Fracture analysis using 3D seismic attributes in the Hunton Limestone, Oklahoma, USA

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Summary

The Hunton Limestone in Oklahoma is an important reservoir in the oil and gas industry. Al-Shaieb et al. (1993) find that fractures in the Hunton Limestone are one of the key components of porosity with fracture permeability enhancing production. Fracture identification from surface seismic is an important topic, but little research in this area has been done on the Hunton Limestone. Hart (2006) has analyzed fractures using post stack seismic in the San Juan Basin, while Narhari et al. (2009) have analyzed fractures using post stack seismic data in Kuwait, both sandstones. Nissen et al. (2009) have used post stack seismic attributes to map fractures in the Arbuckle Limestone of Kansas, and calibrated their findings using a horizontal well adjacent to, but not in the seismic survey area. To our knowledge, little has been published on quantitative correlation of lineaments seen on post stack seismic attributes to fractures seen on horizontal wells. Therefore, this project is very important to developing an understanding of fracturing in limestones. From a preliminary 3D seismic attribute analysis of the area of interest, the attributes of curvature (positive and negative) and energy ratio have been the most helpful in predicting where a high density of fractures might exist and their general orientation. In addition to these attributes, approximately 10 miles of proprietary horizontal image logs have been obtained in the area of interest and will be studied to correlate fractures in the logs with proposed areas of fracturing in the seismic volume. This correlation should provide valuable information to locate and identify fracture patterns in the Hunton Limestone and enhance the ability to predict good areas of high porosity and permeability in both the Hunton and possibly other carbonates too. Fieldwork is being conducted in a specific test area in Oklahoma where an outcrop of the Hunton Limestone is exposed to characterize fractures in outcrop and create an analog for fracture patterns in the subsurface. Seismic data will be obtained in the outcrop area to further characterize the visible fractures with a seismic wavelet. After obtaining and studying all of the data, it is proposed that fractures and fracture patterns in the Hunton Limestone will be better understood and the ability to predict areas of high density fractures will be enhanced.

Introduction: The Hunton Limestone

The Hunton Limestone or Hunton Group lies beneath the Woodford Shale which is separated from the Hunton by an unconformity. The Hunton Group is made up of shallow-marine carbonates deposited from the Late Ordovician to the Early Devonian and formed on a gently inclined ramp. Due to this depositional environment, the Hunton is laterally extensive in Oklahoma (Al-Shaieb et al., 1999).

Method: Seismic Attributes

The operator acquired a small 3D survey over the target area, which was processed through prestack time migration. The data quality at the Hunton horizon (Figure 1) is good, but suffers from acquisition footprint. Next we generated horizon slices through volumetric estimates of coherence and both long-wavelength and short-wavelength curvature (Figures 2a, 2b, 2c, and 2d). The long wavelength curvature attributes are typically indicative of larger bends and folds, while the short wavelength curvature attributes aide more in identification of smaller features, like possible fracture areas. Areas shaded dark red are most positive curvature, while conversely areas colored dark blue are most negative curvature for both long and short wavelength calculations. The coherence attribute (e.g. Chopra and Marfurt, 2007) measures the similarity between waveforms or traces such that areas of high discontinuity appear as darker shades of grey to black, while more continuous areas vary from light grey to white (Figure 3). With sufficient offset, diagenetic alteration, or change in impedance, fractures and faults theoretically should be found in areas of high discontinuity and areas where the curvature is highest. In Figures 4a, 4b, 4c, and 4d we co-render the coherence image with the four previously-displayed curvature images allowing a visual correlation of incoherent areas with high curvature.

Method: Initial Calibration with Image Logs in Horizontal Wells.

Next, we correlate possible areas of high fracturing in the attribute volume with the location of one of our image logs shown by the yellow line on Figures 2-3d. Using XY coordinates from the horizontal well mentioned above has allowed us to pinpoint specific locations within the seismic data to allow for specific study of those areas in well logs. At present, our correlation is only visual and a more detailed analysis of the image logs in necessary. In theory this will allow characterization of high fracture density areas in both well logs and seismic data. Next, the entire length of image logs will be analyzed to see potential areas where seismic did not indicate high areas of fracturing and seismic attributes will be recalculated to ensure proper calibration if needed. Following this, field work will be conducted in the area of interest on fractures to understand in outcrop how fractures and fracture patterns behave in the Hunton Limestone. After this characterization, seismic data will be acquired near the field area to allow for seismic correlation with real life fracture patterns which will then be compared with the seismic correlation between the image logs and 3D data previously studied. Theoretically, all of these correlations should be consistent and aide in understanding the complex identity of fractures in the Hunton Limestone. However, there is a possibility that fractures in outcrop will be slightly to significantly different than those in the subsurface due to release of confining pressure with exhumation of the Hunton Limestone. Hopefully this possibility causes only a slight difference, but could pose a significant challenge. However, regardless of the effect of exhumation of the Hunton Limestone, this analysis of fractures using 3D attributes will contribute positively to developing a better understanding of the connection between fractures and surface seismic through correlation between image logs and seismic attributes.

Conclusions

From the preliminary visual correlation between horizontal image logs and the seismic attributes, it appears that there is a relatively high correlation between these data. From these initial successes in correlation it appears that this current workflow may contain the key to high density fracture identification in the subsurface. However, a more detailed image log correlation, fracture analysis in outcrops, and additional seismic data is imperative to calibrate the attributes correctly and is the required next step in the workflow.

Acknowledgements

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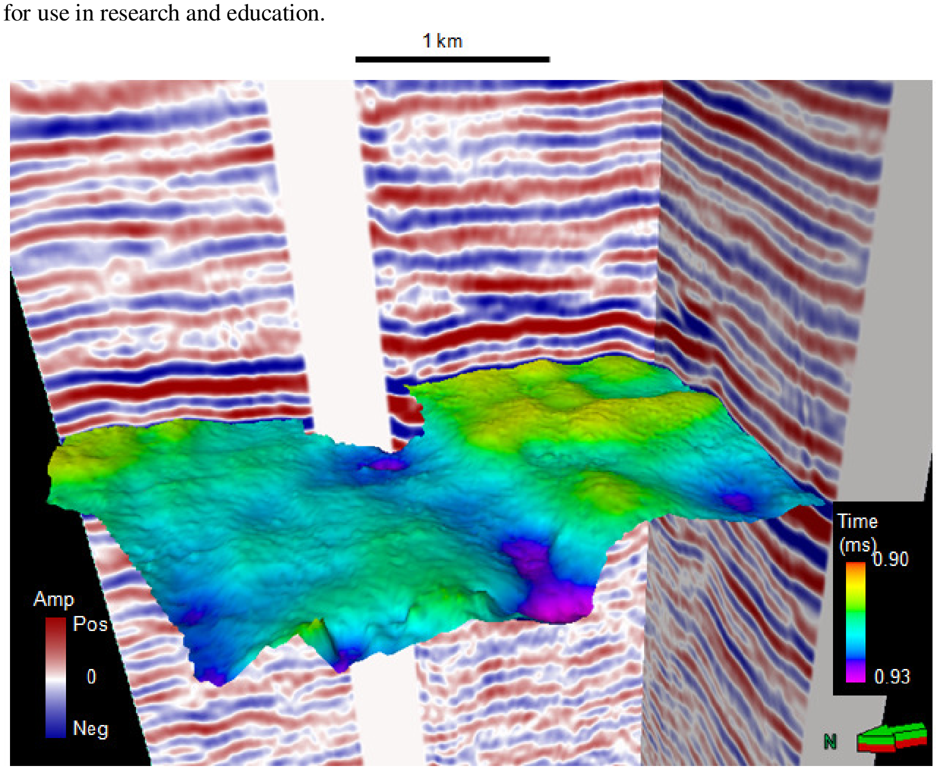
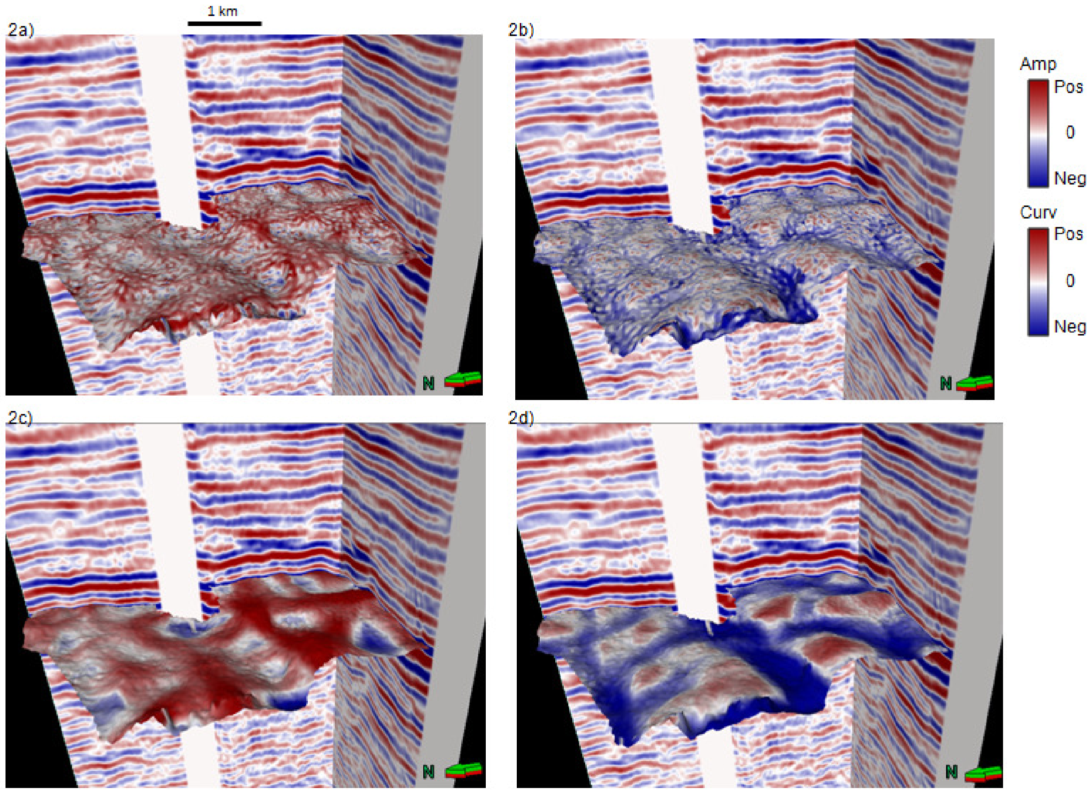


Figure 1 - Horizon slice of the Hunton Limestone shown with the seismic data. The colorbar for the horizon slice shows two-way travel time in ms. Reds and yellows are highs with purples and blues indicating lows. The seismic amplitude colorbar shows positive peaks in red and negative troughs in blue.



Figures 2a, 2b, 2c, and 2d – These figures illustrate positive and negative short wavelength and long wavelength curvature respectively. The seismic data appears to be very high quality and the amplitude is shown by the colorbar labeled "Amp" indicating peaks are red and troughs are blue. The curvature has a similar colorbar and the most positive areas are red and the most negative are blue. These images are shown on the picked Hunton horizon in the seismic data.

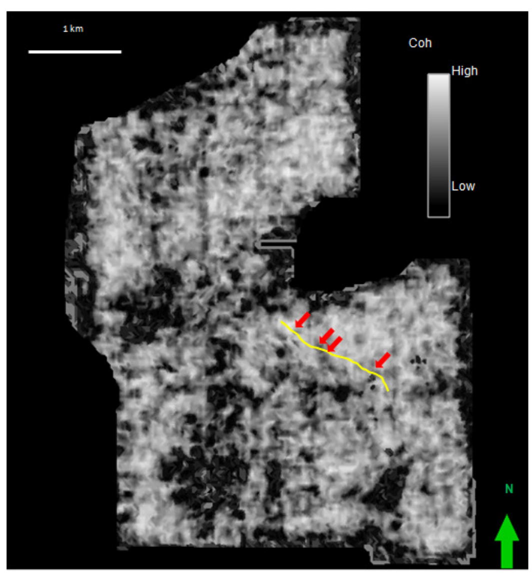
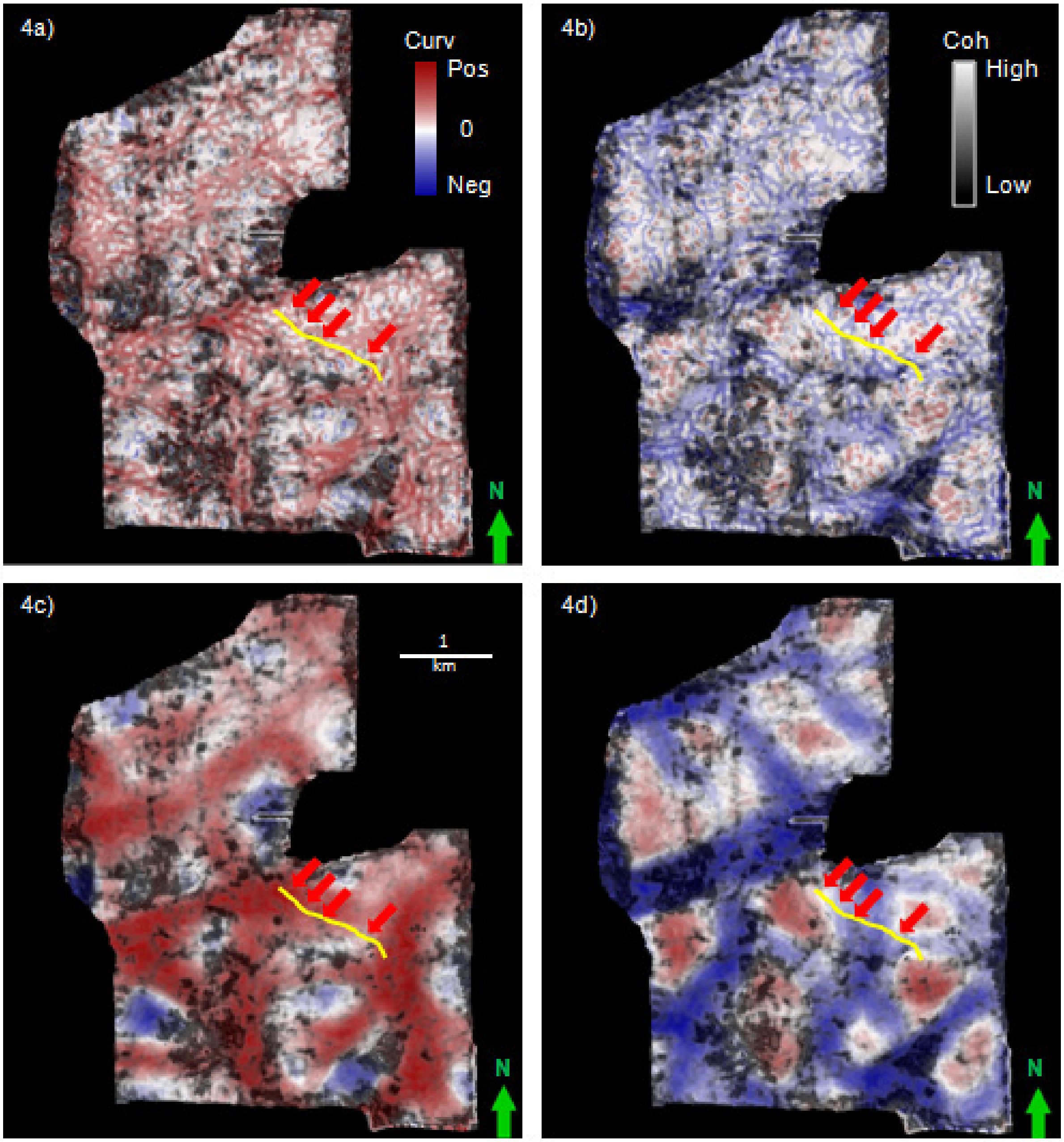


Figure 3 – Coherence attribute showing areas that are coherent and incoherent as indicated by the colorbar. Light colored areas are highly coherent and dark colors are more incoherent. The yellow line is a horizontal well bore in the seismic data. Red arrows indicate areas of possible high fracture density.

Hunton Limestone fractures



Figures 4a, 4b, 4c, and 4d – These figures show a co-rendering of the coherence and curvature attributes previously shown in the figures above. The yellow line on each image is the location of a horizontal borehole. Areas where both curvature an incoherence are high should be good areas to find high density of fractures. The colorbar for curvature shows that red is positive curvature and blue is negative curvature. The colorbar for coherence indicates that light colors are coherent and dark colors are incoherent. Red arrows indicate areas of possible high fracture density due to high curvature and incoherence.