Multiattribute Seismic Facies Expressions of a Complex Granite Wash Formation - A Buffalo Wallow Field Illustration

Oluwatobi Olorunsola, Lennon Infante, Bryce Hutchinson, Jie Qi and Kurt Marfurt
ConocoPhillips School of Geology and Geophysics, University of Oklahoma, Norman

Summary

Although considered one of the most productive oil and gas reservoirs in the United States, the Pennsylvanian-age Granite Wash reservoir remain poorly understood. Amongst a myriad of issues that hinder development of hydrocarbon reserves are an unusually low porosity and permeability estimates, varying grain sizes, mineralogy, cementation and presence of micro-fractures are the more dominant ones. These have not only influenced its complex stratigraphic and structural depositional pattern but have also made the formation difficult to image seismically. To better understand the reservoir geomorphology and lithological heterogeneity, we report what we believe is the first seismic facies analysis of the Desmonesian-Cherokee wash of Wheeler and Hemphill counties, Texas using seismic attributes (geometric and textural) and inversion technique to map specific alluvial fan depositional environments and reservoir facies from seismic data as well identifying productive chaotic facies using these attributes. We also use an unsupervised latent space Generative Topographic Mapping (GTM) technique to classify rock-facies types and reservoir quality using well-logs as ground truth.

Introduction

Often touted as a complex alternating stack of varying lithologic and depositional patterns, the granite wash formation continues to confound experts and operators. Each potential pay zone exhibits a uniquely different reservoir character and as a result requires a slightly different geophysical approach to achieve success (Muhammad et. al., 2014). Due to the low porosity and permeability, varying mineralogical make-up, cementation and presence of micro-fractions, the Granite Wash intervals require careful analysis. Hence, understanding the depositional history and the geological variations is critical to drilling and completion strategies.

Straddling the northeastern Pandhandle area of Texas to western Oklahoma, the depositional settings in granite wash reservoirs occur as a series of alluvial fans, debris flows, and fan deltas containing interbedded shales and carbonates (Mitchell, 2011). The formation consists of five distinct series (Figure 1a): The Virgilian, Missourian, Desmonesian, Atoka and Morrowan. In this study we focus on characterization of chaotic features and alluvial fans deposited on the Cherokee group of the Wheeler and Hemphill counties of the Texas Panhandle with an aim to delineate the granite wash reservoir geomorphology and depositional environment.

Alluvial fans generally exhibit complex stratigraphy and constitute some of the world’s most productive hydrocarbon reservoirs facies. As a result, a clear understanding of their architectural and facies relationship is critical for oil and gas exploration. Following the advent of horizontal drilling and hydraulic fracturing technology, Granite Wash reservoirs have become an important target for oil and gas exploration. Previous geological studies in the area (Bouna, 2000; Parks 2011) agree generally in delineating the fan complex into proximal, medial and distal fans. However, geophysically the granite wash formation remains a challenging unit for seismic characterization, especially within areas proximal to the source (Valerio, 2006; Figure 1b). Due to rapid change in lithofacies, thickness and bed discontinuities, the identification of specific alluvial depositional environments and reservoir facies from seismic data is not well-documented.

**Figure 1:** (a) Generalized stratigraphic column used to classify the Pennsylvanian and Permian strata of the Anadarko basin (after Johnson and Cardott, 1992) (b) Schematic representation of the Amarillo Uplift and its erosion into the Anadarko Basin forming the Granite Wash Formation (after Crawford, 2013).

Geological Settings

The Pennsylvanian Granite Wash formation of the Texas Panhandle and western Oklahoma is approximately 160 miles long and 30 miles wide. This work is mainly focused on the Desmonesian Series of the Granite Wash in the Buffalo Wallow Field area of Wheeler and Hemphill...
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This series is deposited proximal to the Amarillo-Wichita Uplift as conglomerates, and coarse sandstone with a low percentage of interbedded shale. The alluvial fans and fan delta systems in this area contain abundant potential reservoir facies and generally merge down depositional dip to the northeast from the uplift and gradually become less coarse-grained and comprise of fine-to-medium-grained sandstone interbedded with shale, finally grading into fine grained lower gradient systems like fluvial or oceanic depending on the delta type as alluvial or fan-delta (Dutton, 1984; Mitchell 2011). Figure 2 shows the time structure map of the Cherokee Wash with Figure 3 also showing the thickness map of the interpreted seismic volume. We interpret the GRWG horizon as the base of the granite wash.

Data Availability

The 3D seismic surveys were acquired over a 28-sq. mile spanned area of the Wheeler and Hemphill counties in 2011 (Figure). Despite having been processed by a commercial vendor, the post-stack migrated volume still suffers migration aliasing and a relatively low vertical resolution. To improve the signal-to-noise ratio, the post stack volume was passed through two-iterative processes of structure-oriented filtering algorithm. Random and coherent noises were greatly suppressed with the reflectors appearing more continuous and easier to interpret. We also select four well logs for to generate post stack inversion products. These wells were corrected for erroneous reading and borehole effect and were all tied to seismic.

Application

Seismic Attributes Selection

Our choice of attribute selection is primarily guided by the aim at which this work is carried out. Facies identification objectives associated with mapping chaotic depositional trends, reservoir geomorphology and heterogeneity are more suited to select-type geometric, textural or seismic inversion attributes. Application of multiattribute facies analysis for reservoir characterization have also been proven to achieved excellent results in mapping both lateral and vertical lithofacies heterogeneities in a complex carbonate wash in the Vera Cruz basin, Colombia (Roy et al., 2012). In our case we use coherence, coherent energy, curvature, peak frequency, GLCM entropy and heterogeneity, p-impedance and reflector convergence. Coherence measures waveform similarities and enhances our ability to visualize structural and stratigraphic discontinuities on horizon slices. Figure 6 shows a coherence time slice extracted along the top of the Cherokee wash. In this image, the fan edges are easy to identify.
delineate. The area bounded by the white dotted line is interpreted as an evidence of a Canyon feature. Figure (7) also shows co-rendered coherence and coherence energy attributes. Bright colors indicate thicker, sandier portions of the fan geometry.

We also apply select texture attributes with the intent of establishing correlative nexus between productive facies and chaotic depositional fan features. These attributes provides clearer pictures of the distribution, volume and connectivity of hydrocarbon bearing facies reservoir (Chopra et al, 2007). Figure 7 shows a gray-level co-occurrence matrix (GLCM) entropy texture attribute. This attribute provides measures of disorderliness or complexity of a seismic image and thus provides lateral variations of reflectivity along structural presence.

Finally, we compute p-impedance volume inversion attribute volume in an attempt to map variations in lithology, fluid content as well as the elastic properties of the target formation. Figure 8 also shows co-rendered most-negative curvature and p-impedance volume. Here, relatively low AI values correspond to ‘valley’ estimates of the curvature anomalies. Reflector convergence structural attributes (not shown) show the orientation of the fan thinning (Chopra et al., 2007)

Figure 5: Coherence attribute extracted along the top of the Cherokee wash. Arrows indicate fan, faults and canyon edges. Abrupt changes in waveforms are generally indicative of faults as well as changes in depositional features.

Figure 6: Co-rendered image of coherence attribute with the coherent energy. Note that high relief areas in the image have high coherence energy with fan/fault edges having low coherence energy.

Figure 7: 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

Figure 8: 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 may be proxy for areas of high fracture density. The post stack AI is extracted along the top of the Cherokee wash.
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Methodology

We apply generative topological mapping classification technique (Wallet et al., 2009) to eight seismic attributes that were previously discussed. As the name implies, this non-linear projection technique simply provides a probabilistic representation of the data-vectors in a corresponding lower latent dimensional space.

In a sense, GTM learns the latent space by fitting a probability density function model a lower dimensional surface closely. Our method starts with an array of grid points projected onto a lower dimensional space. Respective grid points are then mapped in a non-linear pattern onto a similar dimensional non-Euclidean curved surface as vector \((m_k)\) projected into a different dimensional space in GTM. Respective data vectors \((x_k)\) mapped to this space are then modeled as a group of Gaussian PDFs centred on these reference vectors \((m_k)\).

We applied the GTM algorithm to our select attributes using coherence, coherent energy, peak frequency, reflector convergence, GLCM entropy and heterogeneity and p-impedance attribute volumes and derived GTM1 and GTM2 outputs. These attributes then results in cluster locations along the two axes in the latent space to be utilized when cross-plotting. Figure (10) shows same time-slice extract along the Cherokee wash through cross-plotting GTM1 and GTM2 projections. The pink color delineations are interpreted as Facies 1 (pink), Facies 2 (dark green) and Facies 3 (lemon green) observed on logs Conglomerates, Shale and Sand lithofacies types. It is observed that Well C, considered a dry well, prongs through the pink-colored lithofacies type.

![Figure 10: Facies volume from unsupervised GTM Classification (GTM3D). Input attributes are Coherence, GLCM (Homogeneity), P-impedance, Reflector Convergence, Peak Frequency. Facies 1, 2, 3 are classified as conglomerates, shales and sands respectively.](image)

Conclusions

The use of geometric, textural and inversion 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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REFERENCES