Geostatistical Integration of Multiscale Data to Construct the Hunton Group Geocellular Model: Upscaling Logs and Downscaling Seismic Impedance Volumes*

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Abstract

The Hunton Group on the carbonate ramp often exhibits highly variable porosity and lithology resulting in heterogeneous production. The generation of an accurate geocellular model requires upscaling of sparse porosity logs followed by their integration with denser seismic impedance volumes. The integration of multi-scalar data consisting of core, logs, and seismic data to construct a 3D geocellular model remains an ongoing challenge. Seismic data provide laterally dense but vertically low resolution, “soft” estimates of lithology and rock properties. In contrast, log data provide corresponding “hard” estimates that are laterally sparse but exhibit high resolution. To bridge this gap in scales, we develop a workflow to upscale well log and core data, and downscale seismic impedance estimates, resulting in an integrated gridded reservoir model with reduced uncertainty.

Our workflow begins with principal component analysis (PCA) of electric logs followed by self-organizing map (SOM) to construct electrofacies logs. We then corroborate the geologic interpretation of the electrofacies predictions using thin sections and borehole images. Porosity logs are correlated with core porosity measurements. Lithology and porosity logs are then upscaled to the size at which the vertical heterogeneity of log properties can be preserved by comparing the logs before and after upscaling. We then construct a vertical variogram from the upscaled well logs and a horizontal variogram from the downscaled acoustic impedance volume.

To populate the 3D volume we (1) establish seismic impedance attribute which correlate to the electrofacies and porosity to design the horizontal variograms for the 3D lithology and porosity models, (2) construct the relationship between the acoustic impedance and lithology and porosity logs at well locations, (3) perform a 3D seismic inversion of acoustic impedance volume, (4) downscale (laterally interpolate) the inverted prestack acoustic impedance volume computed at the seismic bin size resolution to geocellular model grid size, (5) create horizontal variogram maps from the downscaled seismic acoustic impedance, and (6) obtain the horizontal variogram parameters and substitute them into lithology horizontal variogram.
The seismic data helps to design the geocellular horizontal variograms of the lithology and porosity 3D models. We illustrate the value of this workflow through application to a Hunton Group reservoir in the Cherokee Platform, Oklahoma, USA.
1- ABSTRACT

The Hunton Group on the carbonate ramp often exhibits highly variable porosity and lithology resulting in heterogenous product ion. The generation of an accurate geocellular model requires upscaling of sparse porosity logs followed by their integration with denser seismic impedance volumes. The integration of multi-scalar data consisting of core, logs, and seismic data to construct a 3D geocellular model remains an ongoing challenge. Seismic data provide internally dense but vertically low resolution, “soft” estimates of lithology and rock properties. In contrast, log data provide corresponding “hard” estimates that are internally sparse but exhibit high resolution. To bridge this gap in scales, we develop a workflow to upscale well log and core data, and downscale seismic impedance estimates, resulting in an integrated gridded reservoir model with reduced uncertainty.

Our workflow begins with principal component analysis (PCA) of electric logs followed by self-organizing map (SOM) to construct electrofacies logs. We then corroborate the geologic interpretation of the electrofacies predictions using thin sections and borehole images. Porosity logs are correlated with core porosity measurements. Lithology and porosity logs are then upcaled to the size at which the vertical heterogeneity of log properties can be preserved by comparing the logs before and after upsampling. We then construct a vertical variogram from the upcaled well logs and a horizontal variogram from the downscaled acoustic impedance volume.

To populate the 3D volume we (1) generate seismic impedance attribute which correlate to the electrofacies and porosity to design the horizontal variograms for the 3D lithology and porosity models, (2) construct the relationship between the acoustic impedance and lithology and porosity logs at well locations, (3) perform a 3D seismic inversion of acoustic impedance volume (4) downscale (laterally interpolate) the inverted prestack acoustic impedance volume computed at the seismic bin size resolution to geocellular model grid size, (5) create horizontal variogram maps from the downscaled seismic acoustic impedance, and (6) obtain the horizontal variogram parameters and substitute them into lithology horizontal variogram.

The seismic data helps to design the geospatial horizontal variograms of the lithology and porosity 3D models. We illustrate the value of this workflow through application to a Hunton Group reservoir near the Cherokee Platform, Oklahoma, USA.
3- DATA

i. Core

Figure 4. Samples of the Huron core from Robinson 4-A well in Pittsylvania County, Virginia. The core is highly brecciated and crystallized due to the karstification creating fractures. (Milad et al., 2018; Milad and Stal, 2017).

ii. Logs

Figure 3. Multilinear regressions for Well 6 in for the Huron reservoir. Gamma ray is in red, bulk density is in red and if sonic log is in purple. The black curve in the last column is the above 5 Wave velocity and the blue curve is the calculated 5 wave velocity.

iv. Prestack Seismic and Log Data

Figure 8. Variance versus the number of clusters. Sum of squares within clusters (SSW) shows the variance in each cluster. Sum of squares between clusters (SSB) shows how each cluster differs from one another. The "elbow" shape indicated by the red circle represents the optimal number of clusters, 3, where there are small variance within each cluster (SSW) and large variance between clusters (SSB).

Figure 6. Conditioned angle gathers after bandpass filtering and trim statics.

Figure 7. Locations of the logs inside the seismic polygons. Colorful circles are the type of logs at well locations with their respective names. Well logs are available for the prestack seismic inversion.

iv. Prestack seismic inversion

Figure 11. A) Angle dependent wavelets extracted for well to seismic tie and inversion. Amplitudes at time (top) and frequency (bottom) response are shown. B) Inverted P impedance of E-W cross section at the location of Well-11.

Figure 10. Cross plot between the effective porosity and the acoustic impedance colored with the lithofacies.

ii. Electrofacies and Thin Sections

Figure 9. Lithofacies classification in Well-12 using well logs, bench types, and thin sections. Self organizing map was used to cluster logs data.
5- WORKFLOWS

Lithofacies classification using logs, borehole images, and thin sections

- Thin section analysis
- Borehole images
- Well logs
- Digital X-ray techniques

Principal component analysis (PCA) is used to identify log data in thin sections

6- RESULTS

P impedance

$P = \frac{1}{\nu (\mu + \nu)}$

Figure 34. Horizontal variogram map generated from the acoustic impedance (A, B, and C) and variogram variance maps for the lithofacies and facies classes. The horizontal variogram curves (A, B, and C) (Min and max, OZ).

7- CONCLUSIONS

1) The value of this work is to illustrate multi-scale data integration workflow to construct high resolution petrophysical model, which helps decide the horizontal well landing points.
2) Combining well logs and acquiring seismic data are used to construct high heterogeneity lithofacies, porosity, and permeability models.
3) Porosity and permeability models constructed from the stacked well logs while horizontal variograms were constructed from the downscaled acoustic impedance inversion volume.
4) Acoustic impedances was correlated to the lithofacies and porosity.
5) The seismic data helped to design the geologicaliferous variograms of the lithofacies, porosity, and permeability 3D models.

7- FUTURE STUDY

1) To correlate the porosity and permeability models to the production data.

REFERENCES


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- Institute of Reservoir Characterization
- Woodford Shale Consortium
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Figure 13. Proposed workflow to build high heterogeneity lithofacies, porosity, and permeability 3D models by integrating core, logs, and seismic data.

Figure 12. Workflow to build 3D lithofacies models by integrating core data, well log data, and seismic data.