Integrating 3D Seismic Attributes and Post-stack Inversion Techniques for Seismic Facies Analysis: A Granite Wash Play Illustration

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1. Abstract:

Seismic inversion and seismic attributes analysis have become increasingly important for static reservoir properties predictions. This work evaluates these methods through a case study on a complex-natured formation that has been inherently challenging to characterize due to limited seismic resolution – The Pennsylvanian Granite Wash, Anadarko Basin, Texas.

The 3D seismic survey of the study area suffers migration aliasing and relatively low vertical resolution and was subsequently passed through structure-oriented filtering to improve the signal-to-noise ratio. Time-structure, thickness maps as well as co-rendered mixes of different attributes variants such as coherent energy, most positive and negative curvature and energy ratio similarity, gray-level co-occurrence matrix (GLCM) entropy and homogeneity were computed from the post-stack seismic data to aid reservoir delineation and facies classification. Acoustic impedance computed from the seismic amplitude volume integrated with sonic and density logs provided good images of reservoir heterogeneity. Moreover, by combining different geometric attributes with inverted AI, it is possible to build geomorphological model and also delineate lithological heterogeneity within the wash. We also perform a robust multi-attribute seismic facies classification on the target zone using the generative topographic mapping (GTM) technique.

The use of multi-attributes also made it possible to identify specific facies-types as well as fan deposits in the areas. Based on this analysis, low acoustic impedance can be associated with either higher porosity or hydrocarbon vs water saturation. It is hoped that this research direction would extend the petro-physical and seismic expression of the granite wash.

2. Geology:

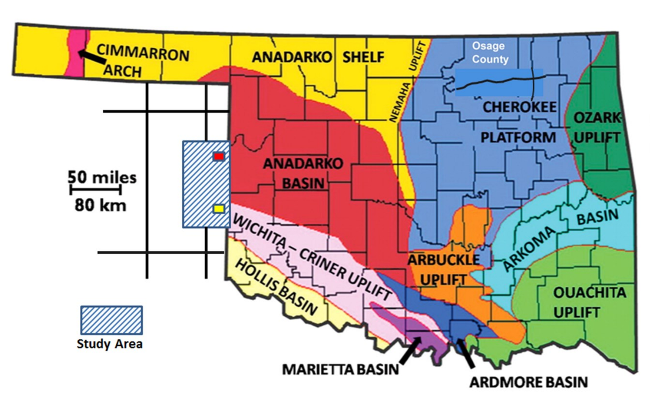


Figure 1: Relative location map of the Granite Wash formation showing major tectonic features of the Texas Panhandle. The bounds of the survey is delineated by the pattern-filled box designated by red and yellow squares (after Cardott and Lambert, 1985)

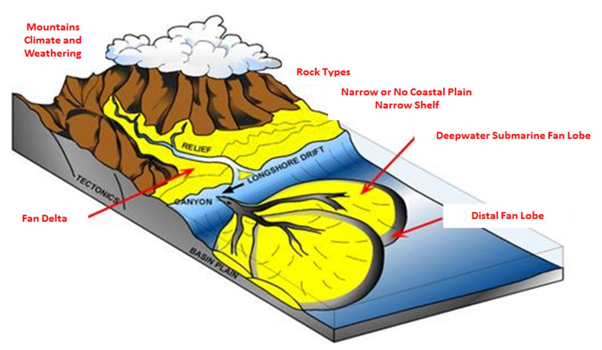


Figure 2: Schematic representation of the Amarillo Uplift and its erosion into the Anadarko Basin forming the Granite Wash Formation (after Crawford, 2013)

The Granite Wash formation of the Texas Panhandle and the western Oklahoma is approximately 160 miles long and 30 miles wide. Erosion from the uplift produced sediments of varying size and lithology that were deposited in the Anadarko Basin to the north. Deposition is thought to have occurred as a series of alluvial fans, turbidites, debris flows, and fan deltas containing inter-bedded layers of marine shales and carbonates (Figure 2). The name "Granite Wash" comes from the primary sediment of eroded granite, but it has come to refer to a broader spectrum of lithologies found in the formation. The structural highs and lows of the basin at the time of deposition due to tectonic activity play a part in its varying deposition. The Granite wash has low porosity and permeability due to a high level of carbonate cement in the sandstone (Mitchell, 2012)

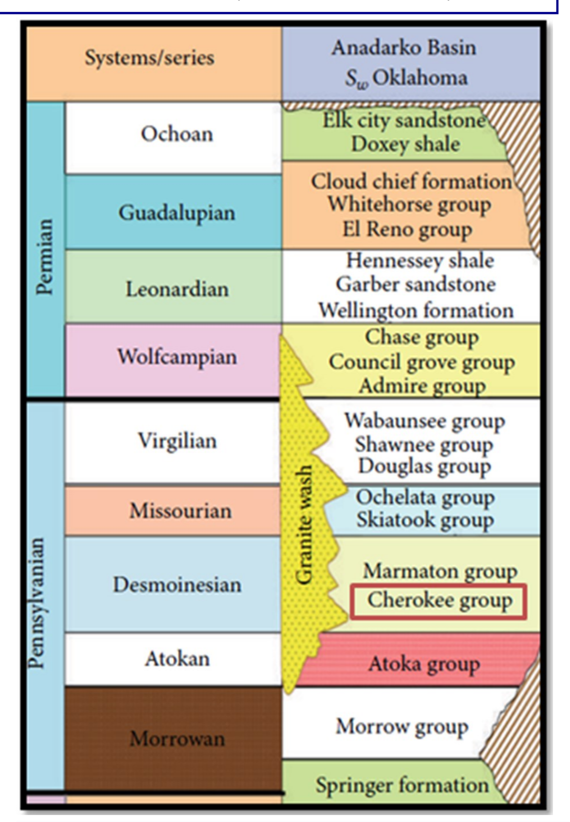
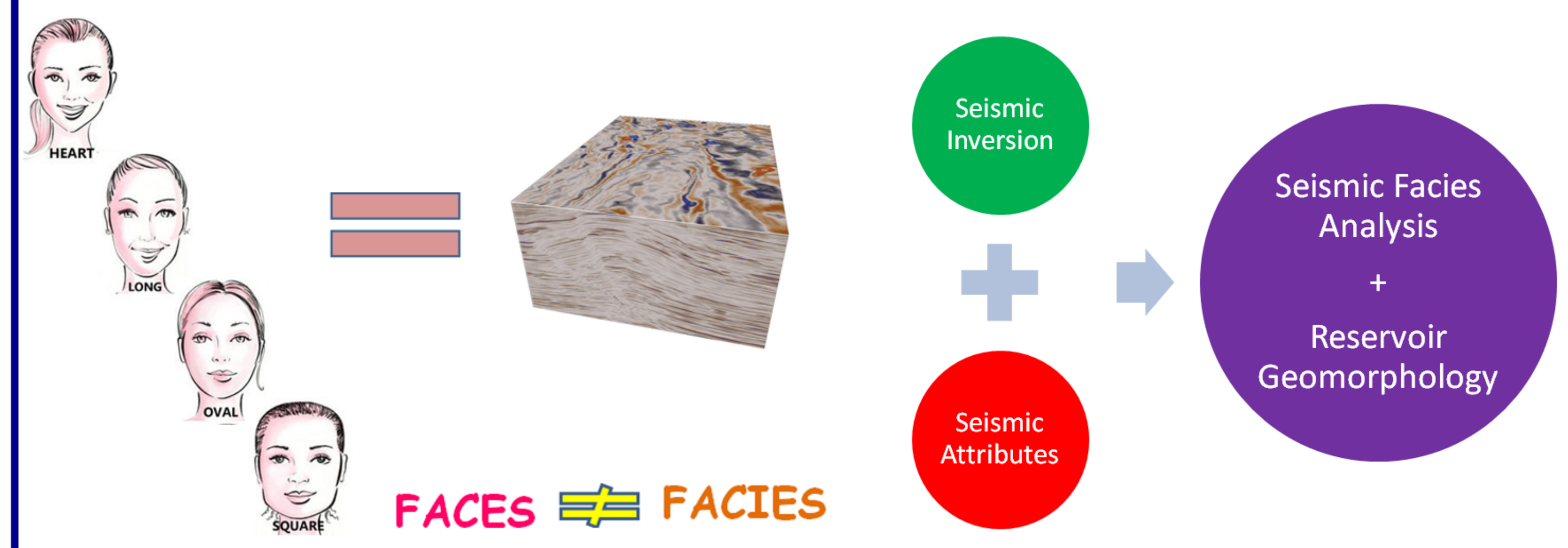


Figure 3: Generalized stratigraphic column used to classify the Pennsylvanian and Permian strata of the Anadarko basin (after Johnson and Cardott, 1992)

3. Motivation:



- Can we identify producing facies using attributes to recognize chaotic facies?
- Identification of specific alluvial fan depositional environments and reservoir facies from seismic data is not well documented. We use latent space modeling technique (GTM) to characterize the reservoir geomorphology.
- Cherokee granite wash has the best petrophysical response due to the availability of completed horizontal wells to validate results.

4.Horizons and Time Structure Maps:

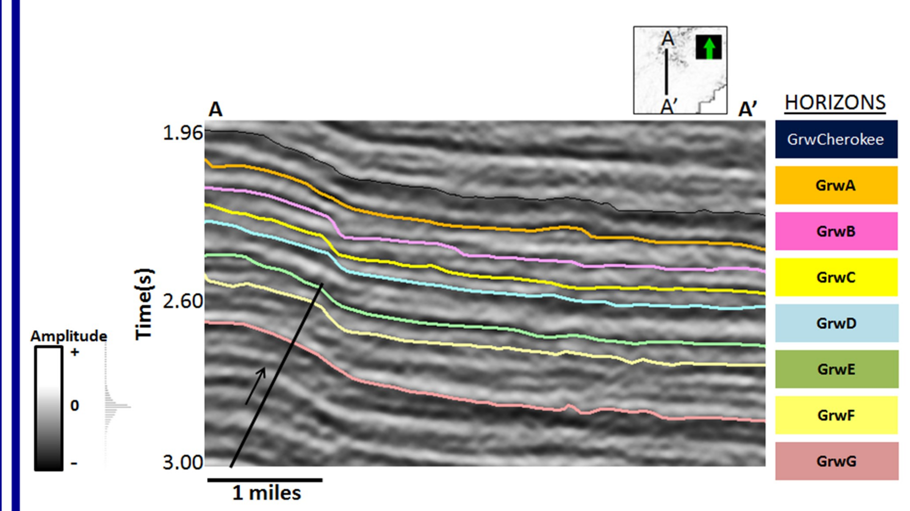
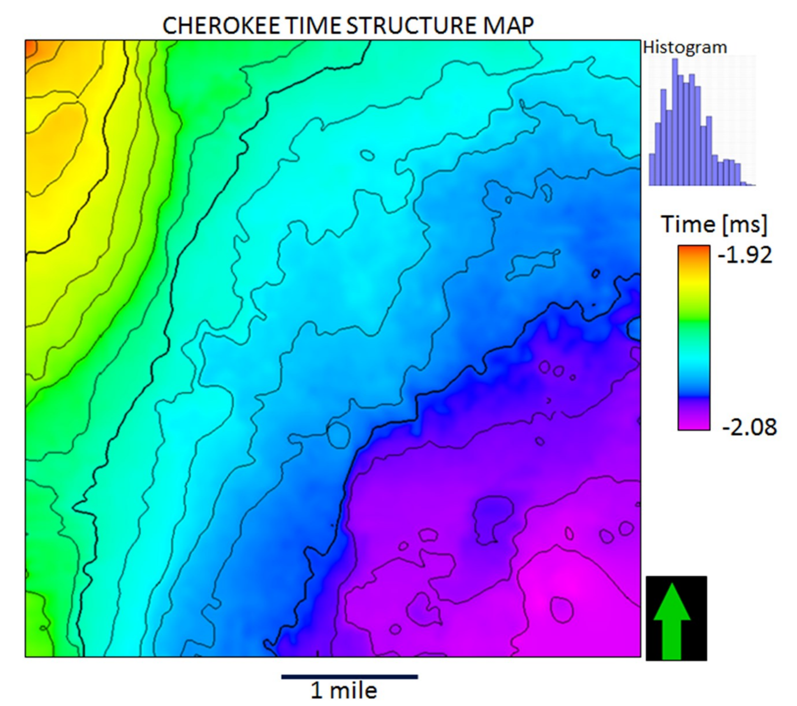


Figure 4: Vertical slices along AA' showing key interpreted horizons and a major fault in the Granite Wash interval. Up dip thinning of the units towards the west is interpreted as evidence of syncdepositional tectonics.



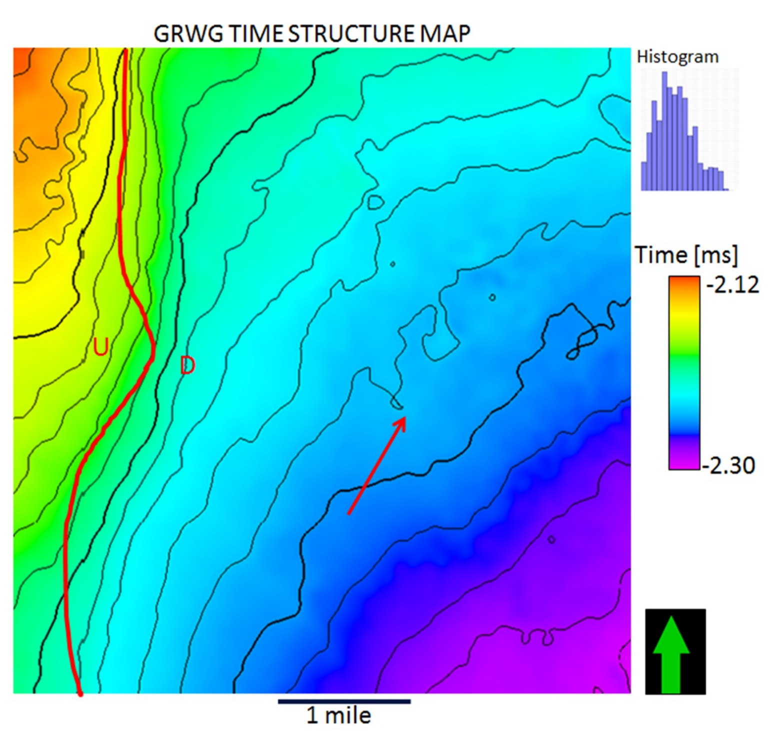


Figure 6: Time structure map for from the Granite Wash G. The red line represents the main fault within the survey and the red arrow represents the paleo-direction the sediment followed as it was been transported from southwest to northeast.

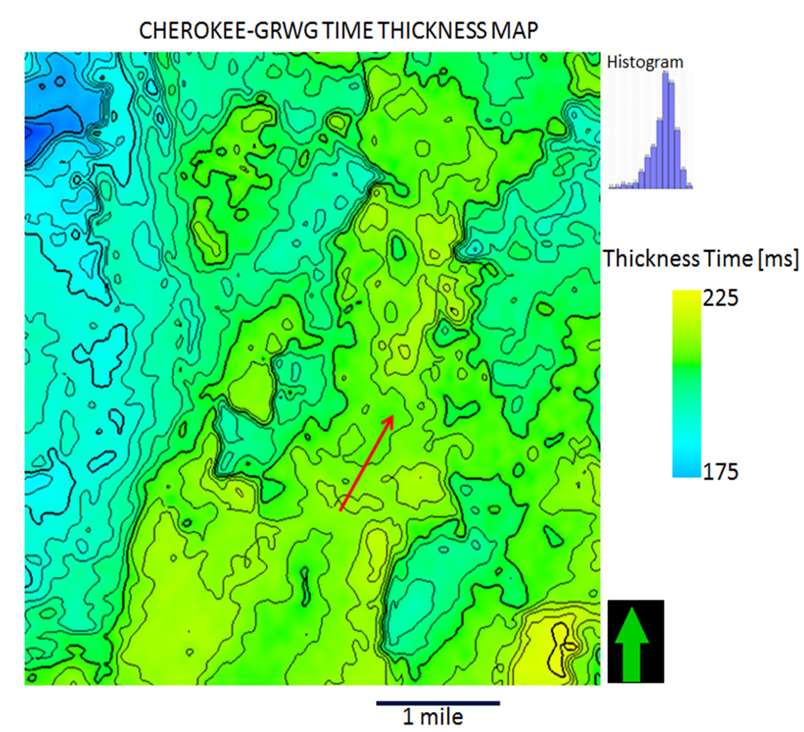


Figure 7: Time-thickness map of the Cherokee-GRWG interval of the Granite Wash. The thickest area lies to the south of the survey. The sediment accommodation in this area is concordant with the accumulation of alluvial fan wedges that become thinner as the fan prograded toward deeper parts of the basin . The red arrow represents the direction of progradation.

3. Post Stack Seismic Inversion and Seismic Attributes Results:

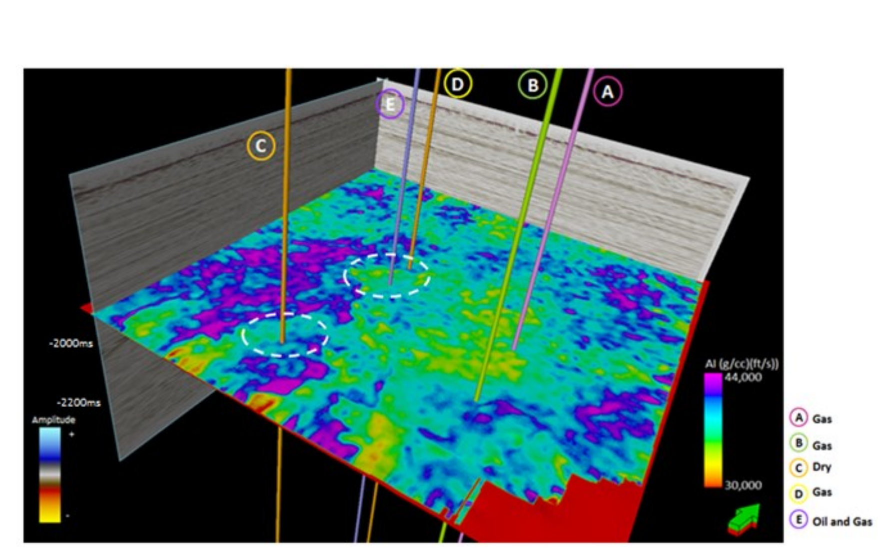


Figure 8: Acoustic impedance (AI) extracts along the Cherokee wash. Well constraints depicts areas of high impedance (Well C) having lesser gas or hydrocarbon potential. Low AI zones (Well E) are viable oil and gas 'pockets'.

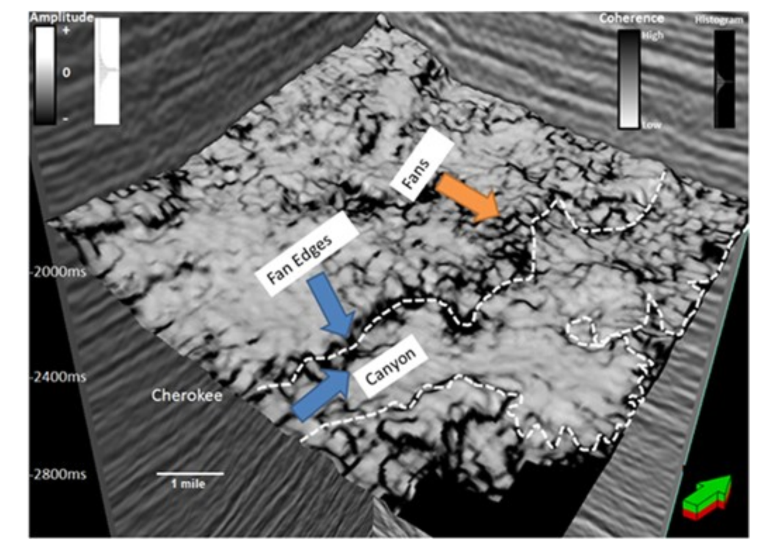


Figure 9: Coherence attribute extracted along the top of the Cherokee wash. Arrows points fan, faults and canyon edges. Abrupt changes in waveforms are generally indicative of faults as well as changes in depositional features.

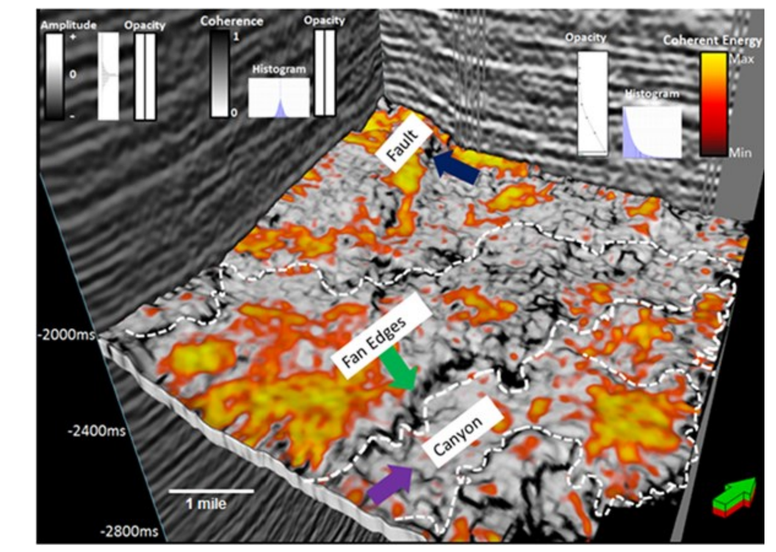
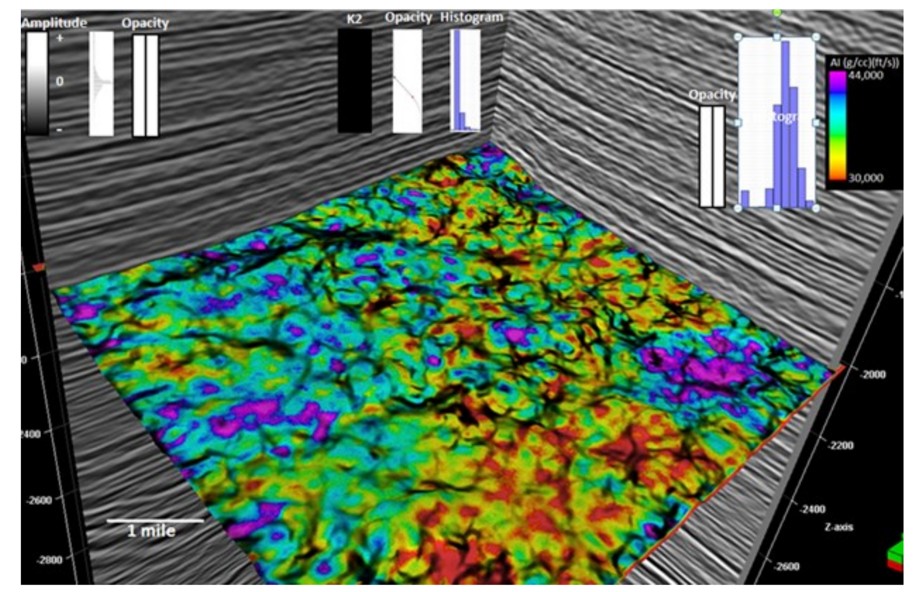


Figure 10: Co-rendered image of coherence attribute with the coherent energy. Note that high relief areas in the image have a high coherence energy with fan/ fault edges having a low coherence energy.



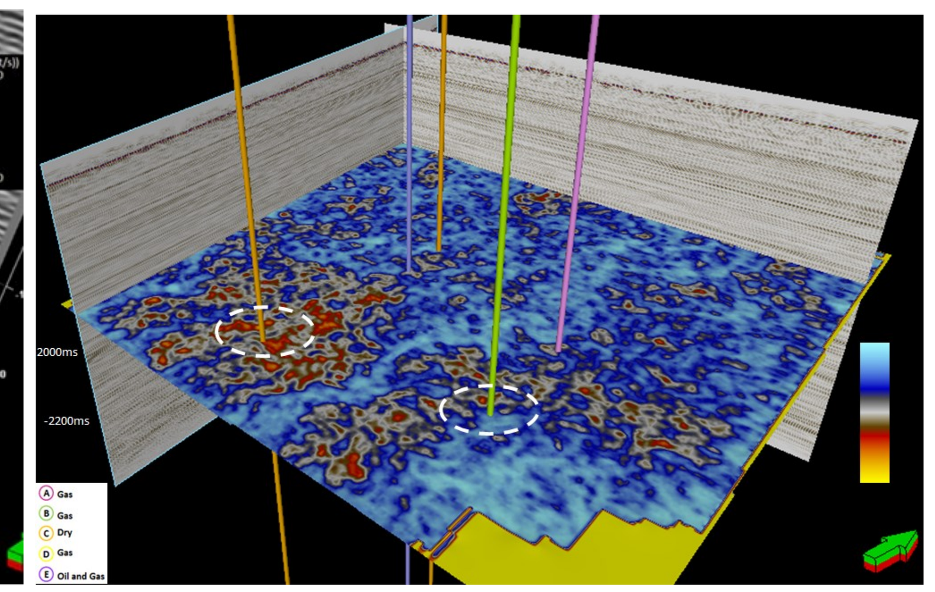
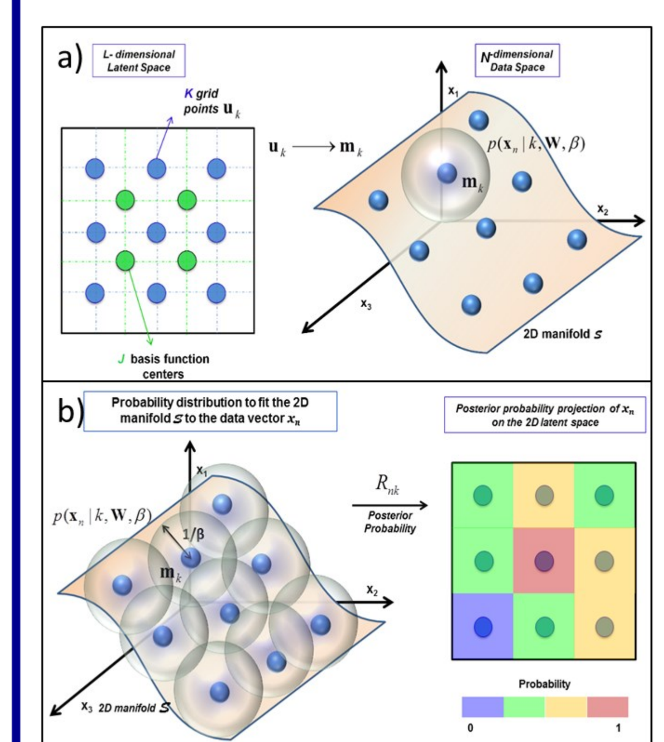


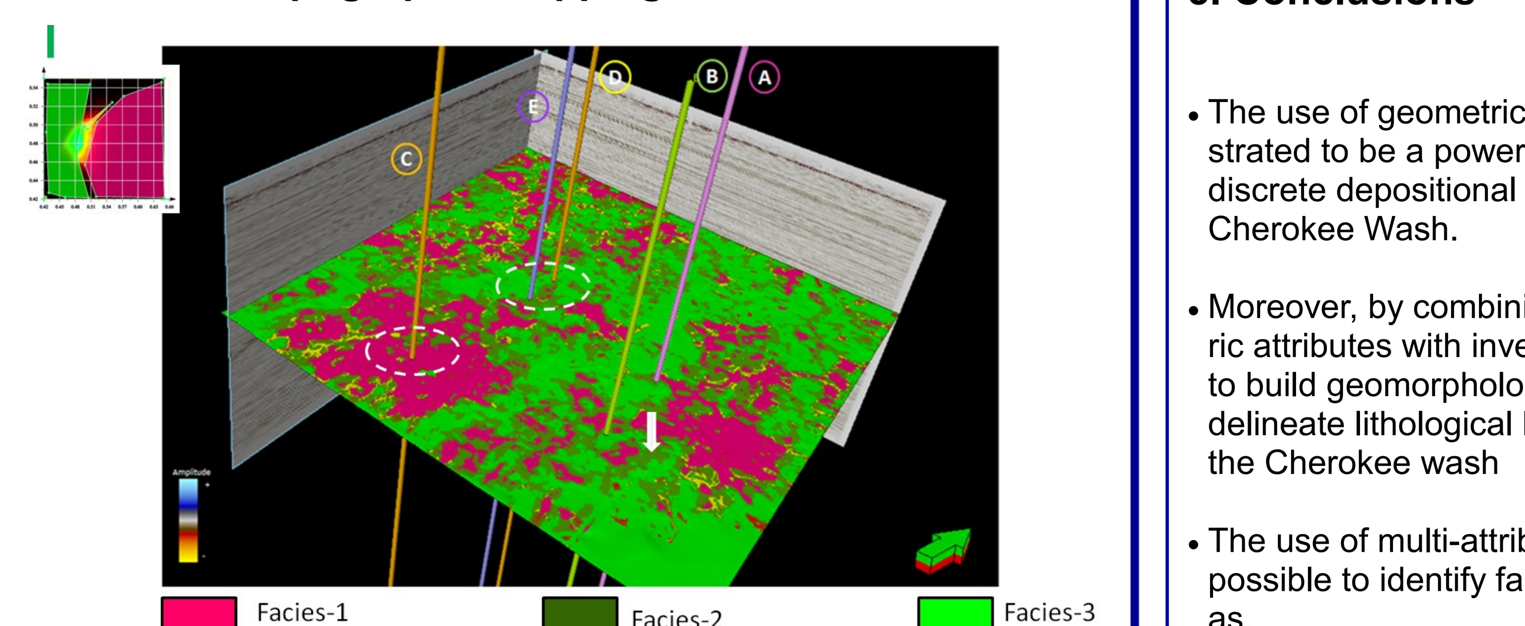
Figure 11: (Left) Post-Stack acoustic impedance inversion co-rendered with K2 most negative curvatures. Note that pockets of low AI correspond to "valley" values of the curvature anomalies. Curvature is an indicator of strain and is a proxy for areas of high fracture density. The post stack AI is extracted along the top of the Cherokee wash.

Figure12: (Right) GLCM entropy attribute: Seismic texture attributes indicate areas that calibrate nicely for gas wells. Gas bearing zones indicate high energy, low entropy, and high homogeneity. Oil bearing areas show moderate energy and homogeneity and low entropy values .

4. Seismic Facies Classification— Generative Topographic Mapping



Roy et. al (2014)



Facies volume from unsupervised GTM Classification (GTM3D). Input attributes are Coherence, GLCM (Homogeneity), P-impedance, Reflector Convergence, Peak Frequency. Facies 1, 2, 3 are classifieds as sandstones, shales and conglomerates respectively.

- Facies estimation is critical in understanding the stratigraphy and lithology of hydrocarbon reservoirs.
- Numbers of seismic attributes have increased , thus providing accurate measures of reservoir morphology.
- However attributes add extra dimensions. GTM reduces these dimensionality by projecting the data onto lower order space in which clusters can be readily identified and easily interpreted.

GTM Theory: Figures (a) and (b) A N-dimensional (N-attribute) data is represented with a lower 2-dimensional deformed manifold. GTM starts with an initial 2-D plane, defined by the first two eigenvectors of the N×N attribute covariance matrix. This plane is uniformly populated with clusters each of which describes a Gaussian PDF. At each iteration, the variance of the Gaussian is decreased. GTM uses non-linear reduction in latent space and provides a probabilistic representation of the data.

5. Conclusions

- The use of geometric attributes is demonstrated to be a powerful tool in delineating discrete depositional environments like the Cherokee Wash.
- Moreover, by combining different geometric attributes with inverted AI it is possible to build geomorphological model and also delineate lithological heterogeneity within the Cherokee wash
- The use of multi-attributes also makes it possible to identify fan deposits in the areas.
- We observed qualitative fan architectural relationships seismic attributes and unsupervised classification (GTM) outcomes
- Facies pattern were derived using our unconstrained supervision technique
- This probabilistic estimates fall into modern risk analysis evaluation of drill locations and reservoir evaluation.

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6. References

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