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Calibrating seismic fracture prediction using borehole image logs, application to the Mississippian Limestone

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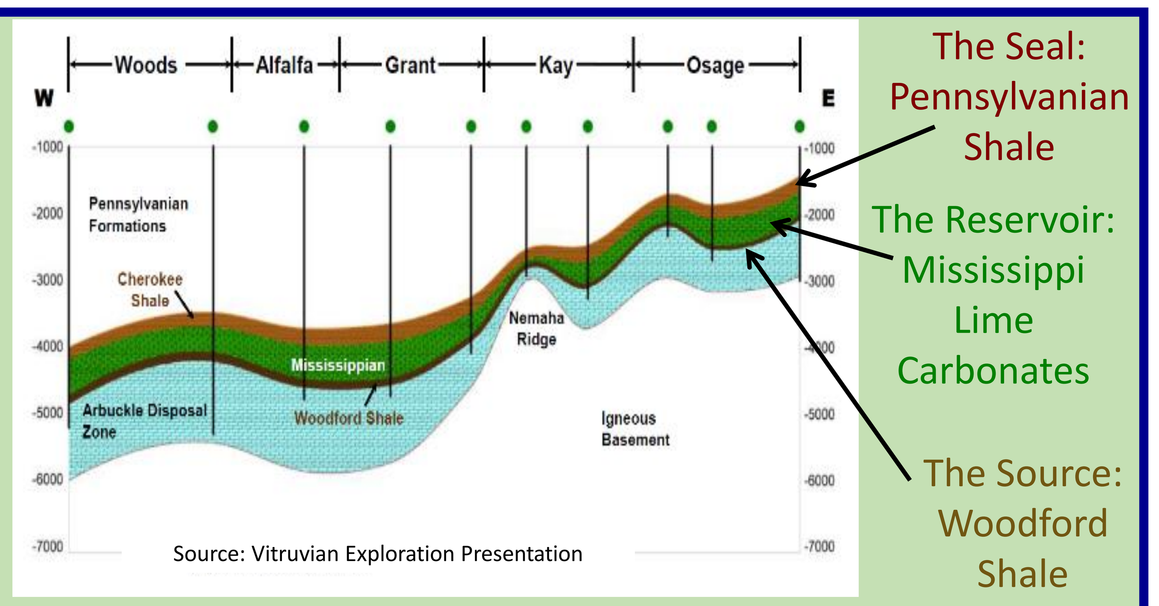
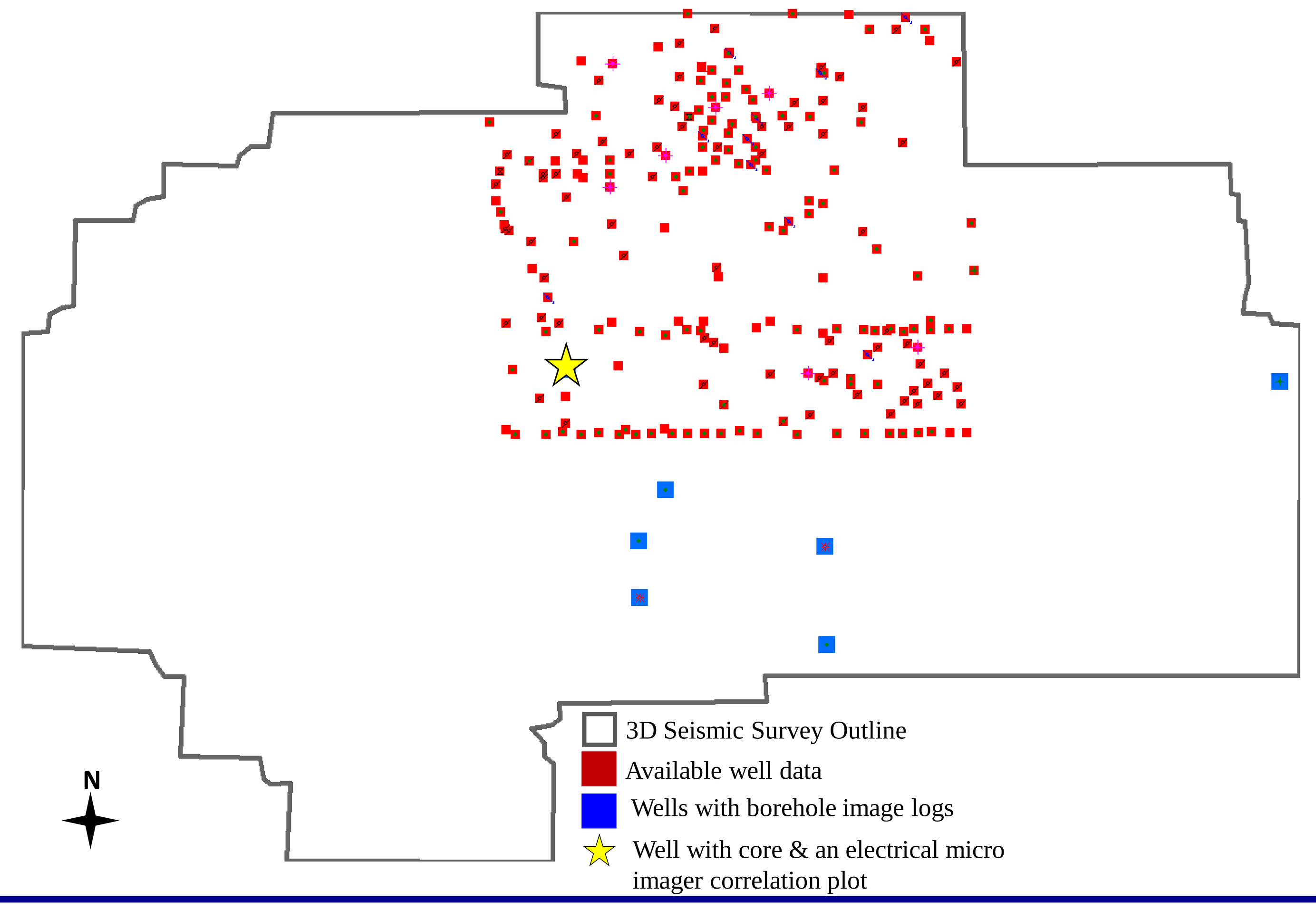
Introduction

The Mississippi Lime reservoir is located in northern Oklahoma and southern Kansas. Drilling activity has increased in the reservoir over the past decade with horizontal drilling and hydraulic fracturing. Hydrocarbon storage cannot be directly attributed to matrix porosity, especially outside of the tripolitic chert. Almost all hydrocarbon reservoirs in sedimentary rock contain fractures, with the majority of them sufficiently fractured enough to be considered fractured reservoirs (Nelson, R.A. 2001). Natural fractures in the Mississippi Lime contribute both to hydrocarbon storage and permeability. The goal of my work is to find a 3D seismic "proxy" to predict the presence of natural fractures away from the well bore. I will determine which seismic inversion and attribute products to use by correlating linear and nonlinear combinations of attributes with fracture intensity measured six horizontal borehole image logs that lie within the bounds of a seismic survey. I will start with the simplest method of multi-variable nonlinear regression. Five of the six borehole images will be used in the generation of the fracture prediction model, in order to quality control check the results of the fracture prediction model with the blind borehole image log not used in its generation.



I will then evaluate other methods including neural networks and proximal support vector machines (Zhang et al., 2015). The resulting fracture prediction model can then be utilized as an input for a previously generated geomodel using traditional well log and seismic data (Lindsey, 2015). The fracture intensity component could potentially provide an explanation for why production levels in some areas do confirm expectations based solely on matrix porosity. In addition, if fracture aperture and geometry can be predicted through core, borehole image logs, and outcrop; the fracture intensity model can then be used to generate a discrete fracture network model. The workflow for creating a fracture intensity model is not only applicable to the Mississippian Limestone reservoir, but is applicable to any fractured reservoir that has borehole image logs and seismic data available.

Data Availability

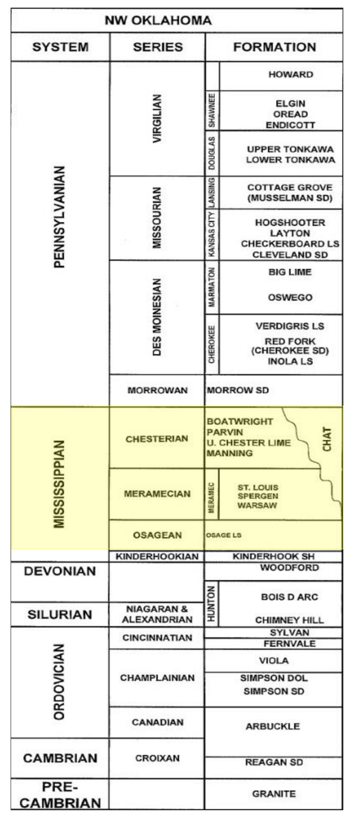


Chesapeake Energy Corporation licensed seismic data, well data, log data, and core data within the Mississippian Limestone in Northern Oklahoma to The University of Oklahoma. The 3D prestack time-migrated data volume with noise reduction covers over 268 square miles of the Mississippian Limestone in Northern Oklahoma. Well data within the northeastern third of the survey was licensed, along with available logs from those wells. Log data includes, but is not limited to gamma ray, density, and sonic logs.

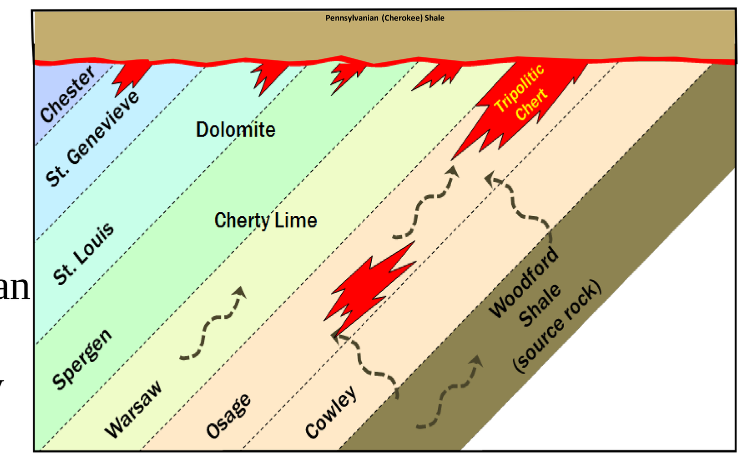
There are six borehole image logs from horizontal wells that lie within the 3D seismic survey, including both the raw and processed .lis files. A vertical wells within the seismic survey contains an electrical micro imager correlation plot with a fracture density .tif image that has fracture density interpretation on the .tif image. This particular vertical well was also cored, enabling correlation between fractures in the core and interpretations on the electrical micro imager correlation plot.

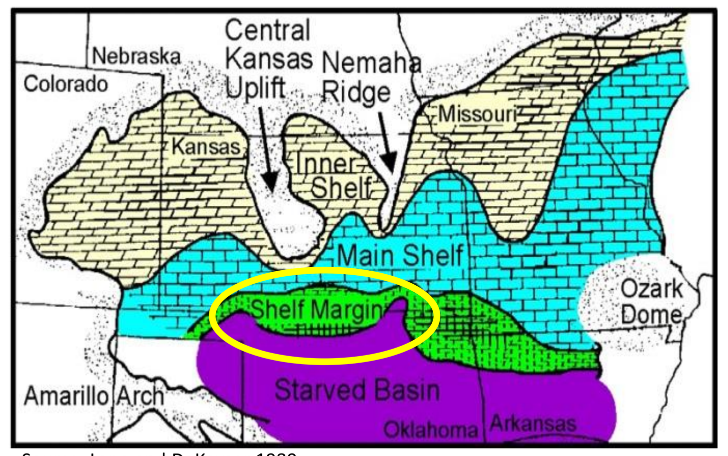
Scaled oil, gas and water production is also available for the licensed wells that wells.

Geologic Background



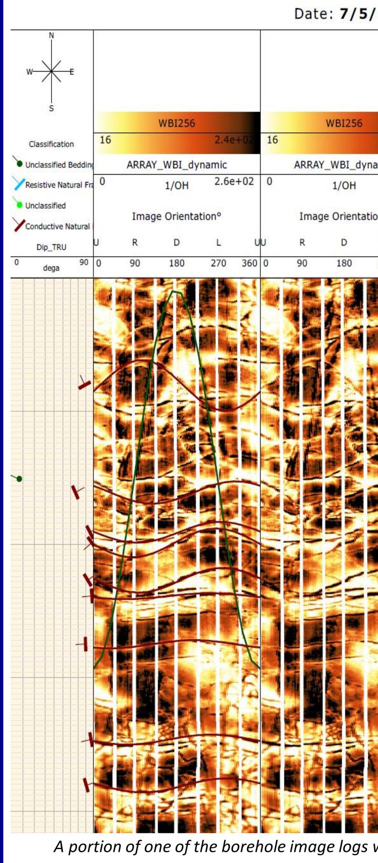
The Mississippian ranges in age from 320 to 360 million years ago (Figure 1). The study area was on the shelf margin of the Anadarko Basin (Figure 2) (Lane and DeKeyser, 1980). Oil sourced from the Woodford shale migrated into the Mississippian Limestone reservoir and was sealed by the overlaying impermeable Pennsylvanian shales (Figure 3). During the early Pennsylvanian, the Mississippian carbonates were exposed and eroded. Much of the reserves lie in porous carbonates where porosity truncates against the Mississippian Pennsylvanian unconformity (Figure 4). The Mississippian reservoir is comprised of tripolitic chert, porous limestone, cherty limestone, and cherty dolomitic limestone. Matrix porosity typically ranges from 5% to 20%; however, porosity can range from 20% to 30% in the tripolite. Permeability ranges from .001 to about 1 mD (Matson, 2015). The carbonate component of the Mississippian is a naturally fractured, providing hydrocarbon storage.





Source: Lane and DeKeyser 1980

Methodology



A portion of one of the borehole image logs with fractures interpreted on the left panel in burgundy and bedding interpreted in dark green

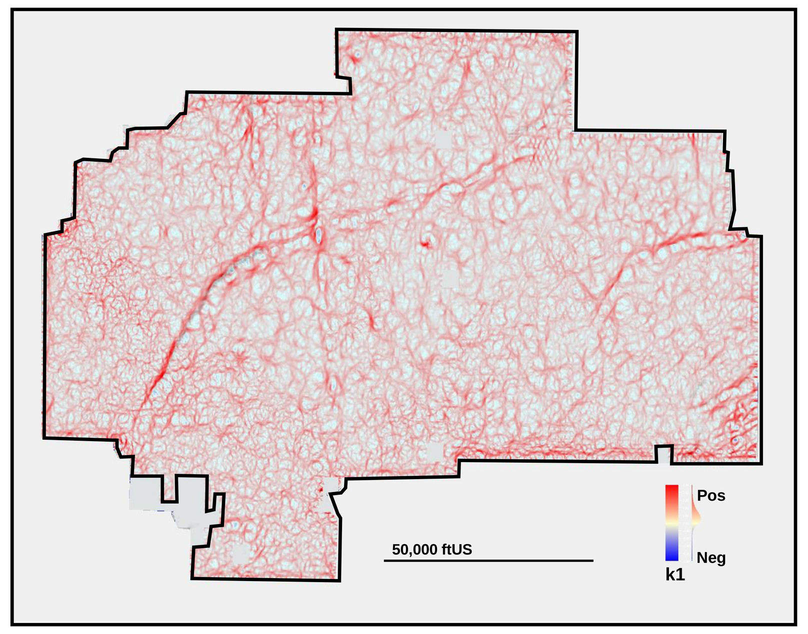
- Interpret fractures on the 6 horizontal wells with borehole image logs

  Use those interpretations to create fracture intensity .las files along the horizontal wells
- Generate seismic attribute volumes for the seismic survey

  To the right is one of the attributes which will be considered to be correlated to the fracture intensity volume
- Convert seismic amplitude, impedance and other attribute volumes to depth

  To depth convert, interpret the Mississippi Lime, the Lansing? shallower horizon, and the deeper Viola? horizon. Pick tops for those corresponding formations as well to depth convert
- Bring the depth converted attribute volumes and the fracture intensity .las files into Transform

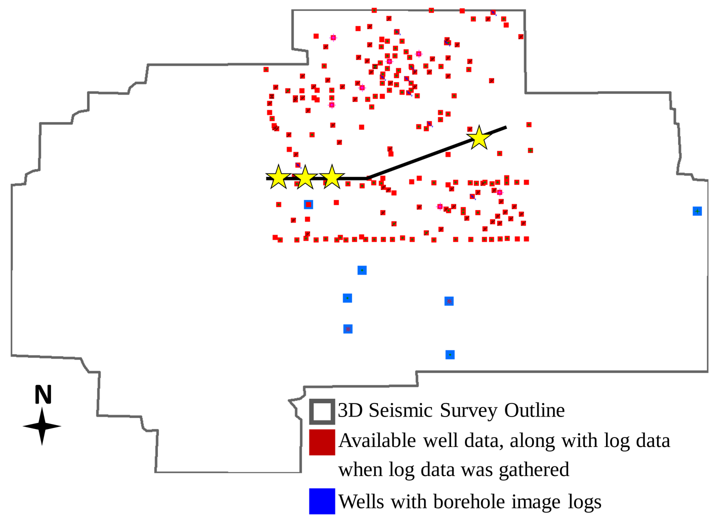
  Extract the attributes along the horizontal of the wells that also have the fracture intensity .las files



One of the AASPI attributes, most positive curvature, extracted off of the interpreted Mississippian top; which will be considered for the nonlinear regression to estimate fractures

- Use non-linear, multivariate statistics to find the combination of attributes that best predict the fracture intensity logs

  Then apply the result to the Mississippian section of the entire seismic survey
- Use the resulting fracture intensity model as an input into Katherine Lindsey's (2015) geomodel, and possibly use it as an input to a discrete fracture network



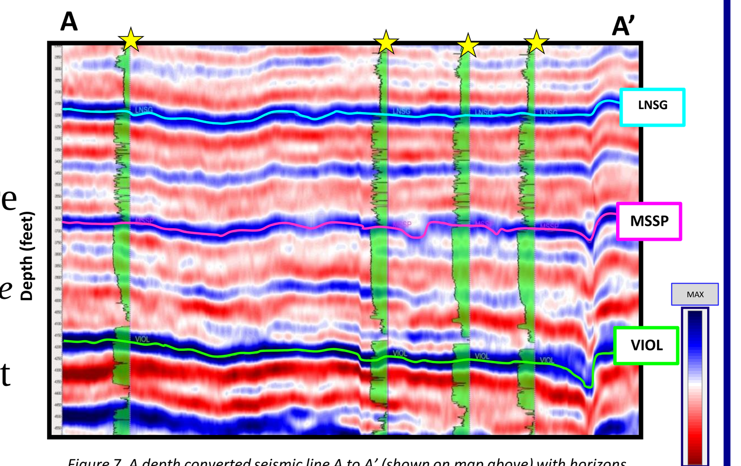


Figure 7. A depth converted seismic line A to A' (shown on map above) with horizons and log markers interpreted for the Lansing Lime, the Mississippian, and the Viola. Interpretations used for depth conversion of seismic volumes

Hypothesis

- Through the use of surrounding attributes, I will be able to predict the fracture intensity in the blind well
- The suite of surface seismic attributes used to predict the fracture intensity in the blind well can be used as fracture intensity proxy in undrilled portions of the survey
- A combination of porosity and fracture intensity will better correlate to well production than porosity by itself.
- The strike of structural deformation measured by curvature and coherence and azimuthal anisotropy will be correlated to the orientation of natural fractures seen in image logs
- Simple linear correlation techniques will fail; rather I will need to introduce concepts of thresholds (e.g. minimum levels of deformation or brittleness) to correlate attributes to fractures in the wells.
- The additional input of fracture intensity into a previously constructed geomodel in the same location will give better insight into the reservoir.

References:

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A special thanks to Chesapeake Energy for licensing data to The University of Oklahoma.