Stratigraphic mapping of the Woodford Shale in Oklahoma

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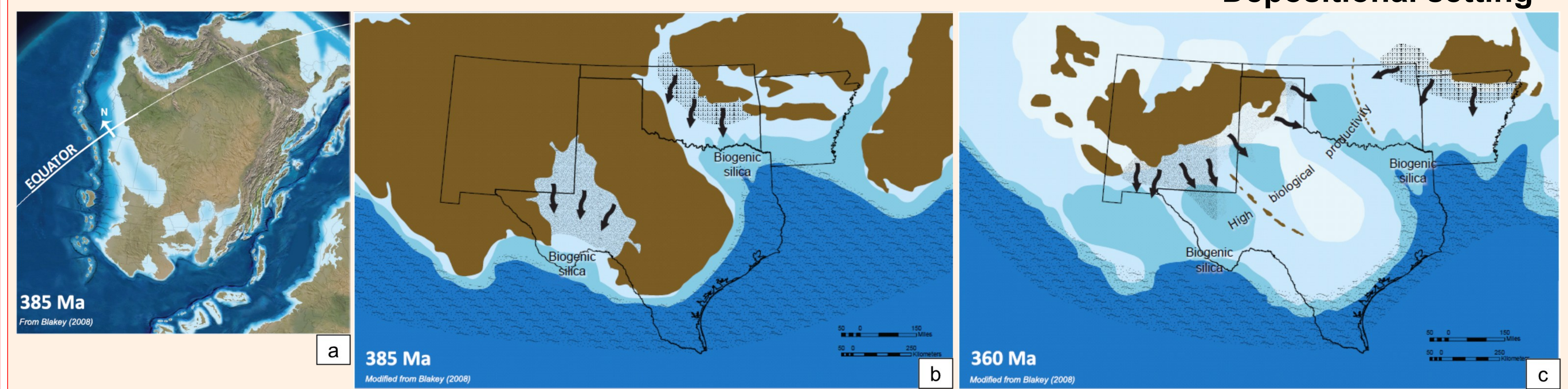
Abstract

Woodford Shale of the southern midcontinent was deposited in an epeiric sea, during an eustatic sea-level rise punctuated by a number of smaller scale transgressive-regressive cycles. Current study focuses on an area of thick Woodford accumulation. Seismic attributes provide a time-efficient mans to track the stratigraphic variations especially when combined with information from visual inspection of whole core, laboratory measured petrophysical properties, and thin section analyses. Changes in the lithofacies, gamma-ray characteristics, mineralogy, relative abundances of biogenic silica, and fossils versus kerogen helped to identify individual depositional cycles in a semi-quantitative manner. Correlation between petrophysical properties and acoustic data allowed us recognize seismic responses to those stratigraphic variations. Mineralogically, the Woodford Shale is a silica-rich mudstone and silica-enrichment is one of the most important factor enhancing the brittleness of this gas-shale. However, two different sources of silica complicates the identification of sweet-spots. Sources of silica can be described as: biogenic silica, most commonly associated with organic matter (TOC) enrichment and detrital silica. In conclusion, it can be stated that TOC content and mineralogy can be used in combination to understand the changes in the depositional setting.

Depositional setting



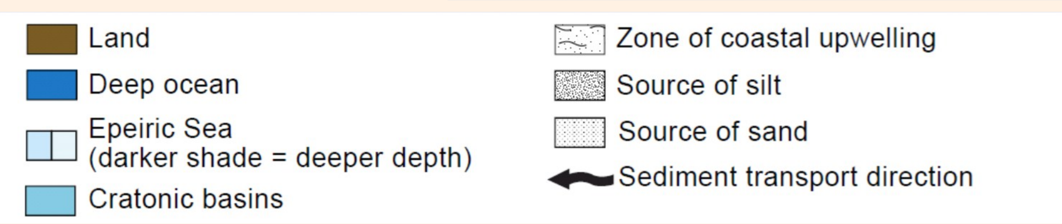


Figure 1: a: Paleogeography of North America (Laurentia) at the beginning of the Late Devonian; b & c: Plate tectonic reconstruction indicates that most of North America was sub aerially exposed prior to the Late Devonian and became a major unconformity surface. Modified from Comer (2008).

During Woodford Shale deposition North America was located in the dry topics near 15° (Blakey, 2008) south latitude (Figure 1) and was characterized by a set of conditions that favored the accumulation of thick organic-rich black shale. Presence of scour bases, erosional surfaces, and debris deposits at both macroscopic and microscopic scales indicate that the Woodford deposition took place within the storm wave base. Water depth was below 100m., as proposed by Schieber (2004) for the Woodford equivalent Chattanooga Shale. The physio-geographic setting of the Woodford-sea enforced restricted open marine circulation. Absence of significant rainfall precluded large river discharge and minimized the influx of terrestrially derived clastic sediments as indicated by paleoclimatic studies (Comer, 2008) with resulting strong density-stratified water column with occasional remixing. Detailed core analyses revealed that the planktonic primary producers dominated the Woodford-sea with overall very small amount of benthic organisms. Steady influx of upwelled oceanic nutrients triggered the high biologic productivity in the surface water. In the study area, the Woodford Shale is characterized by black shales along with cherty black shales, silty black shales and some dolostones. Comer's (2008) regional study across different basins revealed that the Woodford Shale lithology is dominated by black shale along with chert, siltstone, sandstone, dolostone and light-colored shale, with hybrid mixtures between them. The depth of the Woodford Shale in the Anadarko Basin ranges from 5,060ft on the northeastern shelf to 25,115ft in the deepest part of the basin (Cardott, 1989). Thicknesses range from less than 25ft in the northern shelf areas to more than 900ft along the frontal Wichita fault zone (Cardott, 1989). Vitrinite reflectance increases systematically with depth (Cardott, 1989).

Seismic Attributes illuminating physical setups of the Woodford Shale

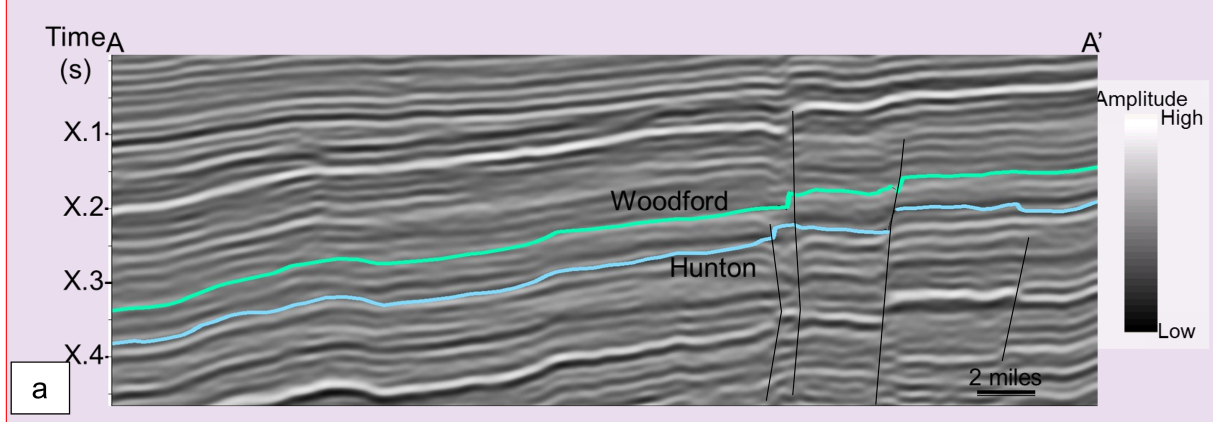


Figure 2a: Vertical seismic section showing seismic amplitude along with the interpreted Hunton and Woodford horizons. Faults are highlighted by black lines.

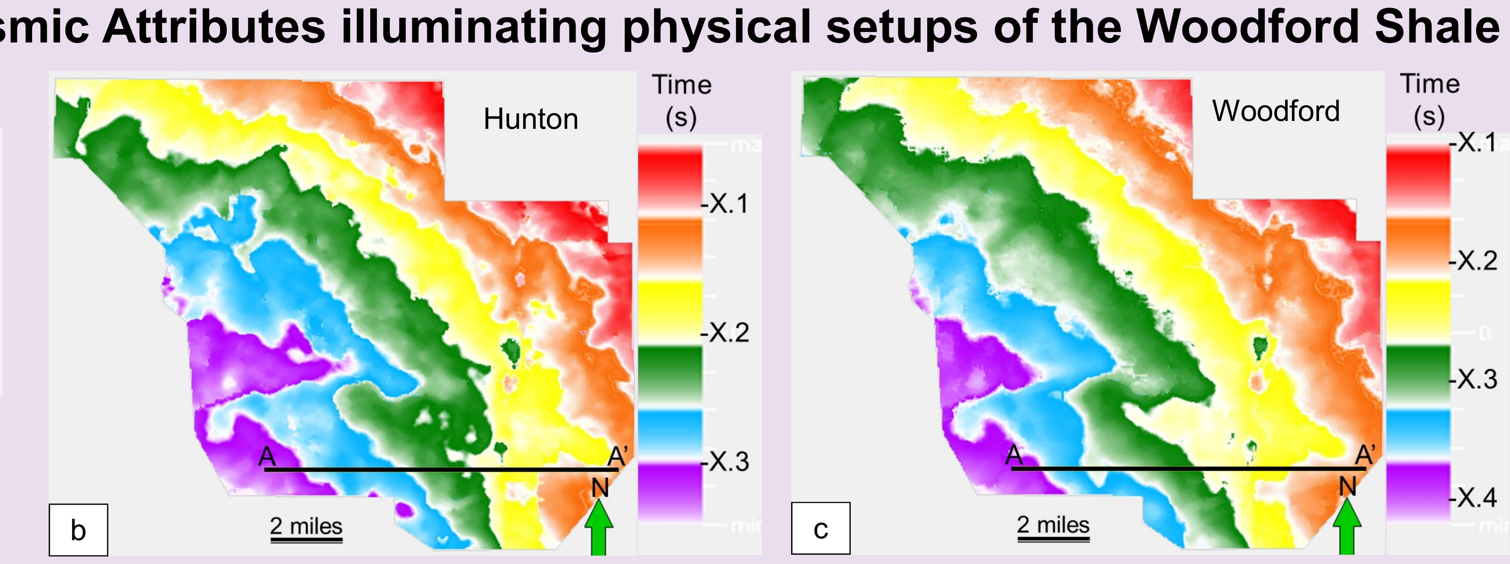


Figure 2b, c: Time structure maps of the underlying Hunton Limestone (b), and the Woodford Shale (c). Note, the similarity between these maps. An indication that the original basin structure is preserved despite of the post-depositional tectonic deformations.

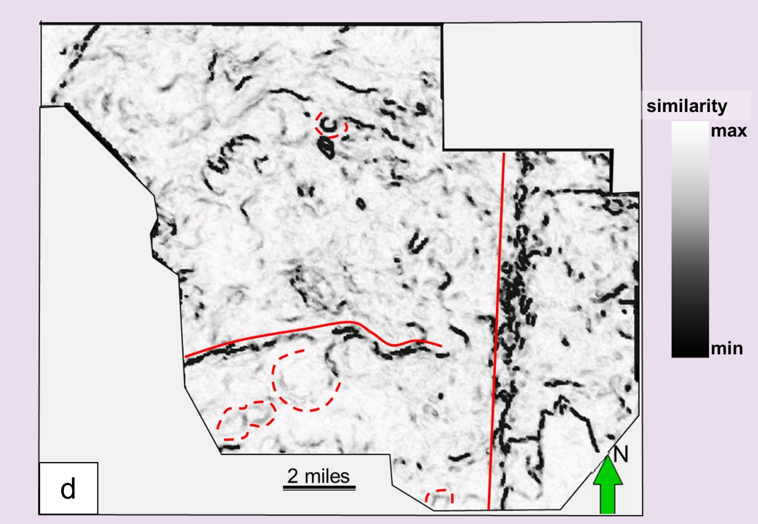
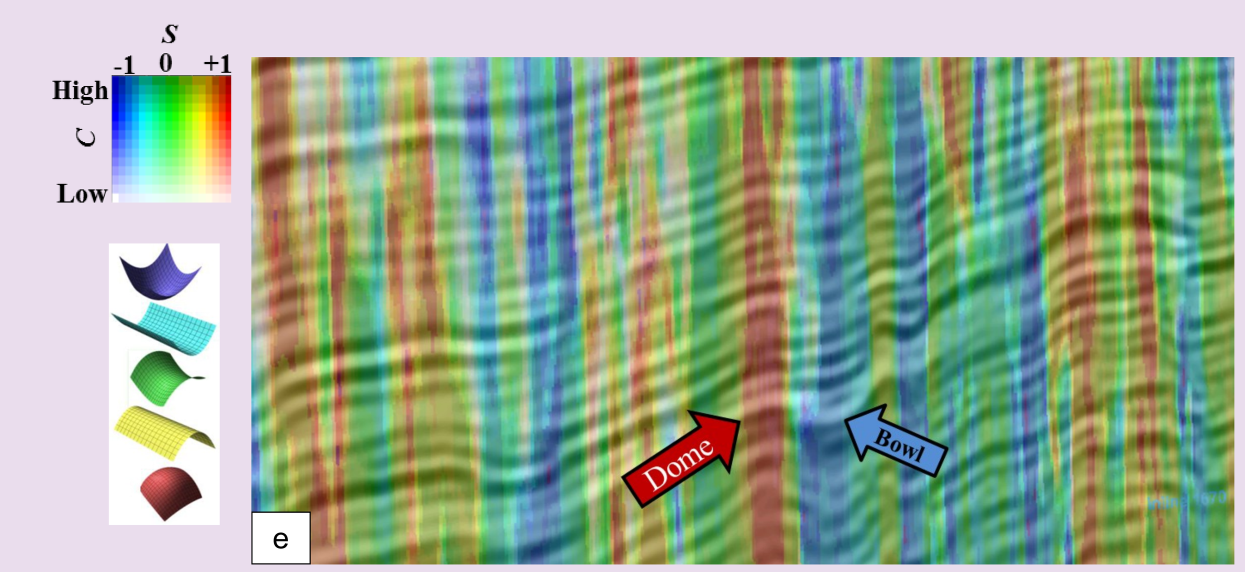


Figure 2d: Outer product similarity is illuminating the irregular unconformity surface at the top of Hunton Limestone. The Woodford Shale was deposited on top of the Hunton Limestone. Low values indicated by darker color: represent linear features like faults, joints etc. (red solid lines) as well as some collapse features or fracture zones (red dashed lines). Collapsed or karst features are likely areas of comparatively thicker accumulation of the Woodford Shale.



Blumentritt et al., 2005

Figure 2e: Shape versus curvedness co-rendered with seismic amplitude. Shape versus curvedness further illuminates different geomorphological features.

Seismic Attributes illuminating stratigraphic features within Woodford Shale

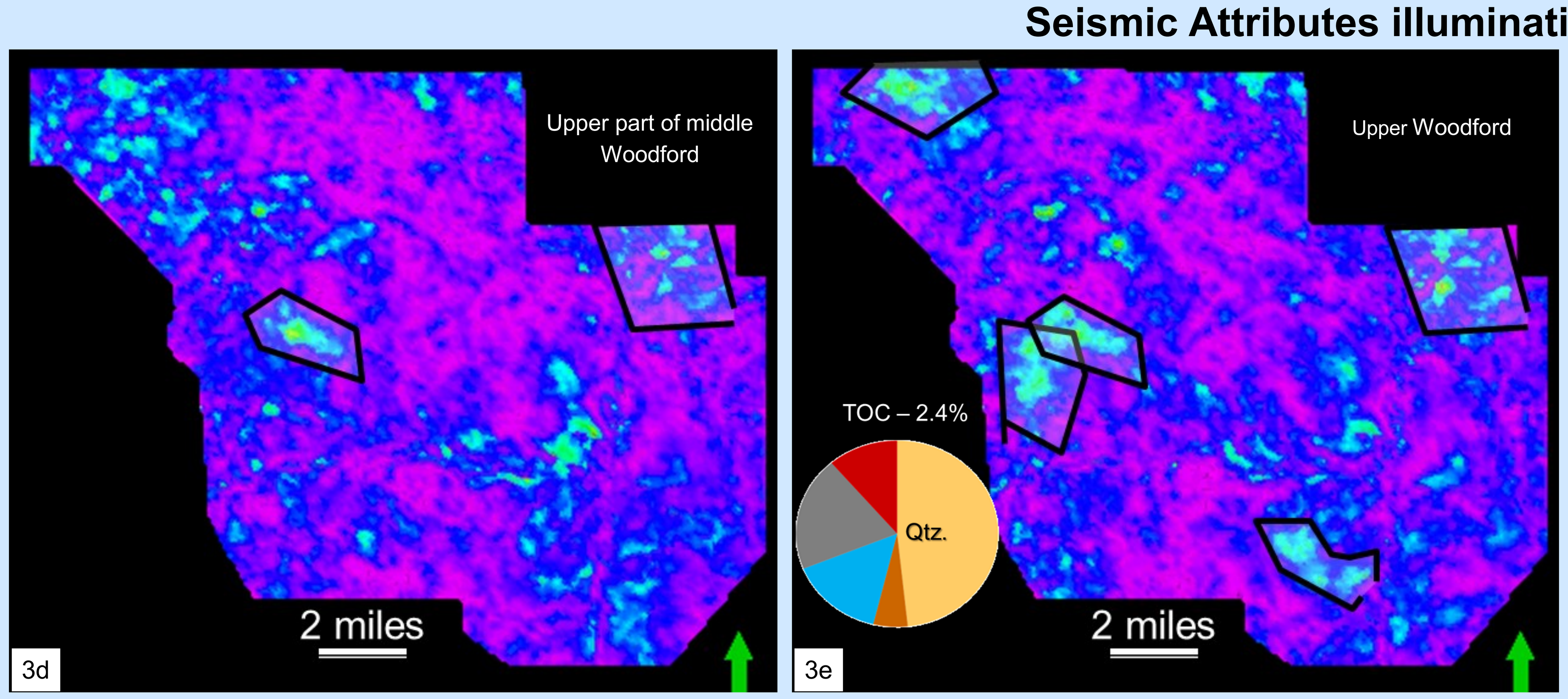


Figure 3: Stratal slices generated by co-rendering coherent energy with in-line energy gradient. Figures from bottom to top represent top of the Hunton unconformity, in the middle of the Woodford Formation and near the top of the Woodford Formation respectively (a, b, c, d, e).

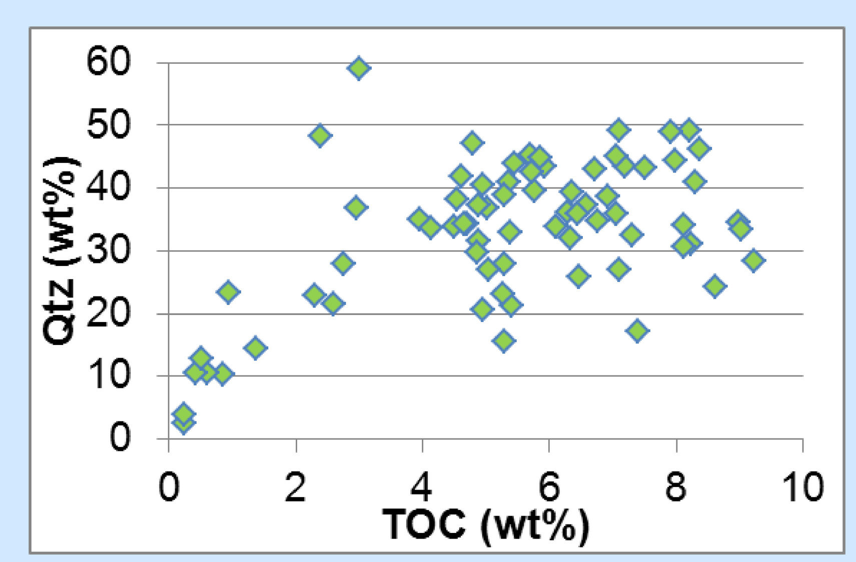


Figure 3f: Total organic carbon versus quartz concentration. Laboratory measured data

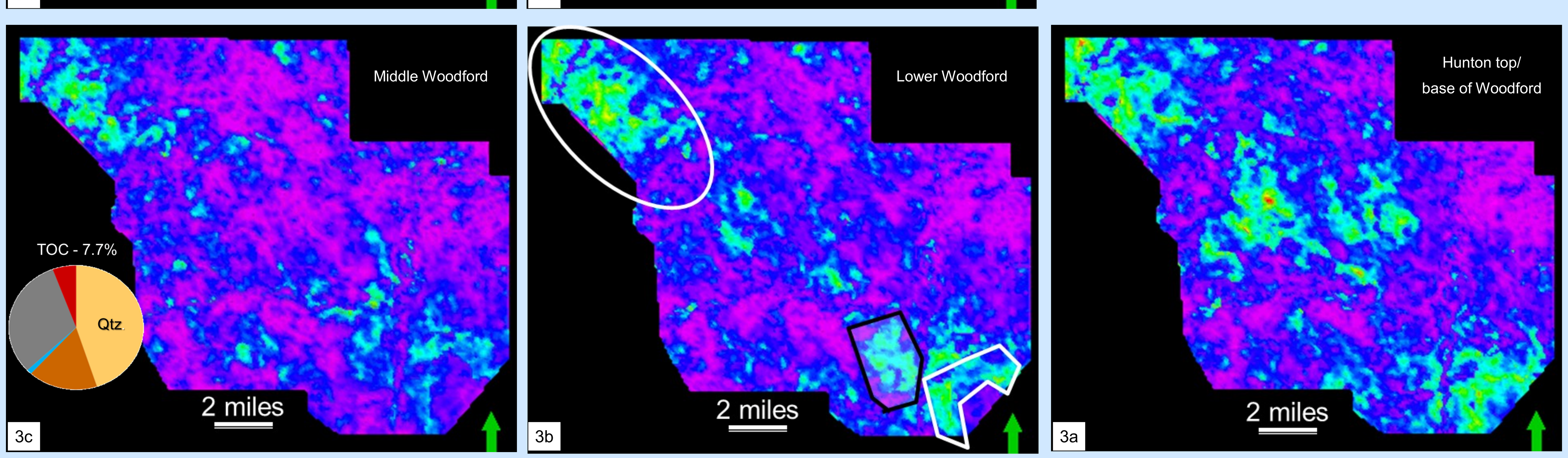


Figure 3

Stratal slices between the Hunton Limestone and the overlying Woodford Shale. Low energy areas (magenta and blue colored areas) in Figure 3a represent the initial shale (low energy) deposition on top of the Hunton Limestone (high energy). High energy areas corresponding to structural highs on the sea floor are potential areas for accumulation of pure biogenic silica along with organic carbon (TOC) and comparatively less affected by minor storm current, debris flows or any turbidity current. Note, shale deposition didn't start in the high energy area in the top left corner of figure 3a and 3b (area marked with white circle) until middle Woodford deposition started (Figure 3c). Black outlined areas (Figures 3b, 3d and 3e) are high energy areas within the Woodford Shale, probably indicating silica enrichment. Based on other studies it has been interpreted that biogenic silica is the dominant silica source with minor amount of detrital silica for most of the Woodford interval in the study area. Well data from the study area also show that TOC has good correlation with the silica content (3f). Hence, such areas are good for hydrocarbon exploration and well placement. Notice, the black outlined area (high energy) in the northeastern part of figures 9d, and 9e corresponds to low energy shale deposit in figures 9a, b, and c. This high energy area is representing increase in chert in the Upper Woodford, as reported in the literature. Analyses of a subsurface core in the study area indicate inverse correlation between TOC and such cherty deposits.

Conclusions

- Sequential seismic geomorphologic analyses with the help of various seismic attributes help us to determine periodic changes in depositional sequence stratigraphic pattern within the Woodford interval.
- Detailed calibration of seismic geomorphology with the petrophysical properties along with acoustic impedance inversion guide us to estimate depositional packages in yet to explore areas.

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References

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