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From digital rock to well seismic tie: Synthetic seismic data generation from well log curves obtained by digital rock analysis

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Abstract

Synthetic seismic data plays an important role during exploration studies and for reservoir characterization as well. Commonly, these data are generated from wireline log curves. This work presents a study related to an innovative technique developed to upscale elastic property trends, derived from plug analysis, onto whole-core dual-energy X-ray tomography images, that were implemented to generate well log curves, and, from these curves, synthetic seismic data was created. The results were compared to synthetic data generated from traditional wireline log curves. 1D synthetic was generated and a well-tie process was performed to verify the correlation with seismic volumes in depth and time domains. Synthetic offset gather was created and an amplitude analysis along seismic events was performed.

Introduction

Synthetic seismic data generation is a very important stage for both exploration and reservoir characterization phases. Once the 1D synthetic is generated, from well log curves, and it is tied to the seismic volume, this process provides important information to the geoscientist such as, for example, a time-depth curve, a depth-depth curve, more accurate values for the seismic events positions and more details about the sub-seismic events. Some of this information can be used, for example, to build the low frequency model for seismic inversion, to update velocity models and to help in a time-lapse seismic feasibility study. Likewise, the synthetic gather can be used, for example, to study the AVO response of the well region and help in a feasibility study. This is normally a regular workflow performed by geoscientists.

The innovation comes when a new methodology was proposed to test hypothesis of obtaining a synthetic seismogram directly from the Digital Rock Analysis (DRA) and upscaled Rock Types (RRT´s) obtained from digitization of the whole core and computation of elastic properties directly from core scanning. Scanned core has all required ingredients that such measurements need in high resolution, that might be able to be converted into the desired supported sampling to compute the reflection coefficient that ultimately would be convolved with seismic wavelet signature derived from field acquired data. Thus, this hypothesis was tested in a real case scenario that is the longest Lula pre-salt core with some challenges also present due to the fact this core is also deeply sided core, and some digital reconstruction was also necessary.

The objective of this study was to generate a 1D synthetic seismogram as well as a synthetic gather from the well log curves generated by DRA techniques. At same time testing this new methodology trying to answer some questions: Would it be possible to obtain a better result due to the nature of the high-resolution DRA obtained from scanned cores? Would it be possible to verify the compatibility of the method with traditional well-seismic tie workflow? Usually, geophysics compute the reflection coefficients based on density and compressional or shear wave and velocities are computed from well log curves. But this time we were proposing that density would be computed directly from simulations obtained from scaling core such as formation velocities. A comparison to the synthetic seismic data generated from traditional wireline well log curves was performed, and results were discussed. This workflow has never been tested yet as far as we know.

Method and Theory

Plug samples representative of different core sections were selected to digitally obtain elastic trends. For each plug, X-ray tomography images were obtained and its mineral composition segmented based on available XRD information and expected formation mineralogy. Digital elastic trends of bulk and shear moduli vs. porosity were obtained by applying a finite element method (FEM) (Garboczi, 1998) on random sub volumes inside the plug images. Observed trends are represented using differential effective medium theory (Xu et al., 2009) with the pore aspect ratio determined by fitting the curve to computed trend data points. Dual energy X-ray tomography images of the core were used to estimate porosity and density at the core scale, and elastic properties were obtained by combining a voxel-by-voxel estimation of the core mineralogy with previously obtained plug trends, like the work previously done by Suhrer et al. (2020). This procedure allowed elastic properties to be computed using FEM directed on resulting core images at regular intervals, generating velocity curves for the entire depth of the core.

After generating log curves from RRTs and DRA techniques, the first step to create the synthetic data was to generate the acoustic impedance curve (Z). For that, it was used the traditional formula $Z = \rho V$, where ρ is density and V is P-wave velocity. The second step was to create normal incidence reflection coefficient curve (R), using $R = (Z_2 - Z_1)/(Z_2 + Z_1)$, where Z_1 and Z_2 are the acoustic impedance for the first and second layer, respectively. The third step was to select a wavelet to perform its convolution with the reflection coefficient curve. The result of this operation is the synthetic seismogram (Dvorkin et al., 2014) and it was generated in depth and in time domains. The amplitudes were calculated using the equations presented by Zoeppritz (1919), which describe the energy partitioning related to the reflected and transmitted waves of an interface (Aki and Richards, 1980). The inputs for gather calculation are the V_p, V_s and density curves, a time-depth table and a wavelet to be convolved with the reflection coefficient. Also, it is necessary to inform the sample interval, minimum offset and offset increment.

Results

The log curves are displayed in Figure 1. The comparison shows that wireline density curve (in blue), in general, has little greater values than DRA density curve (we did not expect to be equal once computation method and wireline measurements are different in nature), but in general they are correlated. On the other hand, DRA velocity curves (green for Vp and light blue for Vs) have greater values than wireline velocity curves (orange for Vp and yellow for Vs). Again, they are different but correlated.

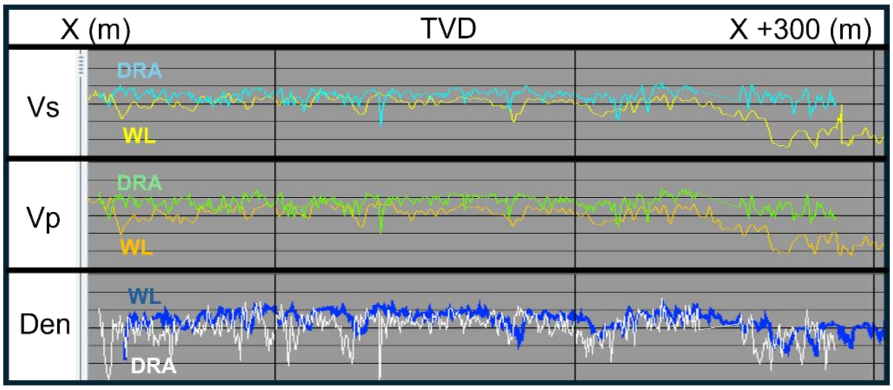

Figure 1: Log curves comparison. In the left, density curves (DRA in white and wireline in blue), in the middle are the Vp curves (DRA in green and wireline in orange) and in the right are the Vs curves (DRA in light blue and wireline in yellow).

The first result was the synthetic seismogram in depth domain (Figures 2A and 2B). After that, well-tie process was performed. The wavelet selected to perform the convolution with the reflection coefficient was a wavelet statistically extracted from seismic volume. After well-tie process, the final correlation coefficient for the synthetic from DRA curves was equal to 0.7, which means a correlation of 70%. For the synthetic from wireline curves, the final correlation coefficient was 0.66, i.e., a correlation of 66%. To have a fair comparison, the same parameters were used, including wavelet and correlation window. Interesting to notice, although the difference is not huge, but in this case a 4% in favor of synthetic seismic obtained from DRA. The same process was carried out for generation of the synthetic seismograms in time domain (Figures 2C and 2D).

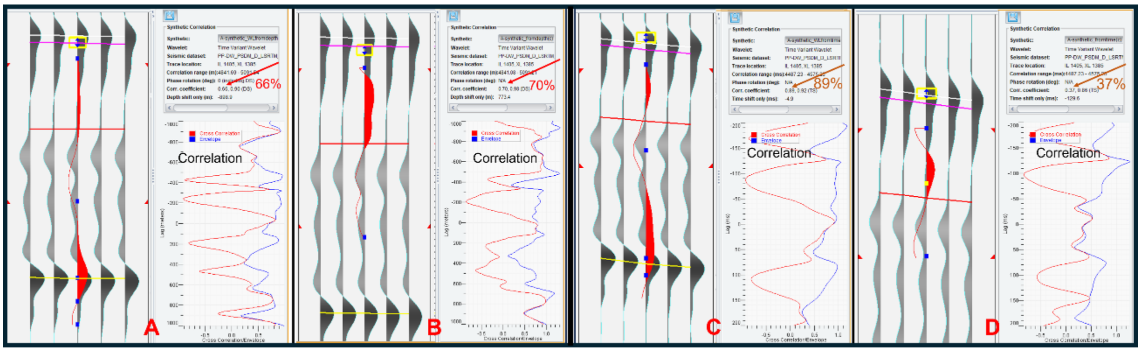

Figure 2: Comparison of synthetic seismograms in depth and time domains. In A and B are, respectively, the synthetics from wireline curves and DRA curves, for depth domain. In C and D, the synthetics from wireline and from DRA curves, respectively, for time domain.

Again, for a fair comparison, correlation window and selected wavelet were the same. The synthetic seismogram created with DRA curves presented a correlation of 37% and the one created with wireline curves had a correlation of 89%. In this case, maybe additional studies should be made for a better wavelet choice or the depth to time conversion of the seismic needs a more accurate velocity model. Also, although the correlation window has been the same, the length in depth of the DRA is much shorter than the length of wireline curves, and this could have caused a problem to the synthetic in time domain. Next step was to generate the synthetic offset gathers (Figure 3). To analyze the amplitude behavior along certain reflectors, the amplitude value was tracked for two different regions and an amplitude versus offset plot was generated.

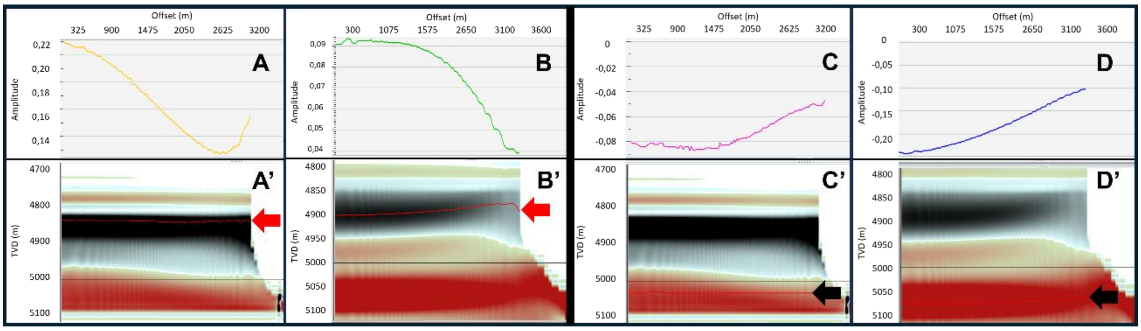

Figure 3: On the bottom, synthetic offset gathers for DRA (A' and C') and wireline (B' and D') curves. The red arrows show seismic reflectors around depth "X+100m" and the black arrows seismic reflectors around depth "X+300m", where the amplitude values were tracked (red lines). On the top, the plots showing the amplitude variation with offset, A and C for DRA and B and D for wireline.

The amplitude behavior of synthetic offset gathers, along seismic event around depth “X+100m”, from DRA curves and wireline curves (Figures 3A and 3B), are conceptually very similar, i.e., the amplitude value starts with a positive value and then the amplitude value is decreasing with offset. The same behavior was noticed when compared to the amplitude response of offset gathers in Figures 3C and 3D. This time, for the selected seismic event around depth “X+300m”, the amplitude starts with a negative value and then its absolute value increases with offset.

Conclusions

An innovative technique based on digital rock analysis (DRA) was applied to create log curves. The core was scanned and, after plug to core upscaling the log curves were generated. When comparing the DRA curves with conventional wireline curves, it was noticed that, in general, the DRA sonic logs presented higher values than wireline curves and the density curve presented the opposite, lower values than wireline curves. Since some of the fluids are missing, the resulting elastic velocities are overestimated. A common method to account for the missing fluid is to estimate the existing fluid-filled porosity to correct for density and then correct for the velocities. The existing fluid in the core can be estimated using as received and saturated plug NMR and extraction procedures such as the Dean Stark process. Such procedures can be integrated to the presented workflow to obtain more representative results of reservoir conditions.

These DRA curves were input to 1D synthetic seismogram creation, in depth and in time domains. When tied to the seismic volume, the correlations, in depth domain, were very similar but, in time domain, the correlation of the seismogram generated using wireline curves was greater. Further studies should be made related to, for example, the chosen wavelet or related to the length of the correlation window. Also, the DRA and wireline curves were used to generate synthetic offset gathers in depth domain. The gathers presented similar amplitude responses for a seismic interface around depth “X+100m” and another around depth “X+300m” as well. In general, both data, DRA and wireline curves, qualitatively speaking, presented very similar results and, for the type of analysis performed, can be considered compatible. Deeper studies including more wells can be carried out to better understand the differences related to the amplitude values and if these differences can give any kind of important information related, for example, to lithology or fluid.

Acknowledgments

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References

Aki, K., Richards, P.G., 1980. Quantitative Seismology, Theory and Methods, W. H. Freeman, San Francisco, vol. 1: 119-148.

Dvorkin, J., Gutierrez, M. A. and Grana, D. 2014. Seismic reflections of rock properties. Cambridge: Cambridge University Press, 388 pp. DOI: 10.1017/CBO9780511843655.

Garboczi, E. J. (1998). Finite Element and Finite Difference Programs for Computing the Linear Electric and Elastic Properties of Digital Images of Random Materials. Gaithersburg: National Institute of Standards and Technology.

Suhrer, M., Nie, X., Toelke, J. and Shouxiang M. "Upscaling Method for Obtaining Primary Drainage Capillary Pressure and Resistivity Index with Digital Rock Physics." Paper presented at the International Petroleum Technology Conference, Dhahran, Kingdom of Saudi Arabia, January 2020. doi: https://doi.org/10.2523/IPTC-20035-ABSTRACT.

Xu S. and Payne M. A. Modeling elastic properties in carbonate rocks. Lead Edge. 2009;28(1):66–74. https://doi.org/10.1190/1.3064148.

Zoeppritz, K., 1919. Erdbebenwellen VIII B, Uber Reflexion und durchgang seismischer wellen durch Unstetigkeitsflachen. Gottinger Nachr, vol. 1: 66–84.