PS Geostatistical Integration of Multiscale Data to Construct the Hunton Group GeocellularModel: 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 heterogenous 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.

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AAPG ACE 2018 ANNUAL CONVENTION & EXHIBITION

The UNIVERSITY of OKLAHOMA
ConocoPhillips
School of Geology and Geophysics

1- ABSTRACT

The Hunton Group on the carbonate ramp often exhibits highly variable porosity and lithology resulting in heterogenous 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.

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2- GEOLOGICAL SETTING

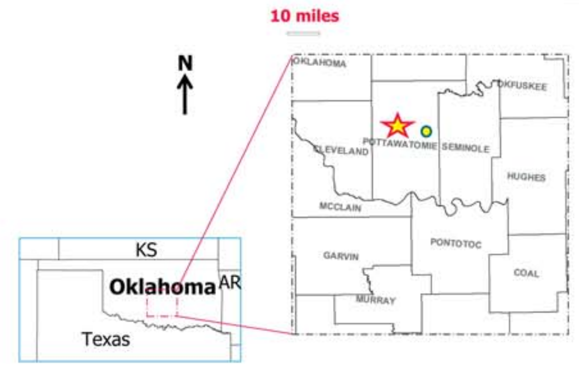
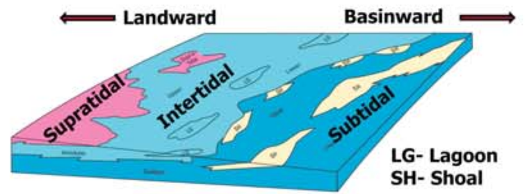


Figure 1. The location of the core in the circle simple, the location of the 3D seismic volume in the star simple, and the locations of the outcrop in the rectangular simples.

Figure 2. Map of Oklahoma showing geologic provinces and the Hunton Group distribution (Northcutt, 2002). Yellow dash lines show the boundaries of the Hunton Group.



- ✓ Shallow-water carbonate ramp sequence <1/5°
- ✓ Hunton strata deposited at several places
- ✓ Between the Ordovician Sylvan Shale and late Devonian Woodford Shale.
- ✓ Three major subdivisions, the Ordovician-Silurian Chimneyhill subgroup, the Silurian Henryhouse and Haragan Formations, and the lower Devonian Frisco and Misener formations
- ✓ Mainly limestone and dolomite.
- ✓ The Hunton ranges from 100 to **400** ft. thick

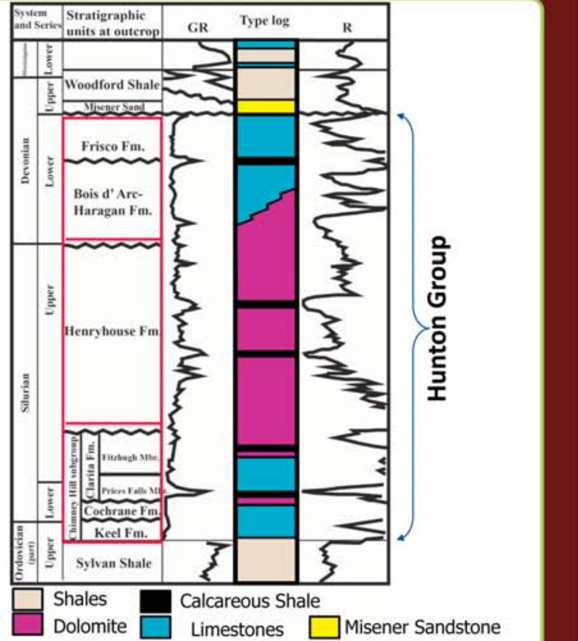


Figure 3. Hunton Group stratigraphic column in central Oklahoma with gamma ray (GR) and resistivity (R) type logs (Fritz and Medlock, 1994; Milad 2017).

3- DATA

i. Core

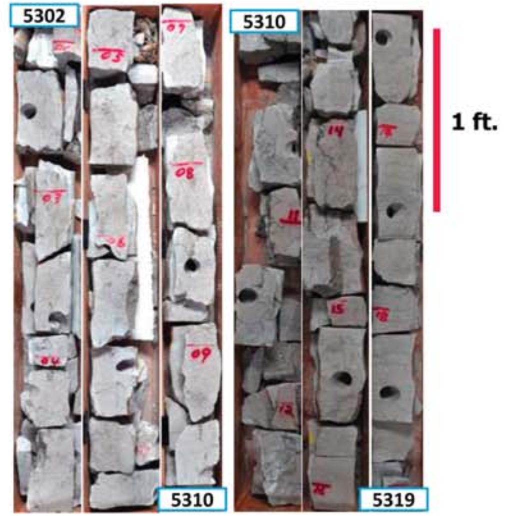


Figure 4. Samples of the Hunton core from Roberson A#1 well in Pottawatomie County, Oklahoma. The core is highly brecciated and crystallized due to the karstification creating fractures. (Milad et al., 2018; Milad and Slatt, 2017).

ii. Logs

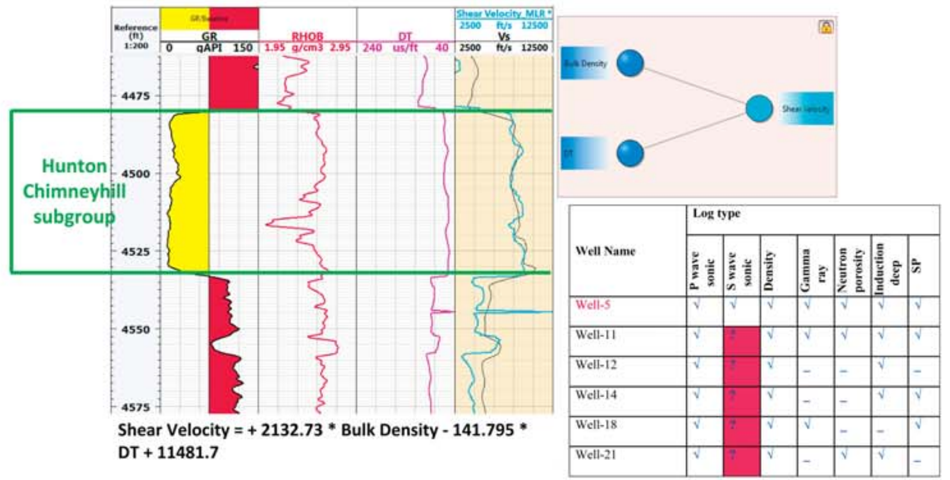


Figure 5. multilinear regressions for Well-5 in for the Hunton reservoir. Gamma ray is in red, bulk density is in red and P sonic log is in purple. The black curve in the last column is the actual S wave velocity and the blue curve is the calculated S wave velocity.

iii. Data Preconditioning

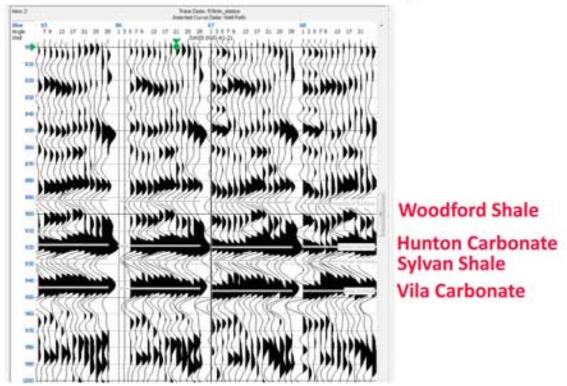


Figure 6. Conditioned angle gathers after bandpass filtering and trim statics.

iv. Prestack Seismic and Log Data

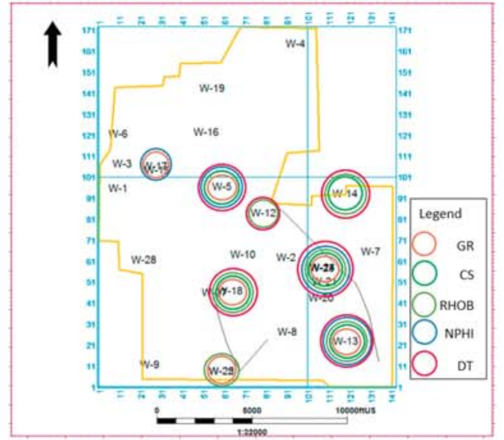


Figure 7. Locations of the logs inside the seismic polygon. Colorful circles are the type of logs at well locations with their respective names. Well logs are available for the pre-stack seismic inversion.

4- METHODOLOGY

i. Optimal Number of Clusters

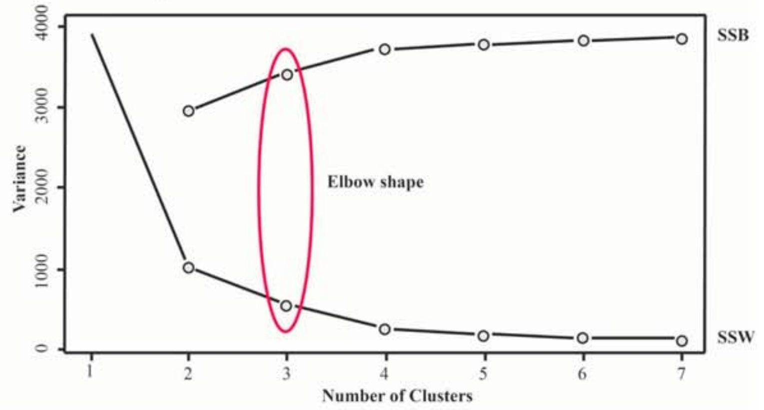


Figure 8. Variance versus the numbers of clusters. Sum of square within clusters (SSW) shows the variance in each cluster. Sum of square between clusters (SSB) shows how each cluster differs from one another. The "elbow" shape indicated by the red circle represents the optimal number of clusters, 3,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

ii. Electrofacies and Thin Sections

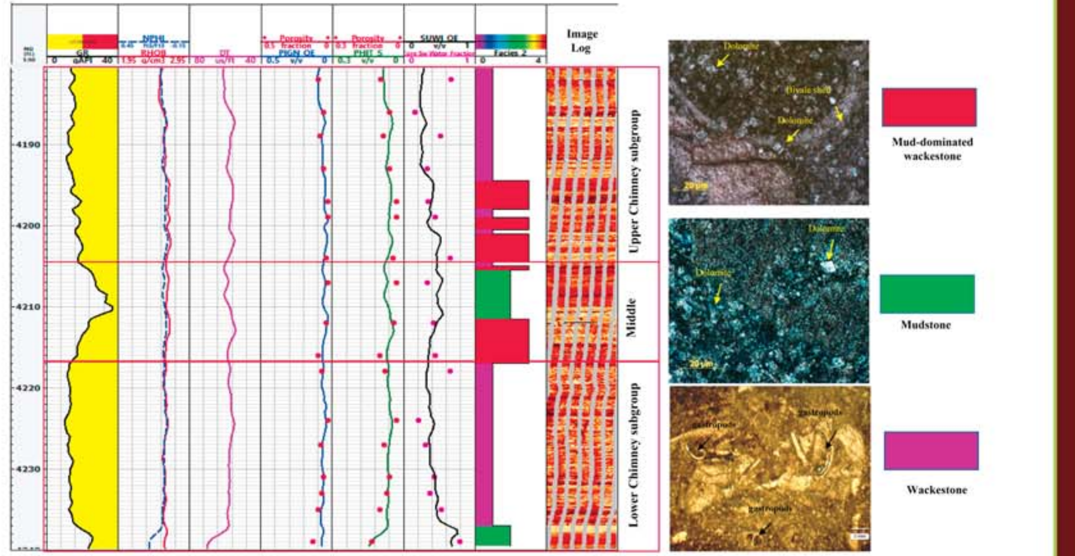


Figure 9. Lithofacies classification in Well#12 using well logs, borehole image, and thin sections. Self organizing map was used to cluster logs data.

iii. Lithofacies and Acoustic Impedance Relationship

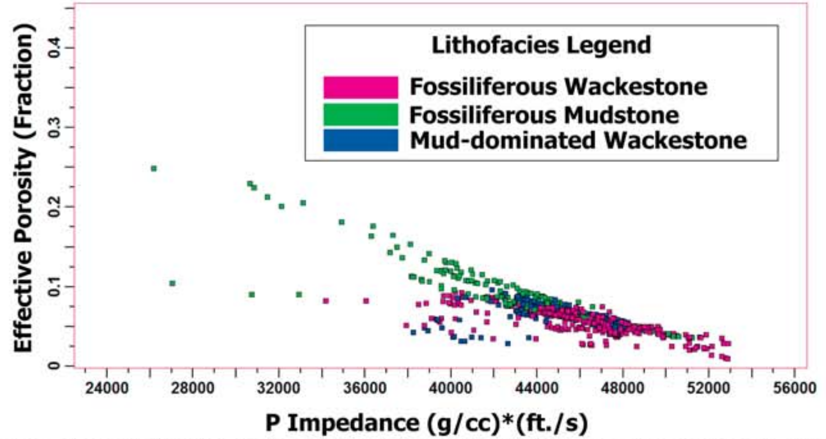


Figure 10. Cross plot between the effective porosity and the acoustic impedance colored with the lithofacies.

iv. Prestack seismic inversion

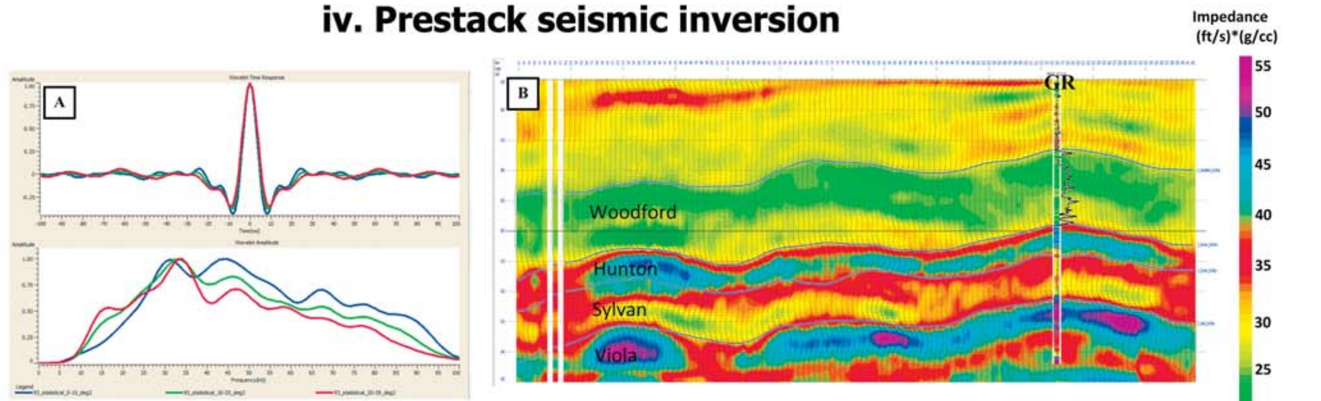


Figure 11. A) Angle dependent wavelets extracted for well to seismic tie and inversion. Amplitudes at time (top) and frequency (bottom) response are shown. B) Inverted P impedance of E-W cross section at the location of Well-11.

5- WORKFLOWS

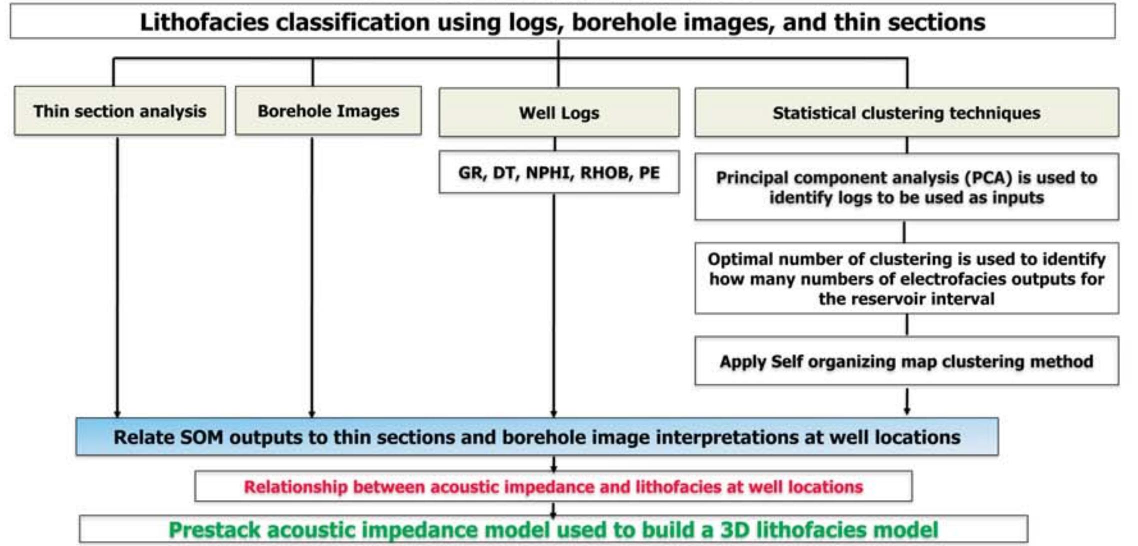


Figure 12. Workflow to build 3D lithofacies models by integrating core data, wireline logs, borehole images, and seismic data.

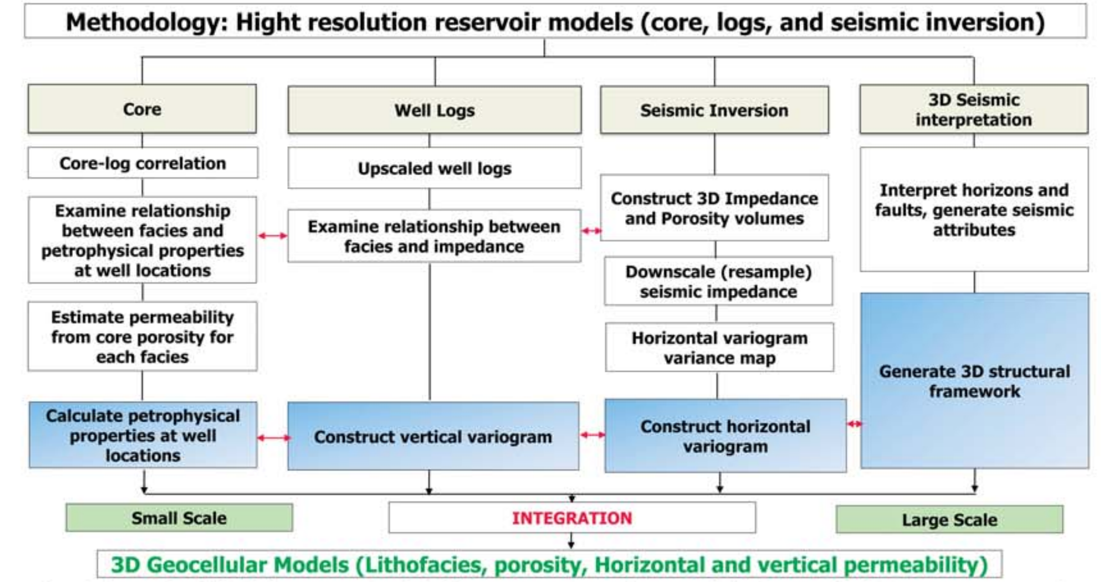


Figure 13. Proposed workflow to build high heterogeneity lithofacies, porosity, and permeability 3D models by integrating core, logs, and seismic data.

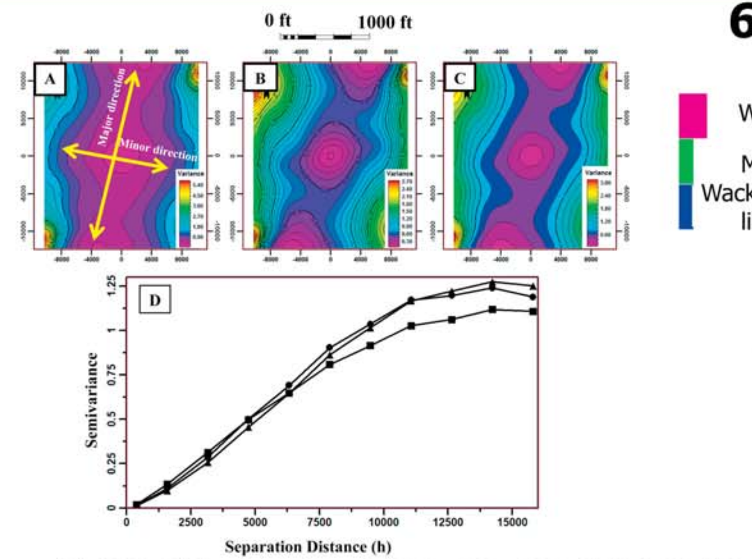
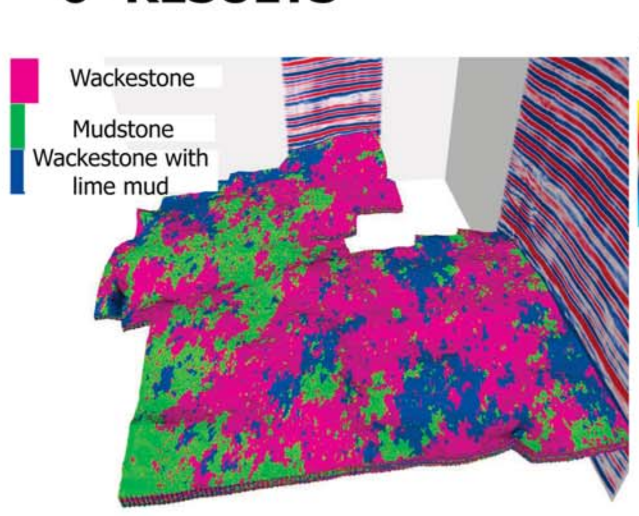
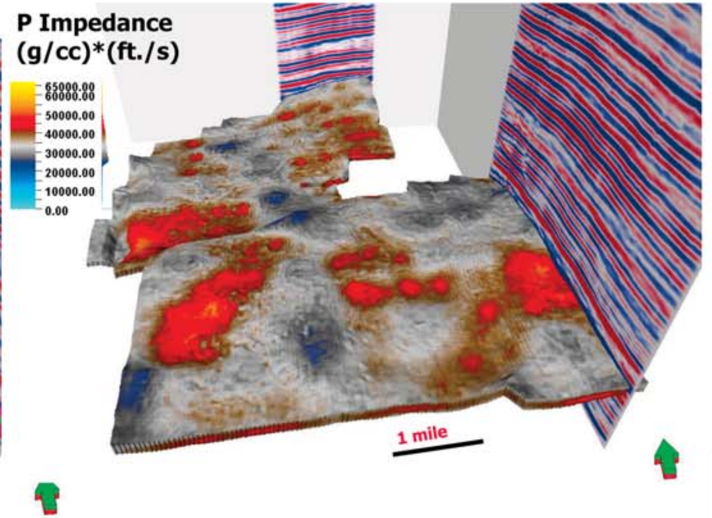
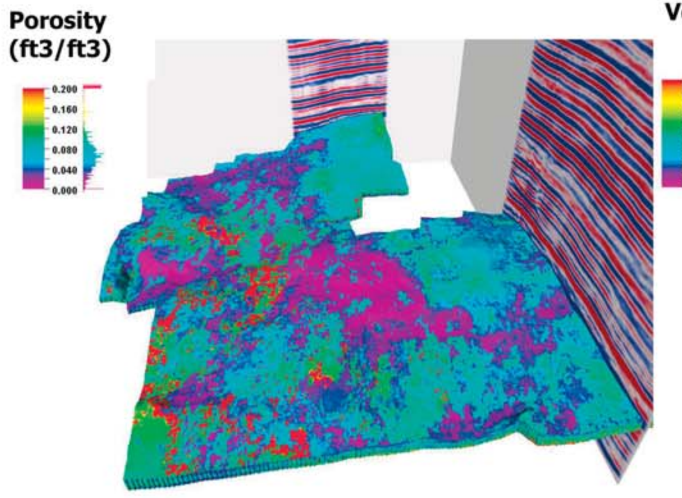


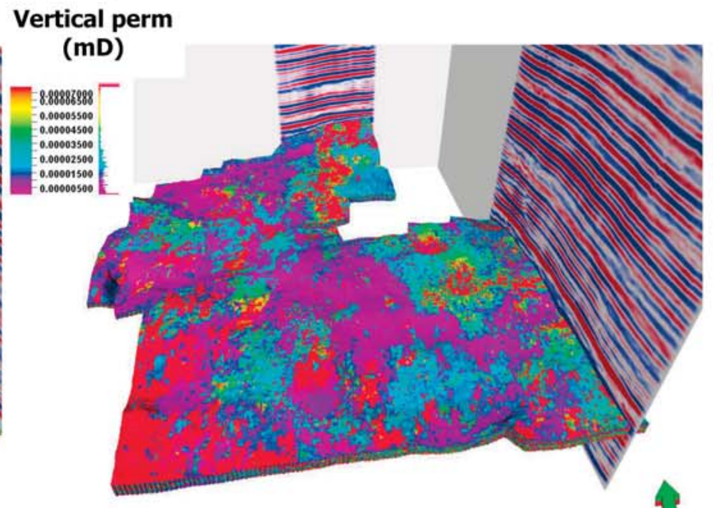
Figure 14. Horizontal variogram variance map generated from the acoustic inversion. A, B, and C) are variogram variance maps for the upper, middle, and lower Chimneyhill subgroup respectively. D) Three curves of the horizontal variogram maps (A, B, and C) (Milad and slatt, 2018)

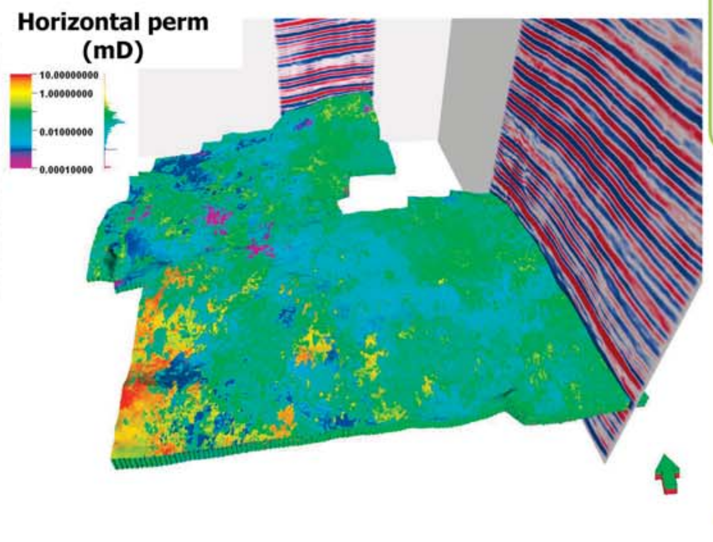
6- RESULTS











7- CONCLUSIONS

1) The value of this work is to illustrate multi-scalar data integration workflow to construct high resolution geocellular model, which helps decide the horizontal well landing spots.
2) Upscaling well logs and downscaling seismic data are used to construct high heterogeneity lithofacies, porosity, and permeability models.
3) Vertical variograms were constructed from the upscaled well logs while horizontal variograms were constructed from the downscaled acoustic impedance inversion volume.
4) Acoustic impedance was correlated to the lithofacies and porosity.
5) The seismic data helped to design the geocellular horizontal variograms of the lithology, porosity, and permeability 3D models.

8- FUTURE STUDY

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

REFERENCES

- Fritz, R. D., and P. L. Medlock, 1994, Sequence stratigraphy of the Hunton Group as defined by core, outcrop, and log data: Bulletin Houston Geological Society, p. 29-58.
- Milad, B., S. Ghosh, and R. M. Slatt. 2018, Comparison of rock and natural fracture attributes in karsted and non-karsted Hunton Group Limestone: Ada and Fittstown area, Oklahoma. Shale Shaker Journal, **69**, no. 2,70-86.
- Milad, B., and R. M. Slatt. 2018, Impact of Lithofacies Variations and Structural Changes on Natural Fracture Distributions. Impact of Lithofacies Variations and Structural Changes on Natural Fracture Distributions. Interpretation: a journal of subsurface characterization. Vol.6(4), p.1 doi: 10.1190/int-2017-0138.1
- Milad B., and R. Slatt. 2017, Integrated 3-D Seismic, Outcrop, and Core Data for Characterization of Natural Fractures of the Hunton Limestone and the Woodford Shale in Central Oklahoma. AAPG 2017 Annual Convention and Exhibition, Houston, Texas, United States, Search and Discovery Article #51382.
- Milad, B. 2017, The Effect of Karsting on Natural Fracture, Hardness, and Brittleness of the Hunton Limestone and Paleo-Deposition of the Woodford Shale: A Study Using 3-D Seismic, Outcrop, Well Log, and Core Data. AAPG 2017 Southwest Section Annual Convention, Midland, Texas, Search and Discovery Article #51417.
- Northcutt, R. A., 2002, History of Hunton Oil and Gas Exploration and Development in Oklahoma: Shale Shaker, p. 149-158.
- Pyrcz, M.J. and Deutsch, C.V., 2014. Geostatistical reservoir modeling. Oxford university press.
- Russell B.H., Hampson D.P., Hirsche, K., and Peron, J., 2005. Joint Simultaneous Inversion of PP and PS angle gathers. CREWES Research Report-17.

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