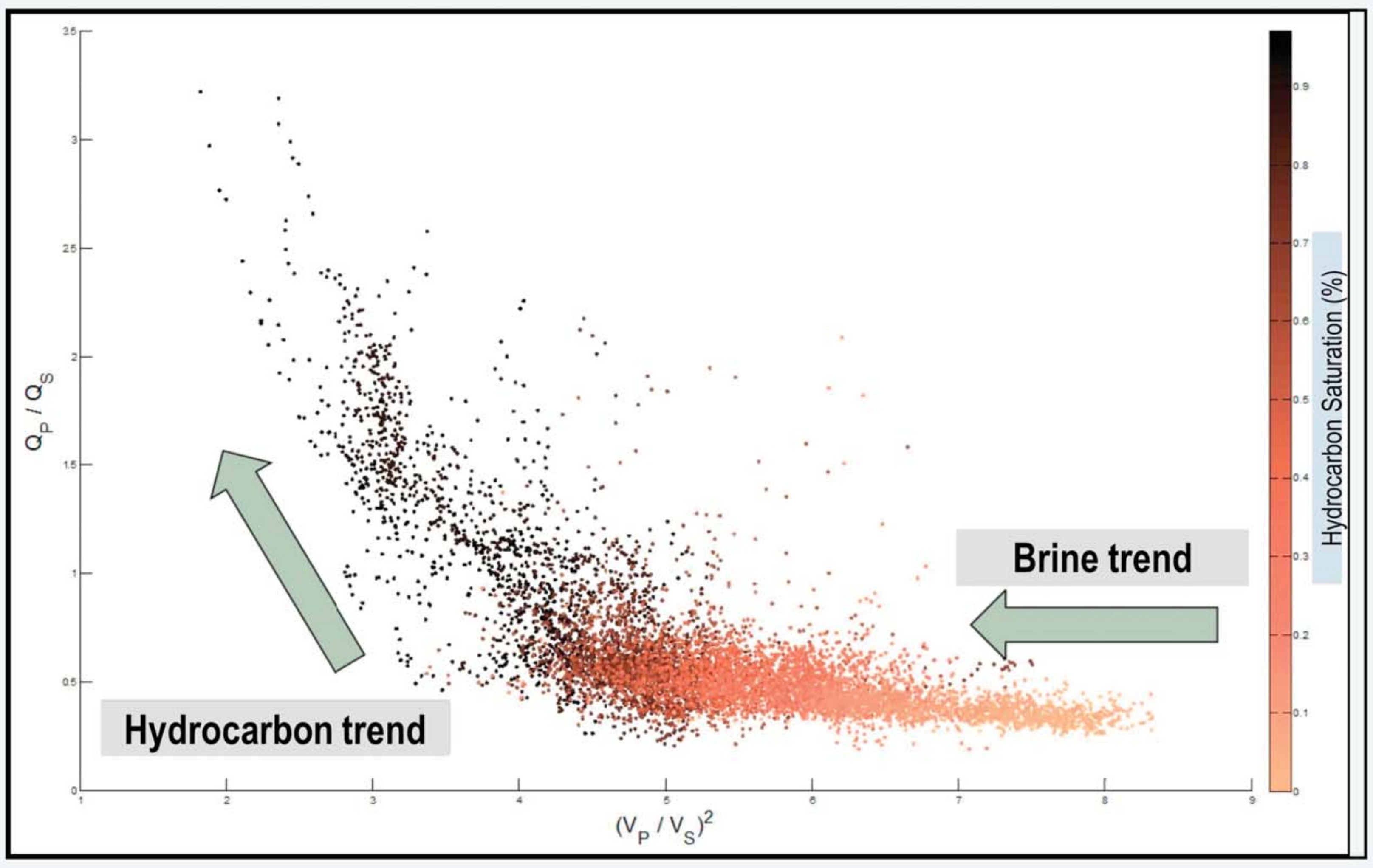


Fig. 7 Crossplot of the quality factor ratio vs. the squared velocity ratio. Light color represents small amount of gas saturation (linear brine trend) whereas darker color is higher gas saturation showing an “hydrocarbon trend” where the higher the gas saturation, larger is the value of the quality factor ratio. Could this trend be observed in the seismic information?

4) Obtaining attenuation from the seismic data

It is important to perform an attenuation analysis in the seismic data to assess its feasibility. This can be accomplished by taking spectral measurements above and below the seismic horizon. By an appropriate normalization, one may compare the frequency differences between each spectrum, which helps in determining which frequency band is more attenuated. One can also take the difference or the ratio between the spectra. That provides a relative quick idea of the attenuation present and helps in deciding which seismic attributes are useful.

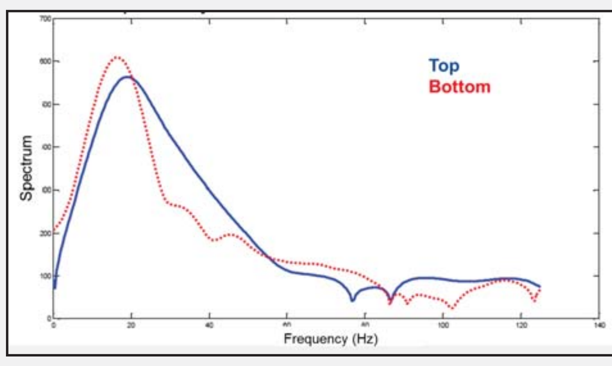
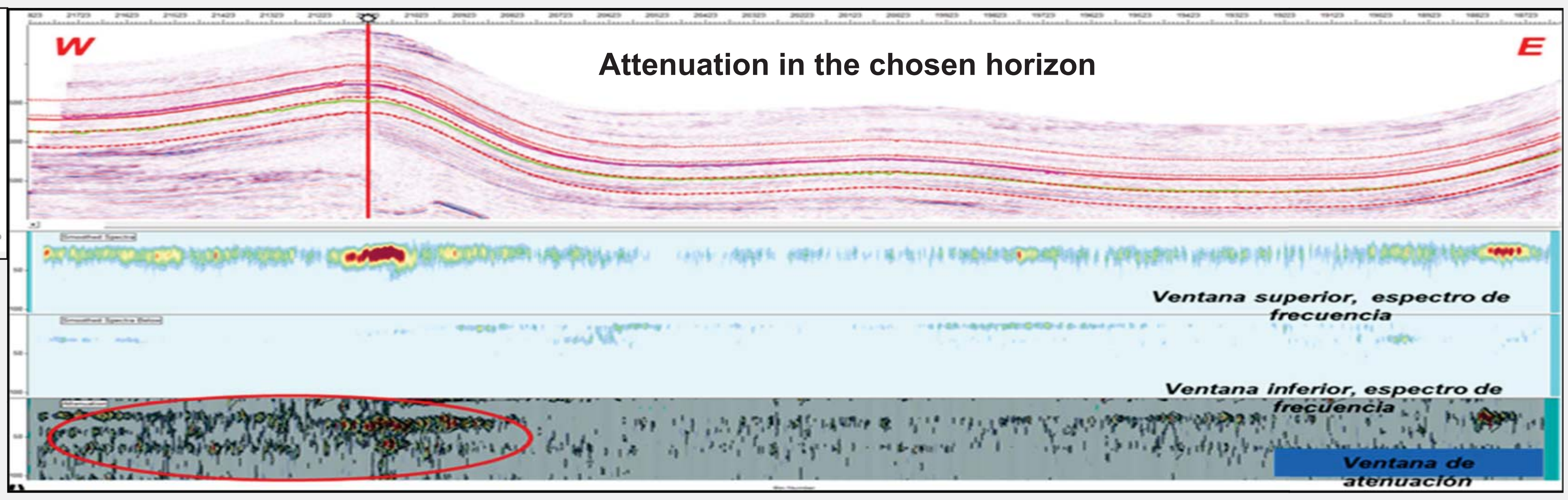


Fig. 8 Example of the spectral analysis in the top and bottom of the seismic horizon.



Several methods for attenuation estimation of the seismic data were analyzed (*e.g.* Del Valle *et al.*, 2002; Ramirez *et al.*, 2005; Cheng, 2013). Synthetic seismograms were generated (Kennett, 1975) using the Backus (1962) averaged elastic and attenuation logs. The seismic models include noise and different frequency bands. It was observed that including the low frequency below 1 Hz improves the stability of the attenuation estimation. The results of the estimated attenuation in real seismic traces around the well were compared to those modeled by rock physics and the seismic modeling.

A seismic facies classification was performed, using the following attributes: attenuation, relative acoustic impedance and spectral decomposition around 30 Hz.

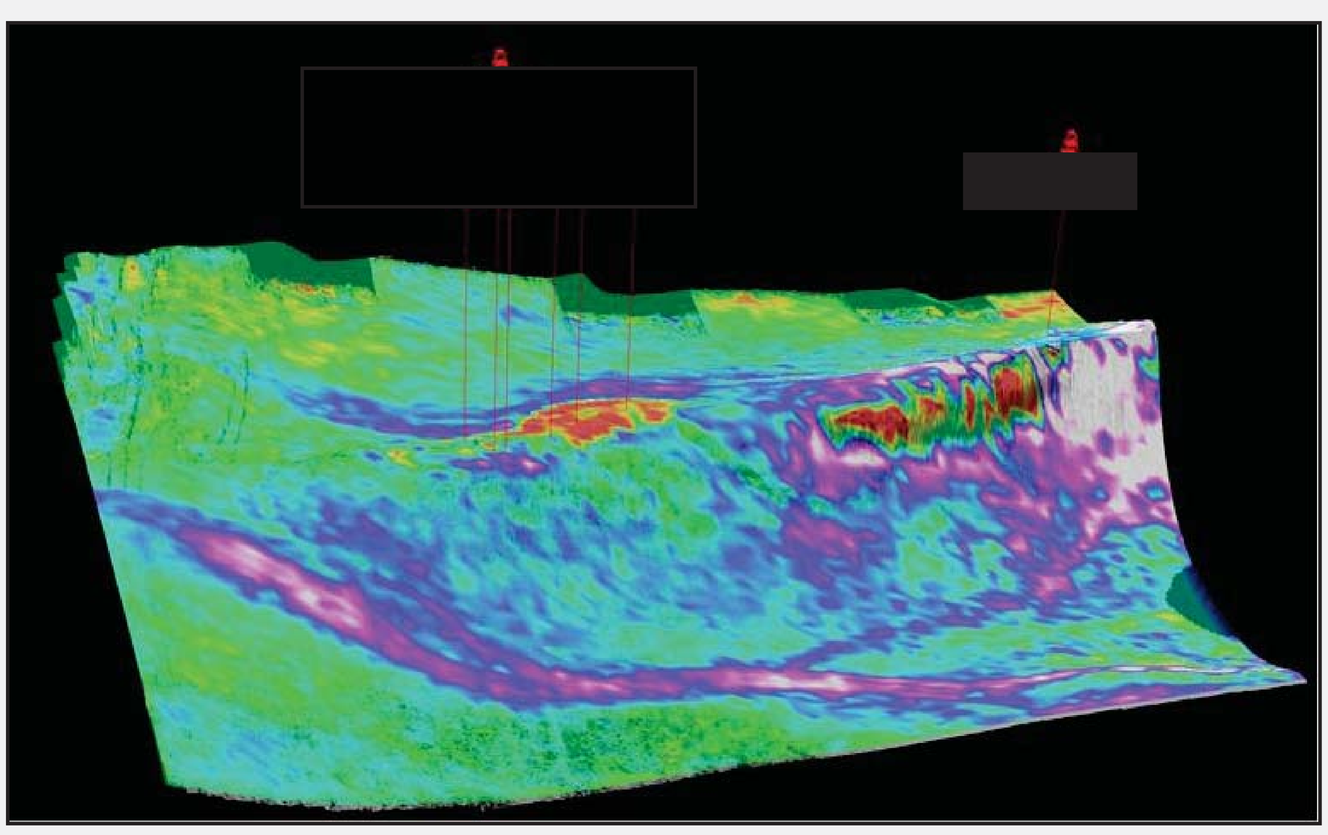


Fig. 9 Acoustic Impedance of the seismic horizon.

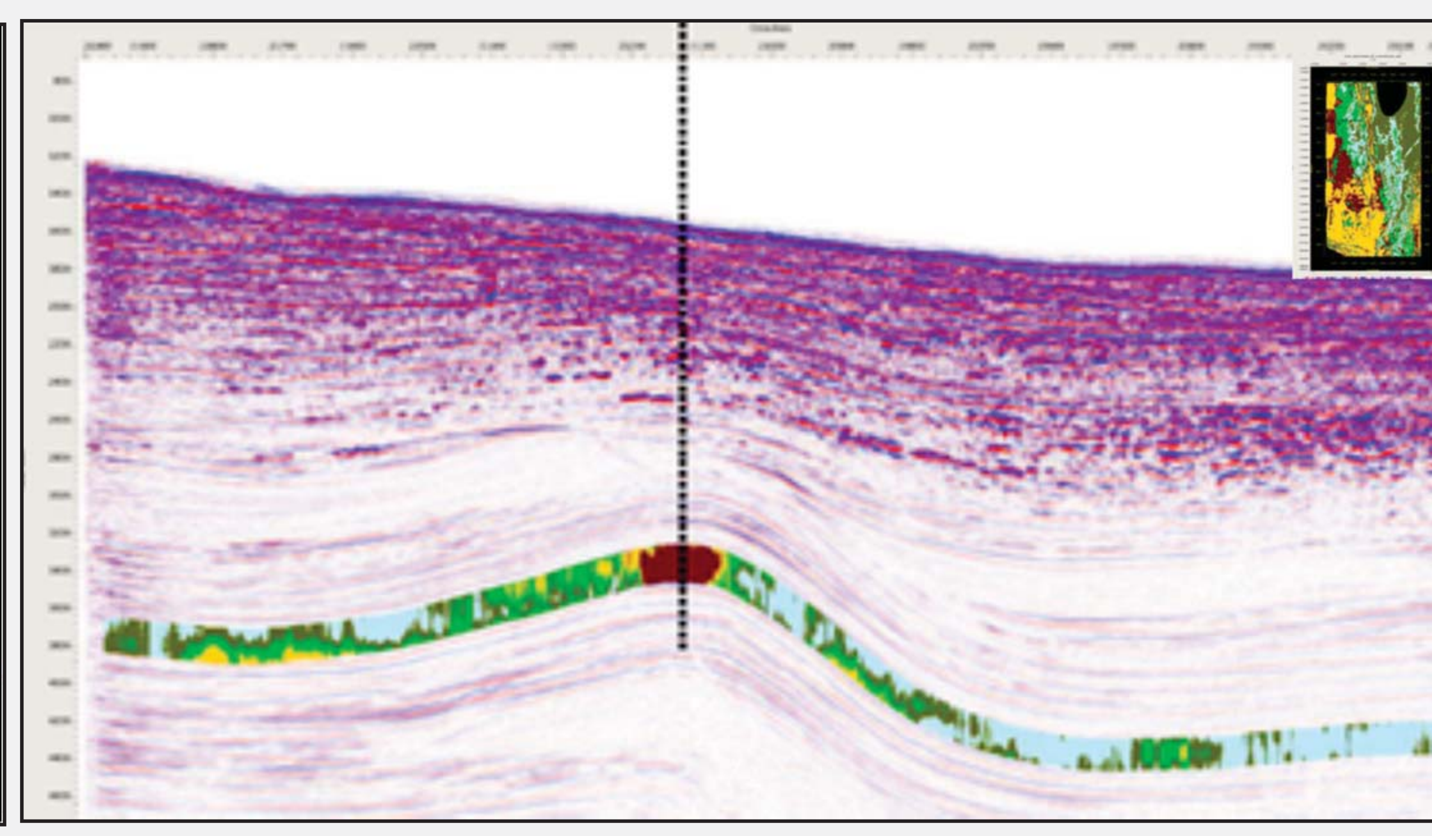


Fig. 10 Seismic facies in the horizon. Five facies were chosen for the classification. Red is gas saturated sand.

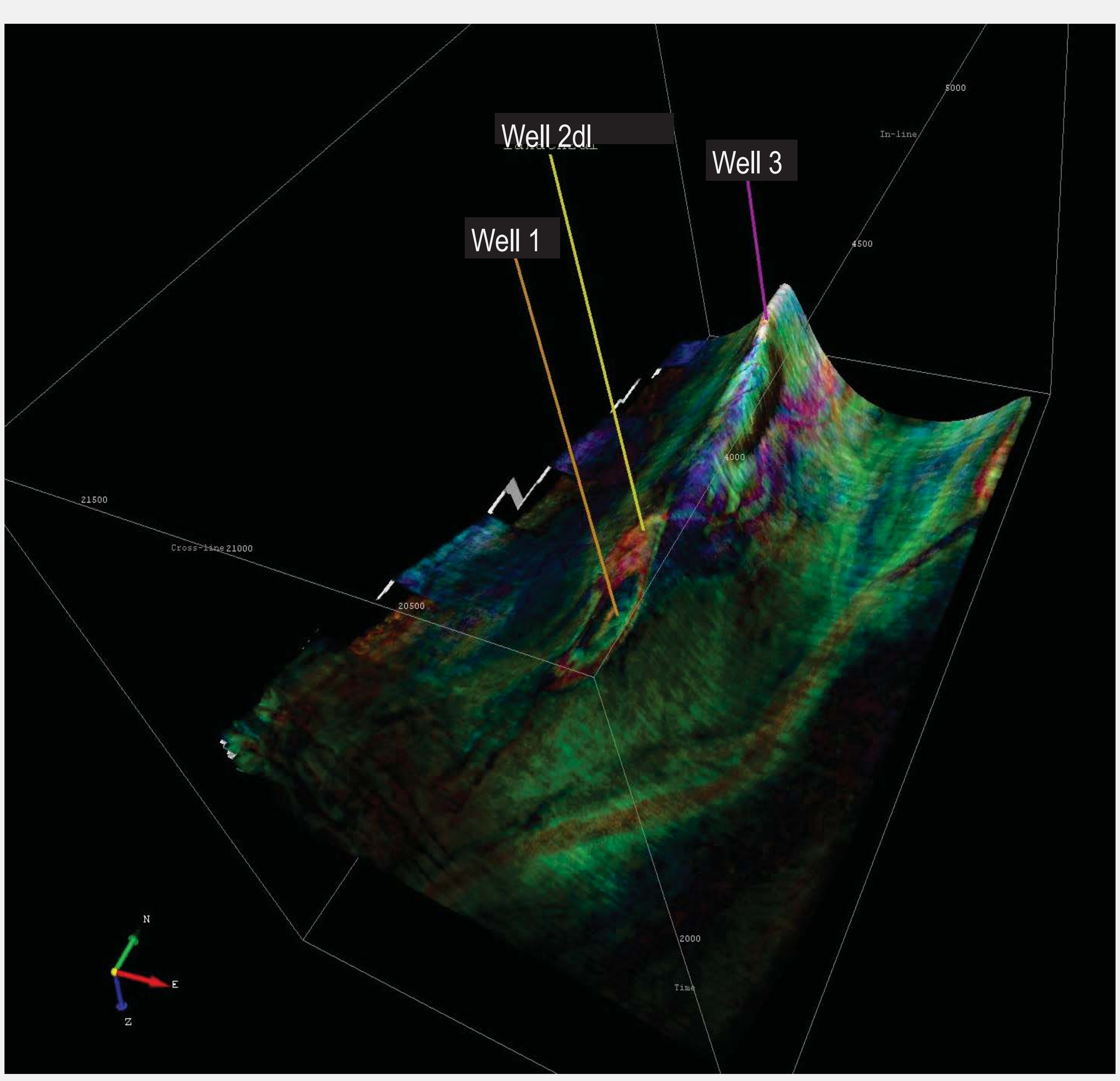


Fig. 11 Seismic facies classification. Red is the gas saturated sand.

Discussion

The workflow was pretended first for the feasibility of the seismic attenuation by performing, at the well level within an interval of interest, the facies characterization and the rock physics modeling. Second, the rock physics model is then treated as a poroelastic media, either by using a rather expensive patchy saturated or a faster but generally reliable viscoelastic model, in order to calculate the attenuation. By increasing the gas saturation, the attenuation pick is shifted to a higher frequency and reduces its value. Finally, the feasibility analysis of the attenuation of the seismic data was useful in providing some insight about what seismic attributes could better contribute in determining a guided seismic facies classification

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