APPLICATIONS OF 3D SEISMIC ATTRIBUTE ANALYSIS WORKFLOWS: A CASE STUDY FROM NESS COUNTY, KANSAS, USA

by

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Abstract

Due to their high resolution and established success rates, 3D seismic surveys have become one of the most important tools in many hydrocarbon exploration programs. Basic interpretation of seismic reflectors alone, however, may result in inaccurate predictions of subsurface geology. Historically, seismic attributes have played a particularly important role in the characterization of the lithological and petrophysical properties of hydrocarbon reservoirs in Kansas channel fill lithofacies. Integration of an analysis based on post-stack seismic attributes may drastically reduce the chances of drilling in unsuitable locations.

Previous theses have focused on establishing a suitable 3D seismic attribute analysis workflow for use in the determination of hydrocarbon production potential in areas of Ness County, Kansas, USA (Abbas, 2009; Phillip, 2011). By applying a similar workflow in the analysis of additional 3D seismic and well log data obtained from a nearby area in Ness County, and comparing those results to existing borehole and production data, this study seeks to test the hypothesis that seismic attribute analysis is a crucial component in the delineation of heterogeneous reservoir stratigraphy in Kansas lithologies. Time-structure maps, in addition to time slices of several 3D seismic attributes including amplitude attenuation, acoustic impedance, and event continuity all seem to indicate that five previously drilled dry wells within the study area were outside the boundary of a meandering, Cherokee sandstone body of potential reservoir quality.

Additionally, comparisons of the results of this research to previous studies conducted in Ness County have provided an opportunity to assess, and potentially contribute to, paleodepositional interpretations made through the utilization of a similar workflow (Raef et al., in press). The results of this study seem to support a broadly NE-SW trending meandering channel system, which is in agreement with the interpretations of Raef et al., and the findings of Ramaker (2009).

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Acknowledgements

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Chapter 1 - Introduction

Seismic Attributes

Since their introduction in the 1970s, seismic attributes have allowed geologists and geophysicists to break down and view seismic traces in terms of unique, quantifiable components such as frequency, velocity, and amplitude (Mourning, 2014). Previous authors (e.g. Chopra and Marfurt, 2008; Suarez et al., 2008; and Verma et al., 2009) have reported on the use of seismic attributes in the characterization of hydrocarbon reservoirs and their utilization in defining channel fill zones. This study will utilize several different seismic attributes, including acoustic impedance (frequency), amplitude attenuation, RMS (root mean-square) amplitude, similarity, and event continuity in order to properly delineate potential hydrocarbon reservoirs (e.g. meandering channel sands) in an area of Ness County, Kansas, USA.

Previous Work

In 2003, Coral Coast Petroleum drilled wildcat well, Keith #1, targeting a Cherokee sandstone in Section 18 of Township 16 south, Range 22 west of northeastern Ness County, Kansas. This well was part of the Wierman field (see figure 1) and produced 162 barrels before it was plugged as dry and abandoned (Abbas, 2009).

Figure 1. Location of Ness County within Kansas, and the location of the Wierman Field within Section 18 of Township 16 south, Range 22 west (from Abbas, 2009).

The focal point of Abbas (2009), was essentially answering the question of “what went wrong” with this particular prospect. In his thesis, Abbas stated that personal communications with the well operator revealed that the potential sandstone reservoir was identified primarily through the occurrence and tracking of a doublet signal reflection found in a seismic survey at the base of the Cherokee formation, just above the top of the Mississippian formation (see figure 2).

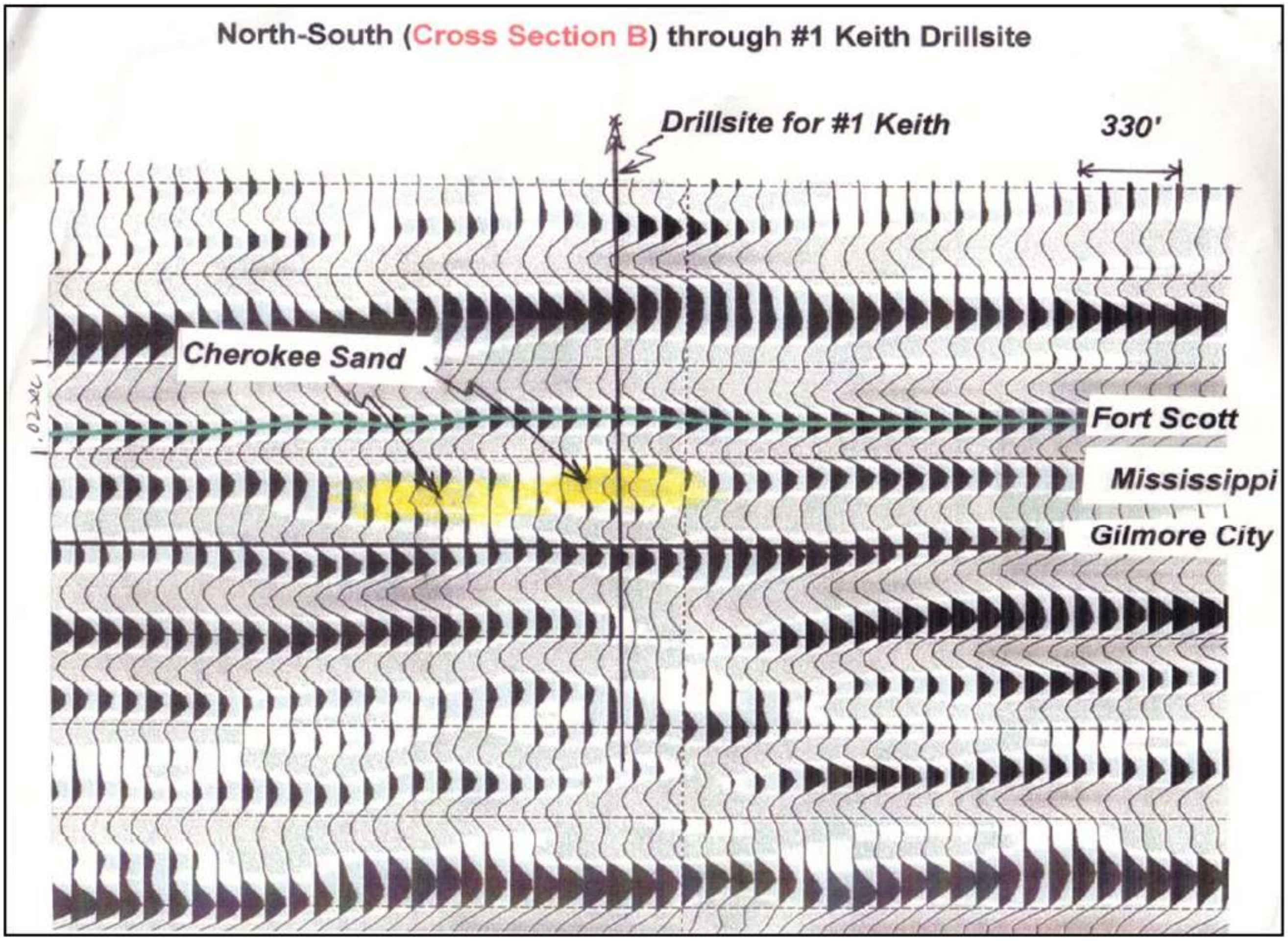


Figure 2. Seismic doublet found at the top of the Mississippian formation (from Abbas, 2009).

In order to accurately assess the situation, Abbas collected 3D seismic data, well logs, and any maps, reports or documents related to the well in question, and then created a workflow incorporating 3D seismic attributes in an attempt to explain the results of the Keith #1 well. Ultimately, despite the appearance of this doublet event within the seismic data, analysis of relative acoustic impedance, RMS amplitudes, average energy, and amplitude attenuation indicated that Keith #1 and several surrounding dry holes all fell within unfavorable areas. Additionally, analysis of isotime maps indicated that the thickness of the Cherokee formation at this location was within the tuning resolution of the seismic data. Thus, the doublet was likely due to tuning as the formation thickness approached the seismic resolution.

Similarly, Philip (2011), attempted to further develop the use of post-stack 3D seismic attributes in the Wierman field and apply them as part of an integrated workflow incorporating well logs, core data, production data, and modern depositional analogues. The attributes Philip selected for the study area were: acoustic impedance, amplitude attenuation, RMS amplitude, and spectral decomposition, as well as curvature and coherence attributes. Many of these attributes have been similarly utilized in this particular study, and more detailed explanations of these attributes and their applications can be found later within the body of this text.

This leads into some of the most recent work in the area – a soon to be published manuscript by Raef et al. (in press) - which presents a workflow integrating post-stack seismic attributes and well-log facies analysis in order to understand the development and depositional setting of the Wierman Field in central Kansas. The ultimate conclusion of this study is that the "dimensions and spatial relationships of the interpreted geobodies are in conformity with the modern shoreline analogues of a barrier beach or strandplain adjacent to an estuary." (Raef et al., in press). Figure 3 illustrates interpreted paleovalleys, structural closure, and the interpreted paleoshoreline.

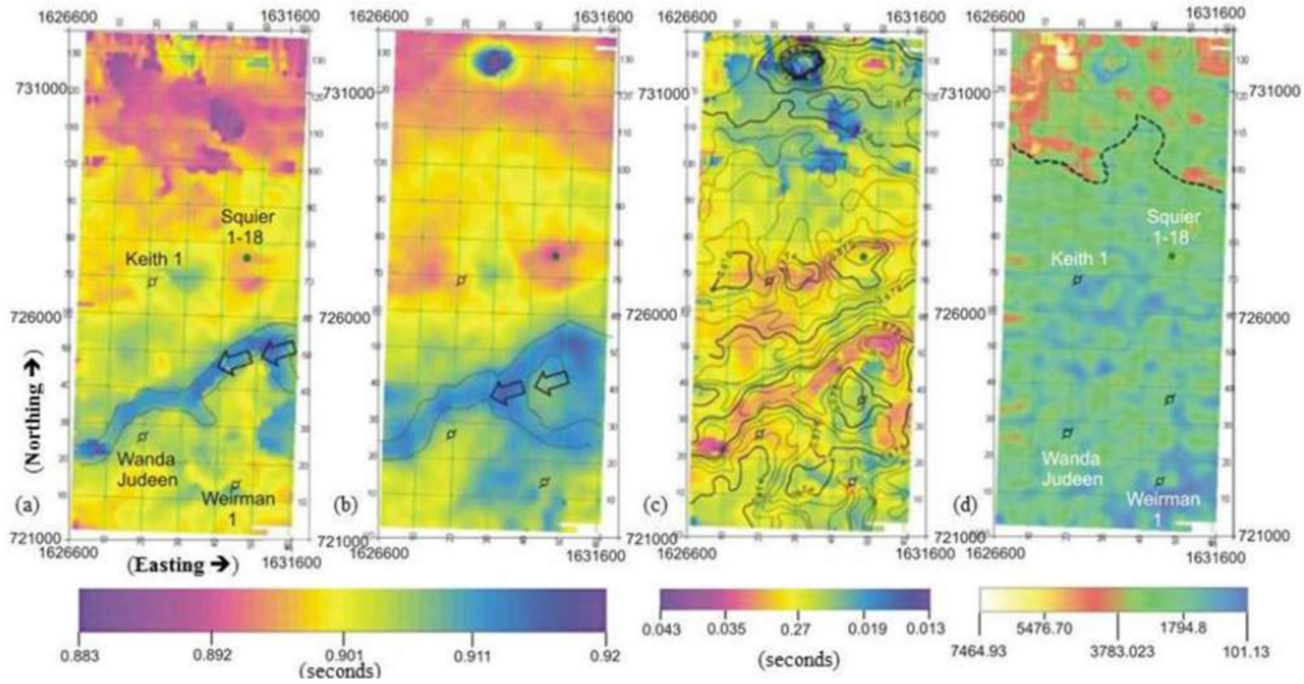


Figure 3. Seismic attributes; (a) time structural map of Mississippian-top seismic time horizon with interpreted paleovalley (arrows), (b) Cherokee-top time horizon with structural closures around the producer well Squier 1-18 and a lack of such closure around Keith 1, interpreted tidal channel branching off towards shoreline (c) isochron (time thickness) color map of Cherokee group and contours of the time structural map of Cherokee top seismic horizon, and (d) stratal amplitude time slice at 25 ms above the Missippian horizon (flattened), an interpreted paleoshoreline at the time of Cherokee sand deposition is marked by a dashed line (from Raef et al., in press).

Raef et al. (in press), suggests that "higher rates of drilling success in the basal Cherokee sands are attainable by:

a) focusing on the proximity of thicker sands, as evidenced by amplitude brightening of seismic reflections close to the Cherokee basal reflections,

b) [considering] the proximity of identified amplitude anomalies to the interpreted paleoshorline,

c) favoring locations of paleotopographic highs on the Mississippian unconformity, when associated with brightening of seismic amplitudes in the basal Cherokee reflections and dimming amplitudes below the Cherokee bottom reflection,

d) [locating] structural closures, [which] in association with the above factors, are of significant weight in reducing drilling risk.”

Thus, the focus of this new study is two-fold: [1] apply the methodologies outlined in the three previously mentioned studies to a seismic attribute analysis being conducted in a nearby area of Ness County and [2] compare these new results to existing interpretations of the depositional setting and production data in order to recommend future action.

Study Area

Data for this particular study primarily originates from sections 10 and 11 in Township 16 south, Range 22 west of Ness County, which is located in the central-western part of the state of Kansas. The eastern side of the county is situated along the western edge of the Central Kansas uplift. The first oil well in Ness County was drilled in 1922, and in 1929, the Aldrich #1 well was drilled on the Beeler anticline, and produced 100 bpd at a depth of 4,422 feet on top of the Mississippian (Abbas, 2009). The majority of current oil production in western Kansas originates from Mississippian limestone; however, as was mentioned previously, production from the relatively younger Cherokee group sandstones is of particular importance for this study.

The following figure illustrates the location of this study, relative to the nearby Wierman field, which is the focus of Philip (2011).

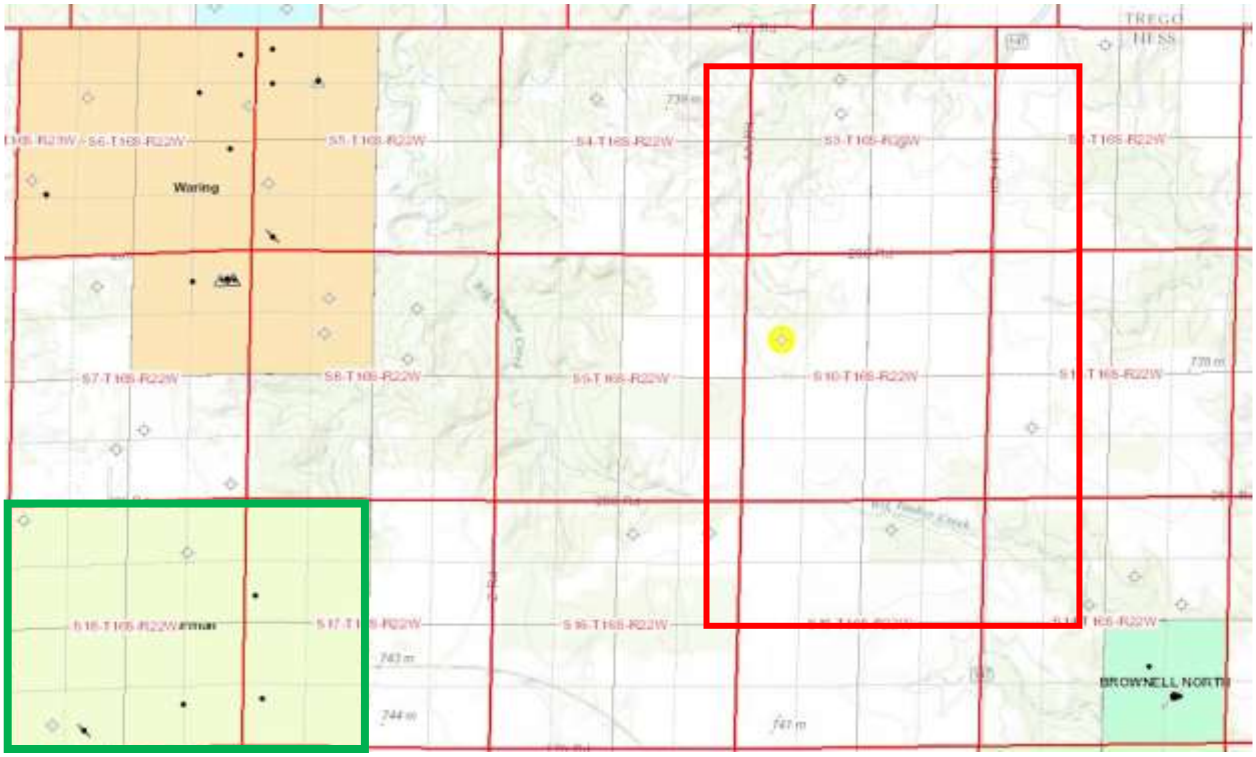


Figure 4. Approximate study area (red box) relative to the previously mentioned Wierman field (green box). The well, Conrath 1-10, is highlighted in yellow for reference.

Chapter 2 - Geologic Setting

Depositional Environment

The target lithologies for this attribute analysis are from within the previously mentioned Cherokee shale, a group of Pennsylvanian-age shales and limestones, with quantities of sand. These sediments range in thickness from 5 to 200 feet and were deposited in a continental environment transitioning into a marginally marine environment as the sea transgressed over the Mississippian unconformity, out of the Hugoton Embayment of the Anadarko basin, and onto the Central Kansas uplift (Cuzella, 1991).

Figure 5 outlines the general stratigraphic succession of the Cherokee shale. Ness County itself is located on the northeastern shelf of the Hugoton Embayment, where sediments of the Desmoinesian Stage rest unconformably on Mississippian carbonates. As previously mentioned, these sediments consist primarily of interbedded carbonate beds and thin shales. Closer to the uplift, fine-grained clastics give way to coarser clastics (sandstones and conglomerates) that parallel the ancient shorelines. By the end of Missourian time, the Central Kansas uplift was inundated and covered with marine sediments.

Shoestring sand lenses (known to operators in Kansas and Oklahoma as the Bartlesville sand) occur in the lower part of the Cherokee shale (Bass, 1936). These slender Cherokee sands are associated with fluvially dominated delta systems where the sediment entered the seaway (Brenner, 1989). It is worth noting that many of the reservoir sandstones found within the Cherokee group are only 10-15ft thick; highly variable in size, shape, orientation, and composition; and are difficult to predict (Cuzella, 1991).

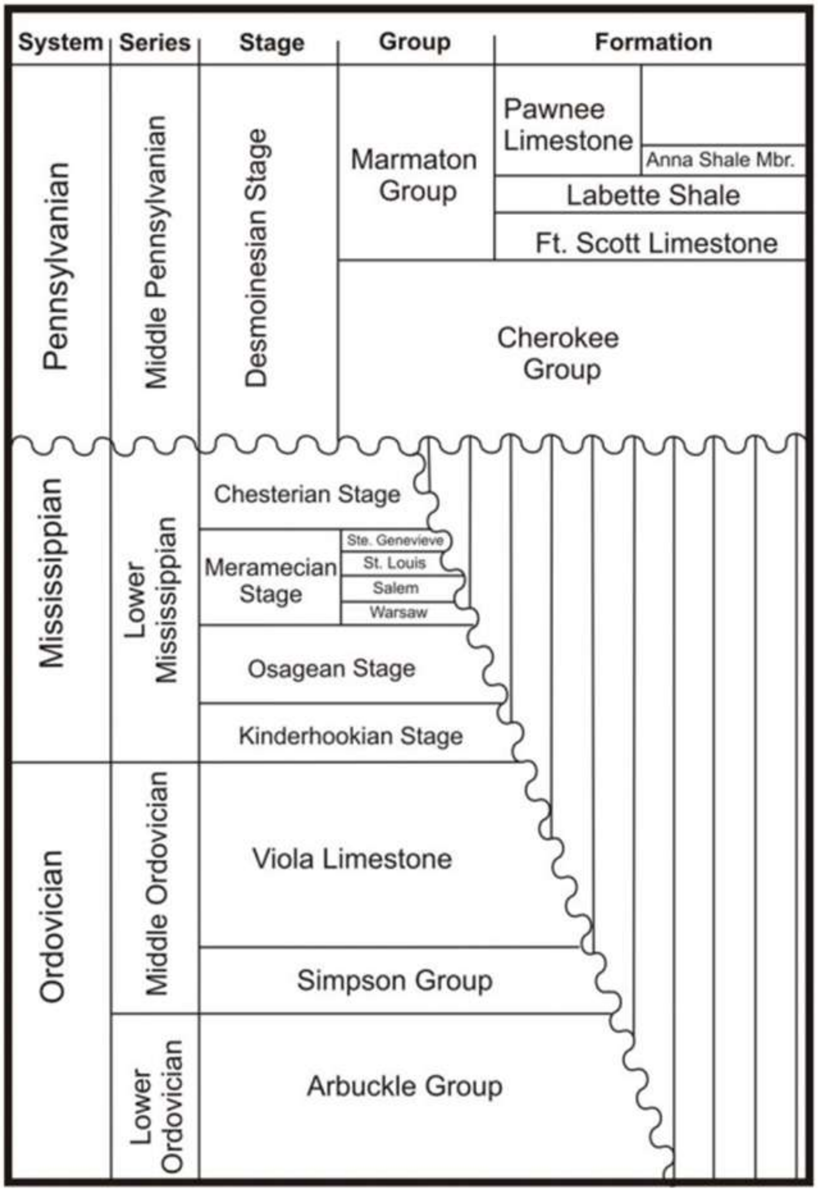


Figure 5. Stratigraphic column of the Ordovician through Pennsylvanian systems (from Ramaker, 2009).

Lithological Description

Ramaker (2009) analyzed six cores from Ness County, and has provided the following recent and locally applicable geologic description:

> The Mississippi unconformity is a karstic surface of Mississippian limestones, from which dolines, as deep as 50 m and measuring 1.6 km across, have been described in the study area, as well as an extensive network of paleovalleys; most of these valleys display a north-south trend. In the easternmost part of Ness County NE-SW oriented valleys join into larger north-south oriented valleys towards the west, and whereas the paleovalleys in easternmost Ness County are relatively narrow, ranging from 0.8 km to 2.4 km with a depth ranging from 3m to 12m, the approximately north-south oriented valleys in the west are 0.8km to 4 km wide and up to 28 m deep (Ramaker, 2009).
>
> The Mississippian surface is overlain by cherty conglomeratic breccia, glauconitic sandstone, and variegated silty mudstone, filling the paleovalleys (Ramaker, 2009). This deposition interval did not result in a very thick clastic sequence, as indicated by the depths of the paleovalleys. Thus, the thickest cherty conglomeratic breccia measures 7 m, and the thickest and most persistent sandstone accumulation 17.5 m (Ramaker, 2009).
>
> The cherty material is poorly sorted, sub-rounded to angular, and is derived from the underlying carbonate successions. It is associated with limestone and dolomitic limestone clasts (Ramaker, 2009). The cherts are reworked residual karst deposits (Zodine-Zeller, 1981, 1985). The sand of the glauconite sand may have been shed from the Paleozoic Reagan Sandstone of the Central Kansas uplift, and the glauconite sandstone probably represents fluvial deposition in an upper estuarine environment (Ramaker, 2009).
>
> This clastic sequence is capped by a paleosoil, representing a sequence boundary, and followed by a thin (40-50 cm) laterally continuous, wackestone-packstone horizon reflecting

an open, shallow-marine shelf environment within the photic zone as well as marine flooding (transgressive sequence, Ramaker, 2009). Gray shale of 0.6 m to 1.2 m thickness, deposited on top of the limestone, represents an offshore environment (Ramaker, 2009). Updip to the northeastern part of Ness County, the sequence boundary is overlain by conglomeratic sandstone and cross-laminated sandstones, which were deposited when accommodation space was created by flooding (Ramaker, 2009).

The conglomeratic sandstones contain chert clasts, measuring up to 2.7 cm, which were shed from the eroding Central Kansas uplift. These clasts exhibit a thickness between 1.2 m and consist of very fine to medium grained, subangular to subrounded quartz sand as well as 10-15% clay, measuring 2m to 33m in thickness. These clasts have formed as nearshore/shoreface deposits (Ramaker, 2009).

Chapter 3 - Data and Methods

Well Data

A total of five wells with targets in the Cherokee formation are located within the bounds of this study area. Those wells, listed from north to south are: Dinkel-Victor 1, Dinkel 1, Conrath 1-10, Wymann 1-11, and Young 1. All five wells were considered dry holes and were plugged and abandoned. The 3D seismic data utilized in this project, and LAS files for the Conrath 1-10 and Wyman 1-11 wells, were provided courtesy of Murfin Drilling Company. For this study, the author will be focusing primarily on the Conrath and Wyman wells.

Conrath 1-10 was completed on September 10, 2005, having been drilled to a total depth of 4530 feet. Drill stem tests were carried out for two separate intervals identified as Cherokee sand. These intervals were from 4308 feet (KB) to 4400 (KB)(TVD) feet, and from

4400 feet (KB) to 4424 feet (KB)(TVD). DST results were not encouraging, with no blows, fluid pressures that died within minutes, and no oil or gas shows within the 5 to 10 feet of mud recovered. The Wyman 1-11 was completed on March 19th, 2006, having been drilled to a total depth of 4500 feet. There were also no oil or gas shows, and no drill stem tests were run. Full well completion reports are available for both wells on the Kansas Geological Survey website. Figures 6 and 7 below provide gamma ray and dual compensated porosity logs for the zones of potential interest in both Conrath 1-10 and Wyman 1-11, respectively. These logs illustrate that while there are zones 10 to 15 feet thick with sufficient porosity to be considered potential reservoirs, the gamma ray signatures for these zones are not particularly clean, suggesting a significant amount of shale.

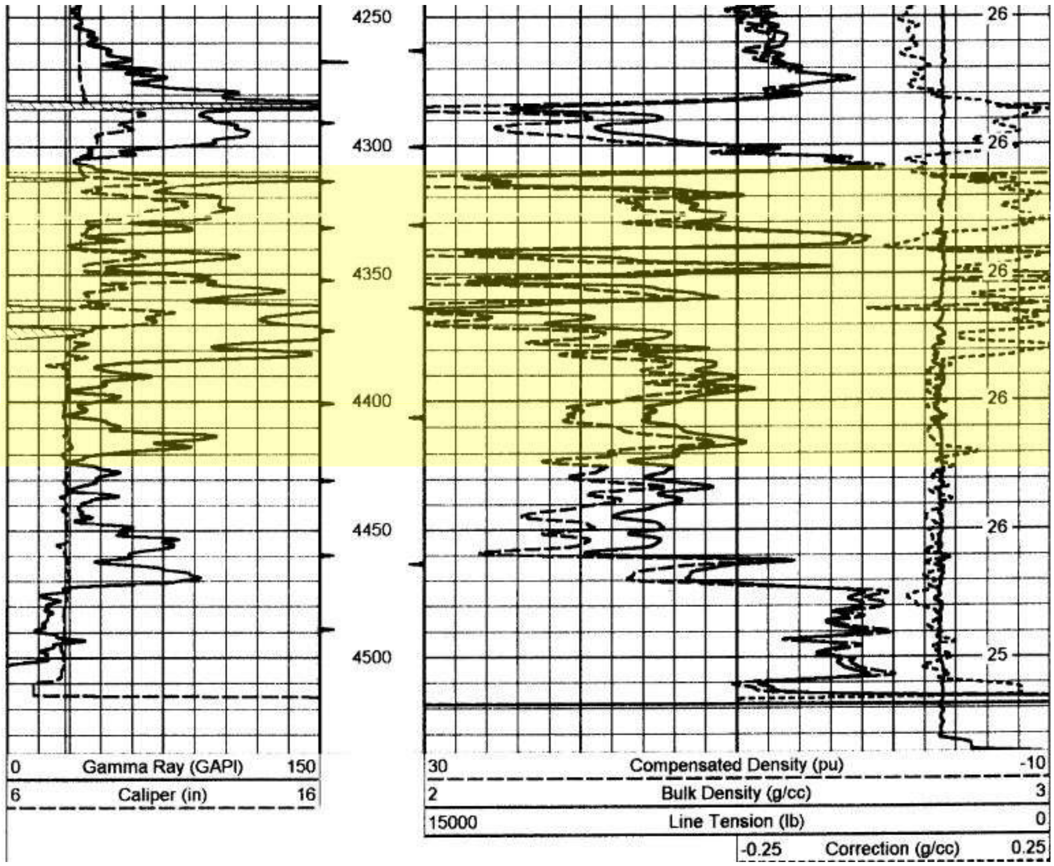


Figure 6. Gamma ray and dual compensated porosity logs for Conrath 1-10. DST zones highlighted for reference.

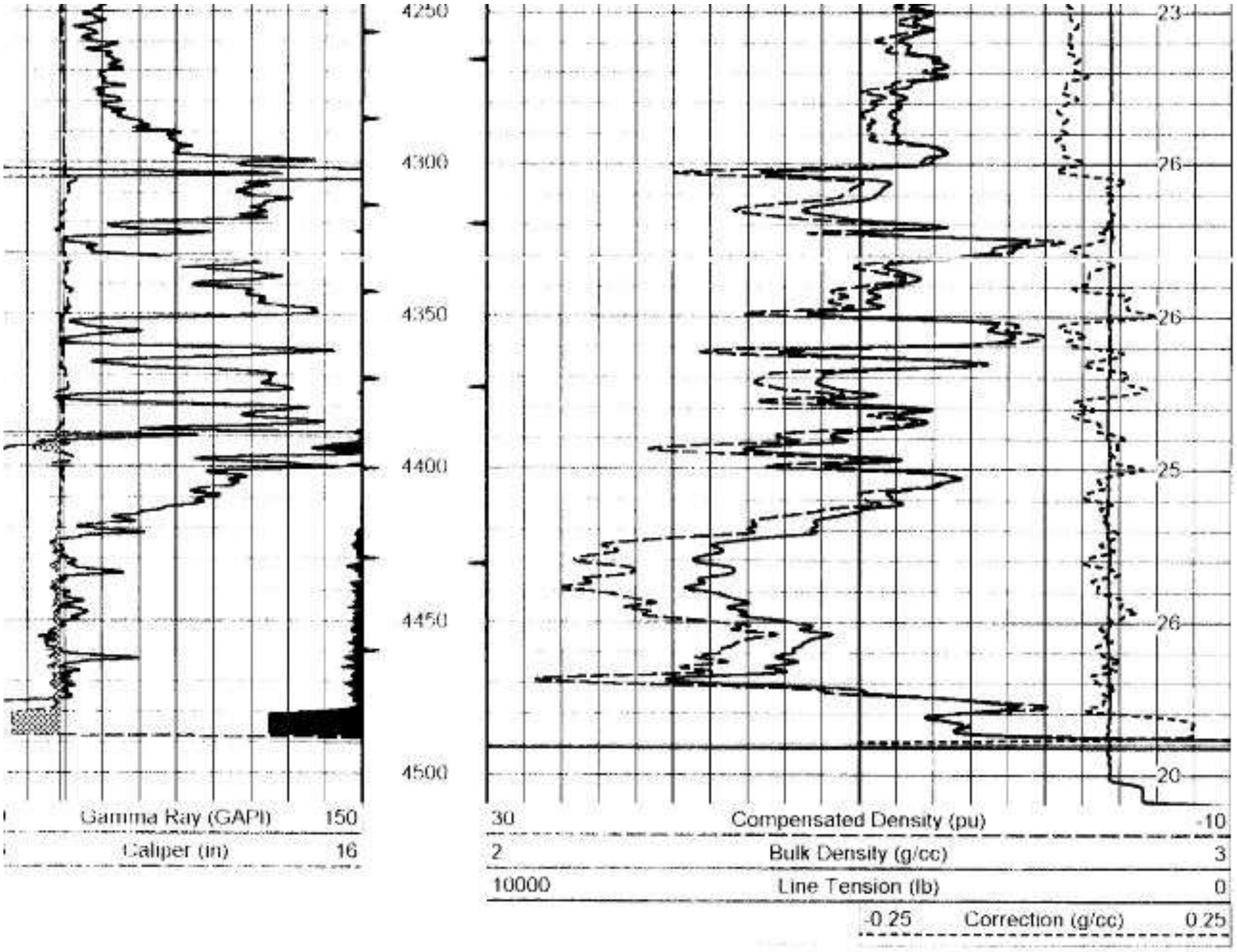


Figure 7. Gamma ray and dual compensated porosity curves for Wyman 1-11.

It is worth noting that trace amounts of oil spotting could be seen in DSTs collected for the Dinkel-Victor 1, and Dinkel 1 wells further to the north.

Seismic Data Acquisition/Loading

In April of 2005, seismic data for the York 3D prospect were acquired from multiple sections (predominantly sections 10 and 11) of Township 16S Range 22W of Ness County. The seismic survey, carried out by Sterling Seismic Services, Ltd, consisted of 112 inlines and 98 crosslines, a 2 second record end time, and a 2 millisecond sample rate. The seismic datum is 2700 feet, and the replacement velocity utilized for the survey is 9000 feet per second.

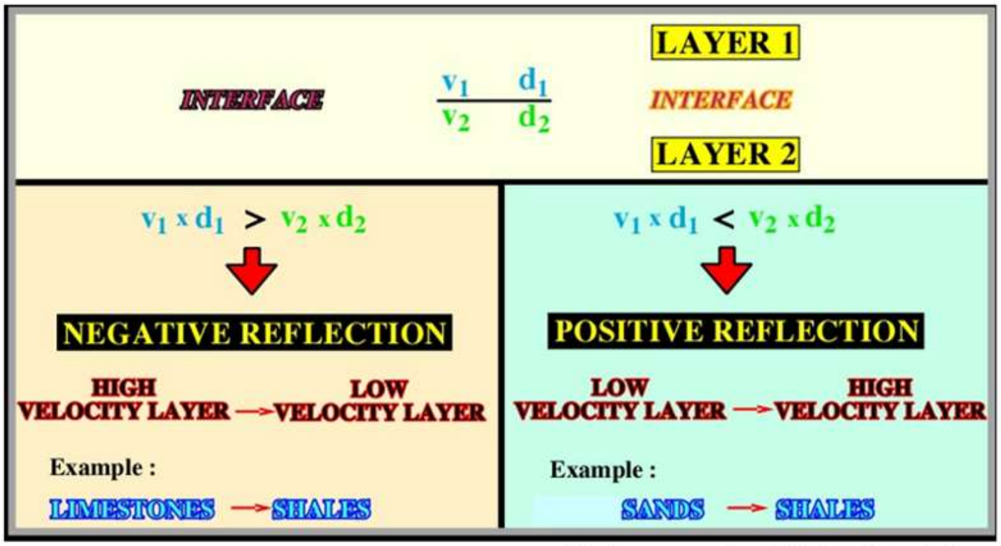
Processing was carried out prior to this study, and the resulting SEG-Y files were imported into Kingdom. Boundary specifications had to be entered in the form of coordinates for each of the four corners of the survey area. Once imported into the Kingdom Software, the seismic data was then combined with the two LAS digital well log files provided by Murfin Drilling to generate synthetic seismograms – a process that is detailed in the following section.

Synthetic Seismogram Generation

For this study, synthetic seismograms were generated at each of the two locations where a well log coincided with the seismic data. Calculation of a synthetic seismogram generally follows several steps. The first step in the process utilizes velocity data from sonic logs and density logs (if the density logs are available) to create a synthetic seismic trace. In this process, computer software such as Kingdom by SMT, is utilized to compute an acoustic impedance log from the sonic velocities and the density data. Acoustic impedance is represented by the equation below, where I is the acoustic impedance, and v and d are acoustic velocity and rock density, respectively. The subscript n denotes the variable layer for which the impedance is being determined.

$$I_n = v_n * d_n$$

At each interface between contrasting wave velocities, the program utilizes the resulting acoustic impedance curve to compute a reflection coefficient. The normal-incidence reflection coefficient for a rock contact is an important quantity. Sheriff (1984) defines it as “the ratio of the amplitude of the displacement of a reflected wave to that of the incident wave." Figure 8 below illustrates how this reflection coefficient is represented mathematically, and provides examples of various interfaces and resulting reflection coefficients.



http://homepage.ufp.pt/biblioteca/Seismic/Pages

Figure 8. Explanation of acoustic impedance and examples of different lithological impedance contrasts (modified from Cramez, 2003).

Following generation of a reflection coefficient series, a wavelet is chosen that has a frequency response and band width similar to that of the nearby seismic data. The synthetic wavelet is convolved with the reflection series for the entire well survey and generates a synthetic seismic trace. Mathematically, the convolutional model can be represented by the equation:

$$x(t) = w(t) * e(t)$$

In the equation above, x(t) represents the synthetic seismic trace, e(t) represents the reflection coefficient series, and w(t) represents the wavelet. Ideally, there is obvious agreement between the newly created synthetic trace and a trace from the seismic line, and the result is something similar to what is depicted in figures 9 and 10 below.

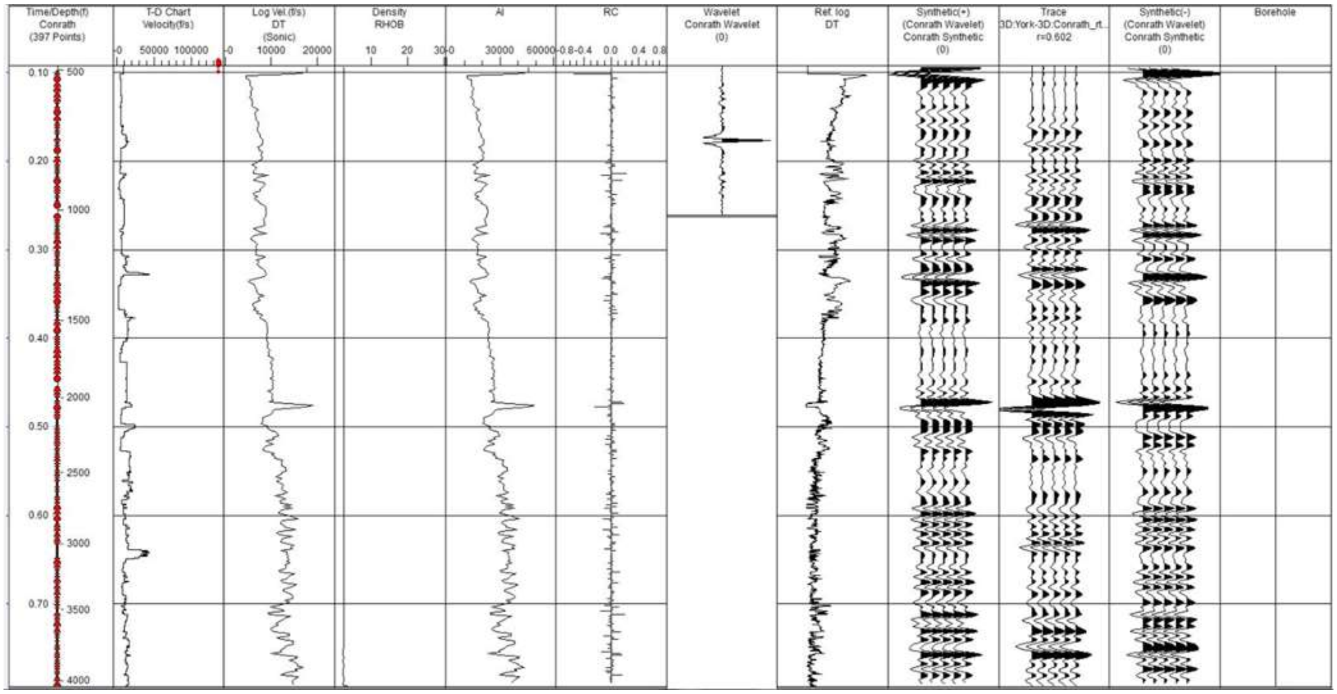


Figure 9. Synthetic Seismogram generated for Conrath 1-10. A cross-correlation coefficient of 0.602, achieved after bulk shift and stretch/squeeze operations, indicates an acceptable but less than ideal correlation to the seismic data.

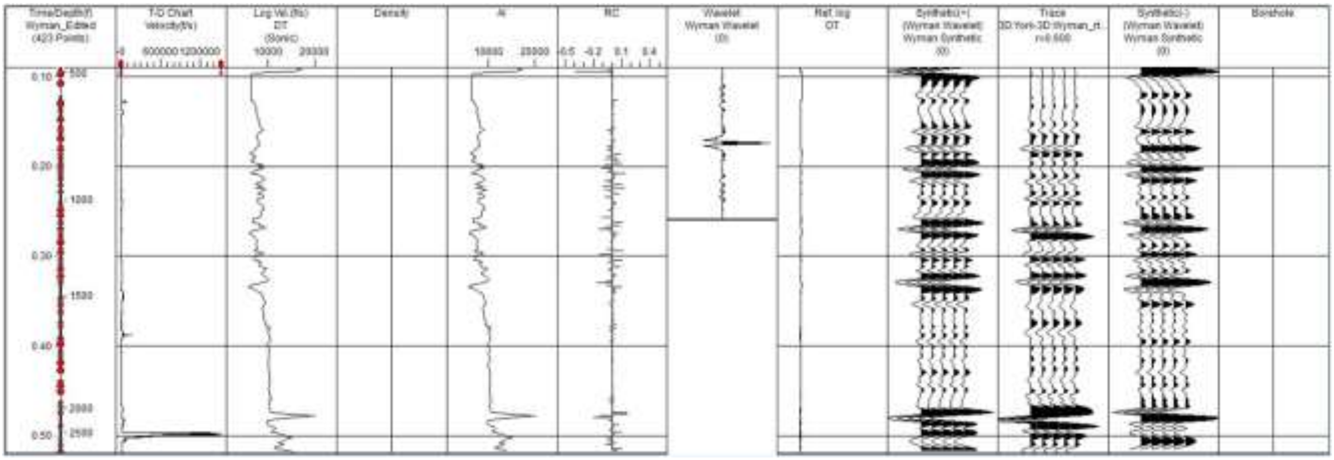


Figure 10. Synthetic seismogram generated for Wyman 1-11. A cross-correlation coefficient of 0.6 was achieved.

Formation Tops and Horizon Tracking

Formation top data from each well log was uploaded into Kingdom Suite, using values taken from completion reports available on the Kansas Geological Survey Website for both the Conrath and Wyman wells. This study focuses on the top of the Mississippian formation, as the Cherokee targets typically appear roughly 10 milliseconds above that formation top in the time domain (Philip, 2011). The top of the Mississippian formation was picked (i.e. manually traced) horizontally in each 3-D seismic inline and cross-line so that it could be automatically tracked throughout the entire seismic block. Similarly, the top of Cherokee formation was also picked and tracked. A seismic cross section is displayed in figure 11, which depicts the relationship between the Wyman 1-11 synthetic seismogram, the seismic reflection series, the formation top data.

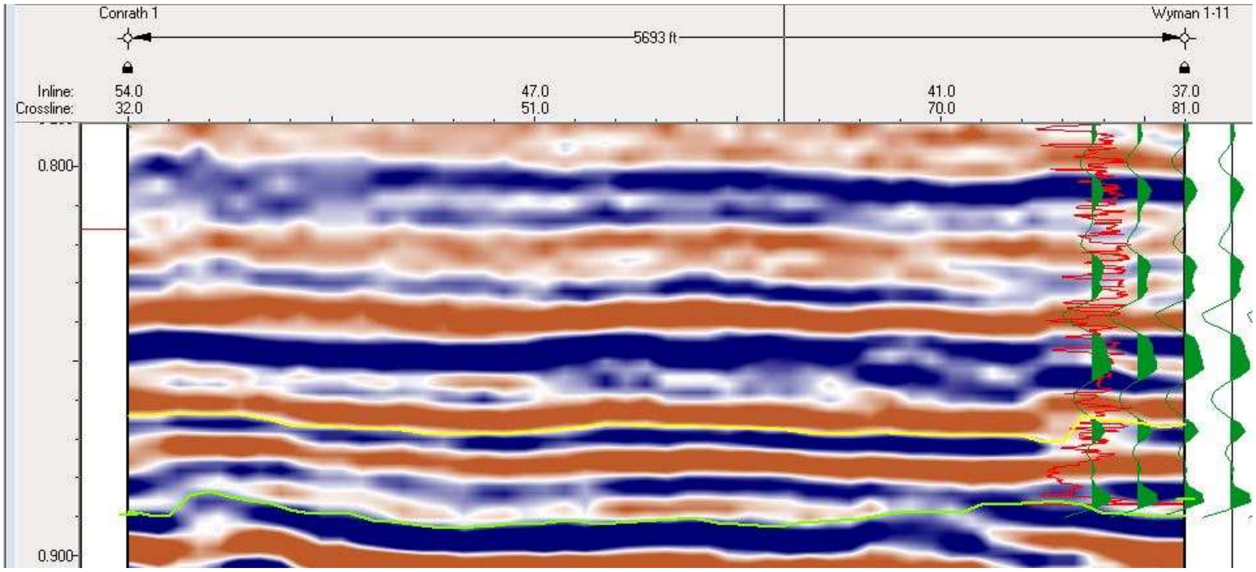


Figure 11. Seismic amplitude section depicting the relationship between the seismic reflection series, the Wyman 1-11 synthetic (green wavelet), the Wyman 1-11 bulk density log (red curve), and the interpreted seismic time horizons for the Cherokee (yellow) and Mississippian (green) formations.

Qualitative Seismic Attribute Analysis Workflow

The seismic attributes that have been generated and analyzed, as well as their implications, have been provided in table 1 below. Each attribute detailed in table 1 has been utilized in the creation of individual time-slices/maps through an area interest at a time-depth of 0.888 seconds. These maps have been combined in various ways in order to compare and contrast the results of multiple attribute analysis simultaneously in the search for patterns indicative of reservoir sands. Amplitude anttenuation, RMS amplitude, and acoustic impedance were selected primarily to emphasize lithology. Event continuity and similarity variance were selected to depict the emergence of structural patterns.

Table 1. Seismic attributes utilized

Attribute	Definition	Implication
Amplitude Intensity/ Attenuation	gradual loss of amplitude intensity due to frequencies above and below point of interest	Greater attenuation would correlate with better reservoir properties.
RMS Amplitude	This is a measure of reflectivity within a time window, calculated as the square root of the sum of the squared amplitudes.	Higher RMS amplitude in the extraction window indicates higher proportions of channel sands or better reservoir facies, especially when coupled with higher attenuation levels.
Acoustic Impedance	product of density and acoustic velocity	Higher average AI correlates with lower proportions of channel sands.
Event Continuity	This is a calculation that assigns an output value of +1, -1, or 0 to all real trace inputs.	This attribute establishes and delineates lateral discontinuities.
Similarity Variance	difference between the instantaneous maximum lateral semblance and smoothed maximum lateral semblance	This attribute helps define local depositional anomalies.

Acoustic Impedance

Acoustic impedance defines the density contrasts encountered at the interface between two distinct lithologies, and is the basis for the generation of the seismic reflectors seen in seismic data. These reflectors are classified as negative or positive reflectors, depending on whether the product of the wave velocity and the density of the material is going from a larger to smaller value, or a smaller to larger value, respectively. When utilized as part of a 3D seismic attribute analysis (particularly within this study area) emphasis is placed on areas with relatively lower acoustic impedance, as this is suggestive of greater reservoir quality, or possibly even an oil or gas rich sand (Philip, 2011).

Amplitude Attenuation

Amplitude attenuation is the gradual loss of amplitude intensity as a wave travels through the subsurface. The extent of amplitude attenuation will vary depending on the medium the seismic pulse is traveling through. An area of meandering outline is characterized by higher levels of attenuation (Philip, 2011; Abbas, 2009). Therefore, in this particular case, attenuation is expected to be greater in zones of favorable reservoir quality (i.e. amplitude intensities will decrease) - demonstrating that amplitude attenuation can be a valuable attribute when utilized as part of a 3D seismic workflow.

RMS Amplitude

Root-mean-square (RMS) amplitude is a computed seismic attribute, and is defined as the square root of the sum of the squared amplitudes in a data set, divided by the sample size of data within the time widow desired. This attribute is used to map hydrocarbon indicators within a zone by providing a statistical measure of the magnitude of variation in amplitude throughout a dataset. Generally, higher acoustic impedance variations (associated with variations within stacked lithology) will result in higher RMS values. In this study, RMS amplitude values were collected over the entire time thickness between the top of the interpreted Cherokee horizon and the top of the interpreted Mississippian horizon.

Event Continuity

Event continuity is an intermediate result of a hybrid attribute computation (Tanner 2003). The objective of this attribute is to develop the lateral continuity of peaks and troughs, and to classify the type of discontinuity. For a given time, all real trace positive peaks are output as +1, and negative peaks output as -1. Everything else will be output as zero. The display therefore will show only the peaks and troughs, all with same magnitude. The development phase will connect like peaks and establish discontinuities (Tanner, 2003).

Similarity Variance

This attribute is the difference between the instantaneous maximum lateral semblance and smoothed maximum lateral semblance (i.e. the average maximum lateral semblance). It shows local depositional anomalies. It may also show the zones of noise or massive non-reflecting areas (Tanner, 2003).

Chapter 4 - Results

Overview

The results of this study are presented on the following pages as time-structure maps of both the Mississippian and Cherokee horizons, an isochron map of the interpreted Cherokee formation overlain by contours of the Cherokee time-structure map, and a series of maps dedicated to time slices displaying each of the various 3D seismic attributes at a time-depth of 0.888 seconds (an area of interest explained in greater detail in the discussion/conclusions section). The red line seen on many of these maps is a cross-section through this area of interest between Conrath 1-10 and Wyman 1-11 (see figure 20). In both the Mississippian time-structure map (figure 12) and the Cherokee time-structure map (figure 13), present-day structural highs are depicted with warmer colors (white being highest) and present-day structural lows are depicted in cooler colors (black being the lowest). These maps illustrate that the five wells within this study were drilled targeting relative structural highs, which is consistent with the traditional exploration model for this area, according to Dr. Matthew Totten (pers comm).

The isochron map for the interpreted Cherokee formation (figure 14) depicts relative thickening of the Cherokee formation in a linear feature of interest southeast of Conrath 1-10, and northwest of Wyman 1-11 (cooler colors indicate thickening of the Cherokee formation). Similarly, the acoustic impedance map (figure 15) showcases areas of low acoustic impedance in cooler colors. These areas of low acoustic impedance are suggestive of lower-velocity, lower-density lithologies such as porous channel sands. The RMS amplitude map (figure 16) depicts RMS amplitude values over the entire interpreted Cherokee group time window. Higher RMS values are depicted with warmer colors. These higher RMS values are associated with a greater amount of lithologic variation throughout the time window. This would indicate the possibility of interlayered sand bodies within a shale or carbonate, for instance.

In the map of amplitude attenuation (figure 17) a greater degree of amplitude attenuation is represented by darker, cooler colors. In this case, greater amounts of amplitude attenuation are associated with better reservoir potential. The event continuity map (figure 18) depicts seismic trace output peaks (values of 1) in red, values of 0 in green, and relative troughs (traces assigned a value of -1) in dark blue. This attribute is particularly useful for highlighting lateral structural discontinuities between seismic traces. Note the dark blue, meandering feature present between the Conrath and Wyman wells. In figure 19, areas that are more laterally continuous (i.e. the difference between the instantaneous semblance and average semblance from trace to trace is less) are depicted in lighter shades of white and grey. Darker colors depict areas that are more structurally discontinuous. These events could represent faults or local depositional anomalies.

Mississippian Time-Structure Map

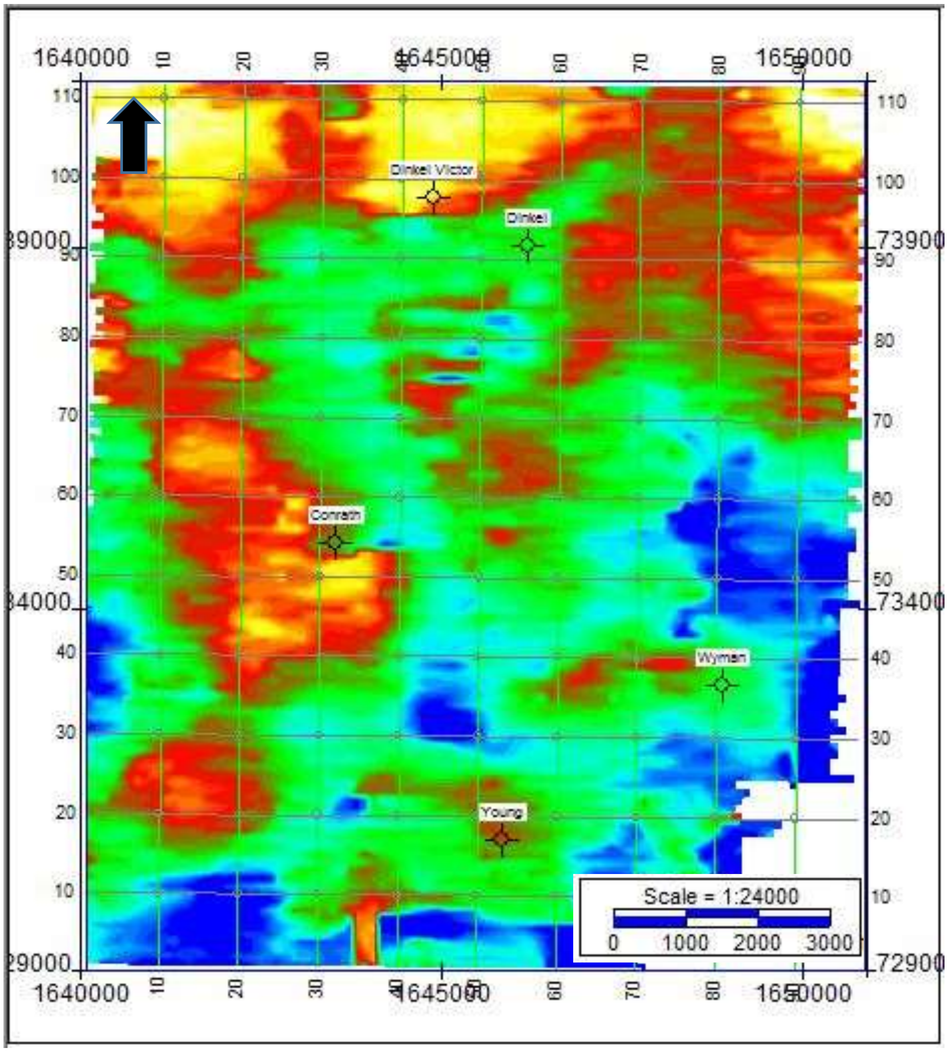


Figure 12. Mississippian top time-structure map. Cooler colors indicate deeper structure.

Cherokee Time-Structure Map

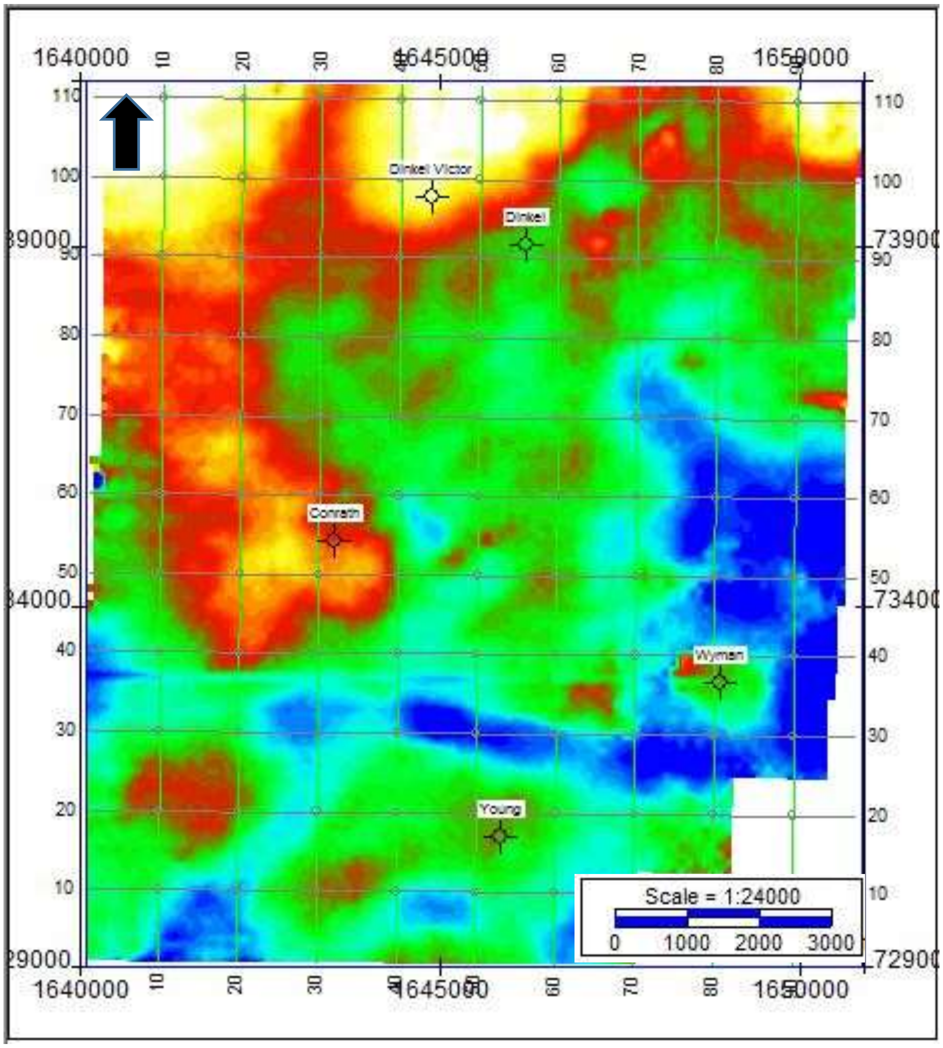


Figure 13. Cherokee top time-structure map. Cooler colors indicate deeper structures.

Cherokee Isochron

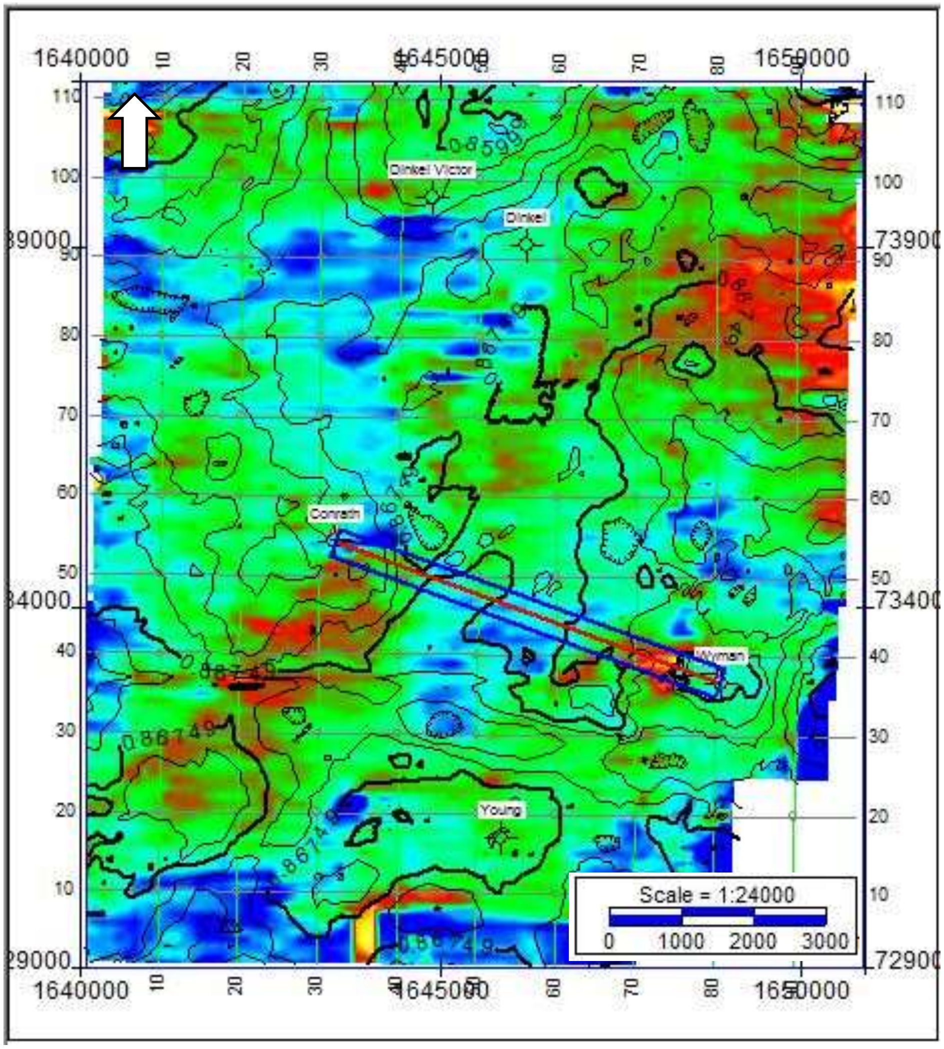


Figure 14. Cherokee group isochron overlain by Cherokee time-structural contours. Contour interval is 0.0015 seconds. Cooler colors indicate thickening.

Acoustic Impedance

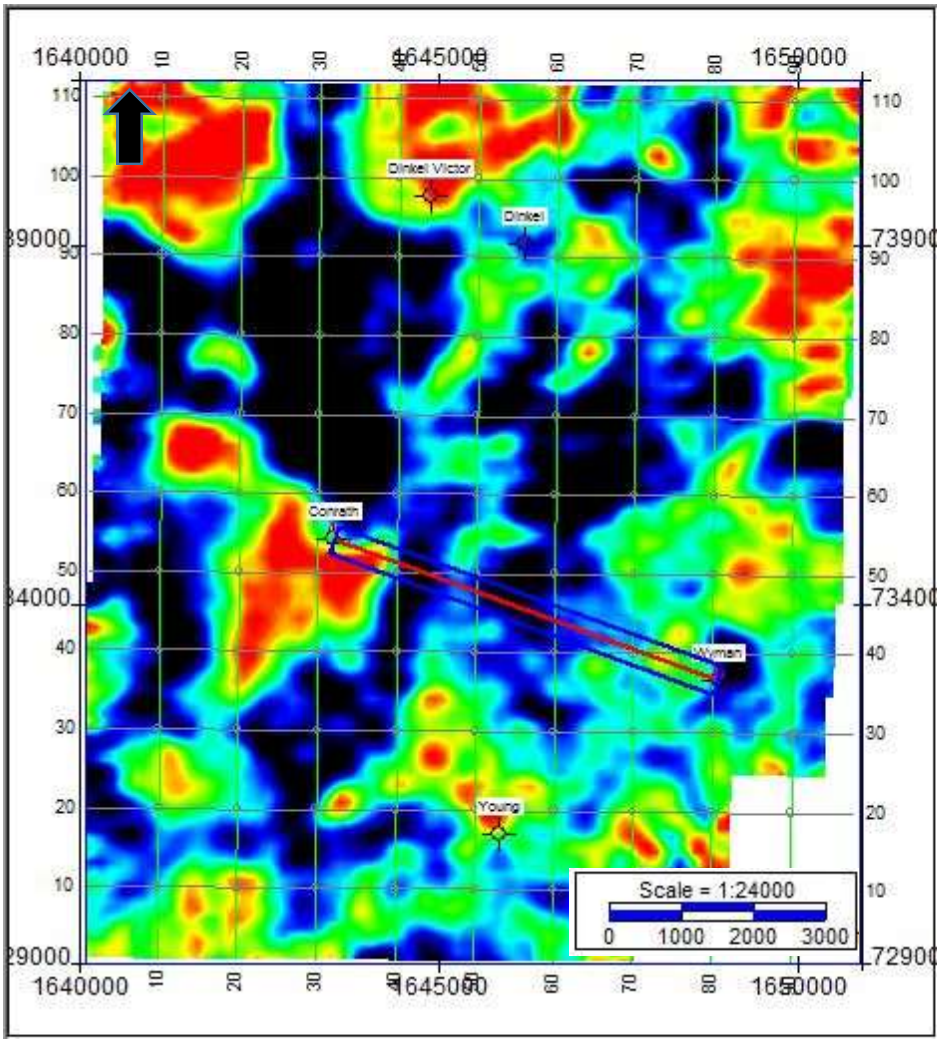


Figure 15. Acoustic impedance map. Cooler colors indicate lower acoustic impedance.

RMS Amplitude

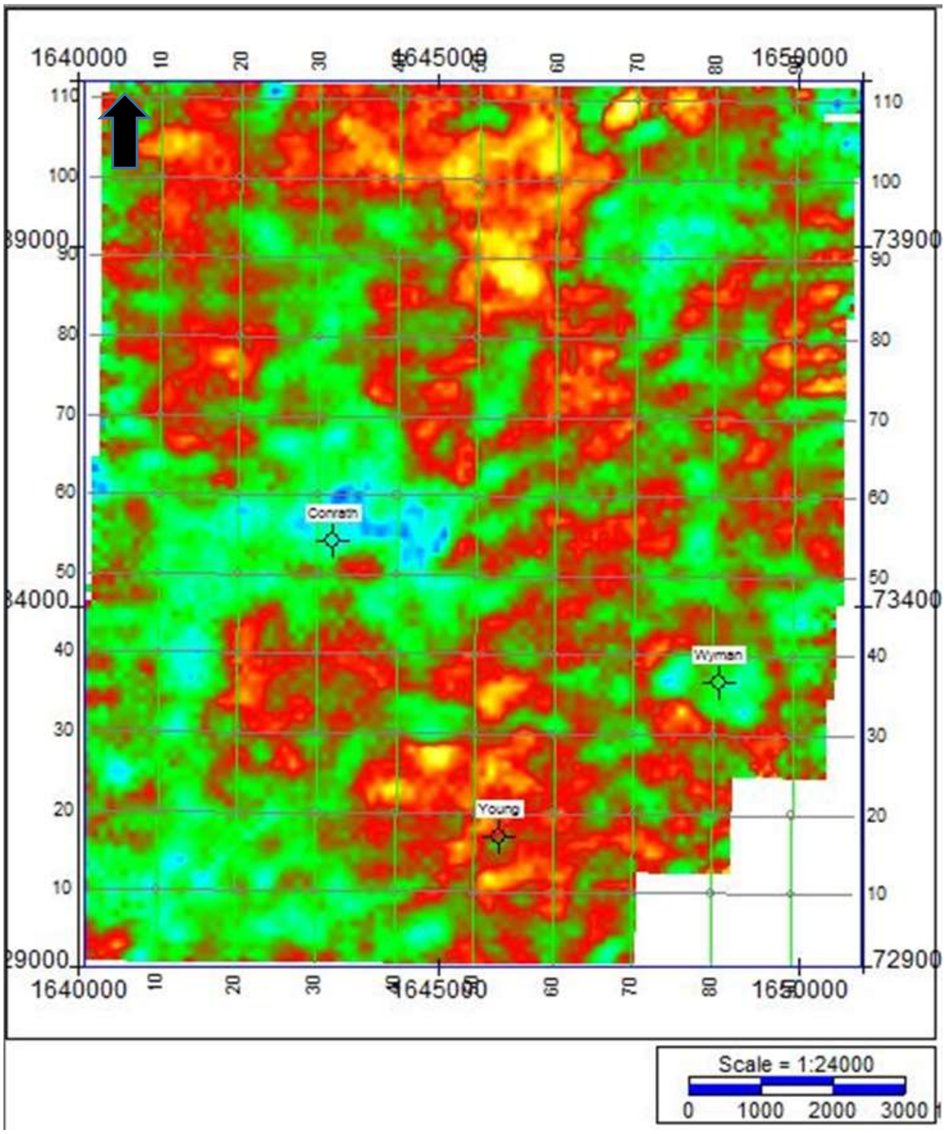


Figure 16. RMS amplitude throughout the Cherokee group. Cooler colors indicate lower RMS values. Higher RMS amplitude indicates more lithological variation over the time window.

Amplitude Attenuation

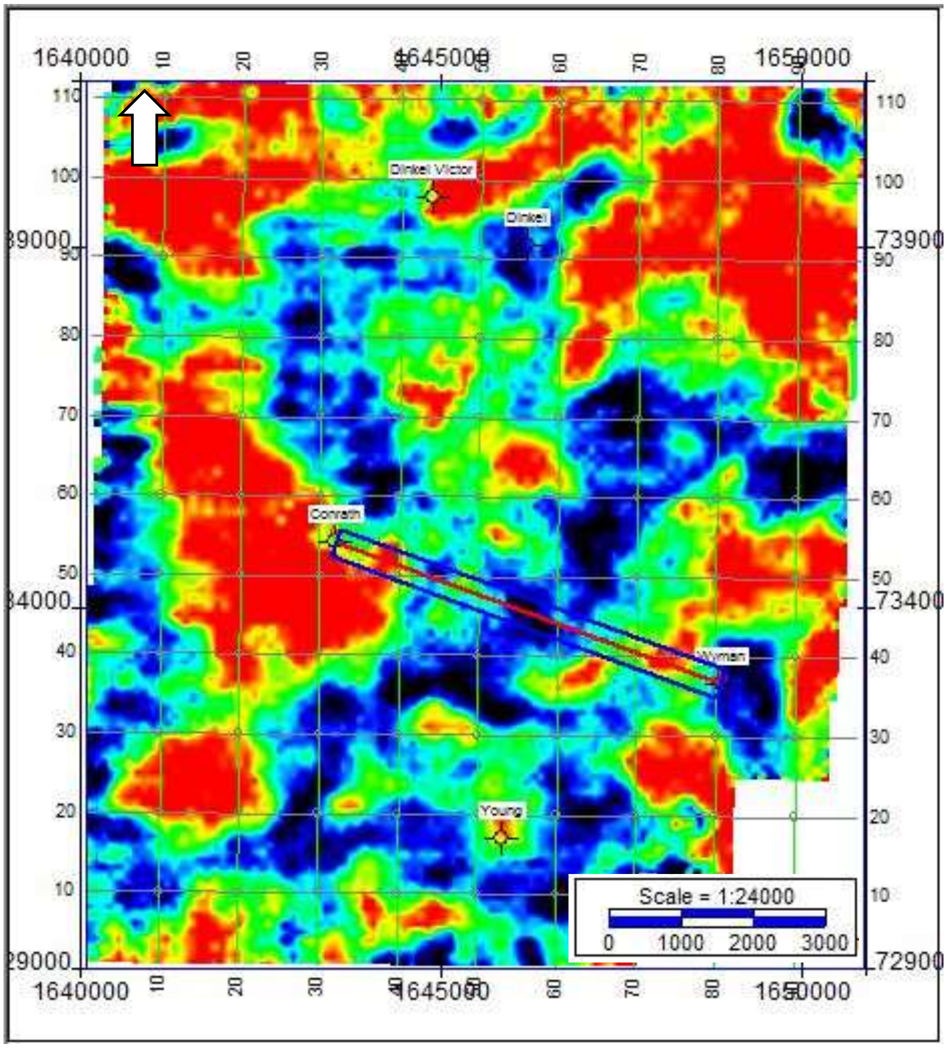


Figure 17. Amplitude attenuation map. Cooler colors indicate lower amplitude intensity (i.e. greater attenuation).

Event Continuity

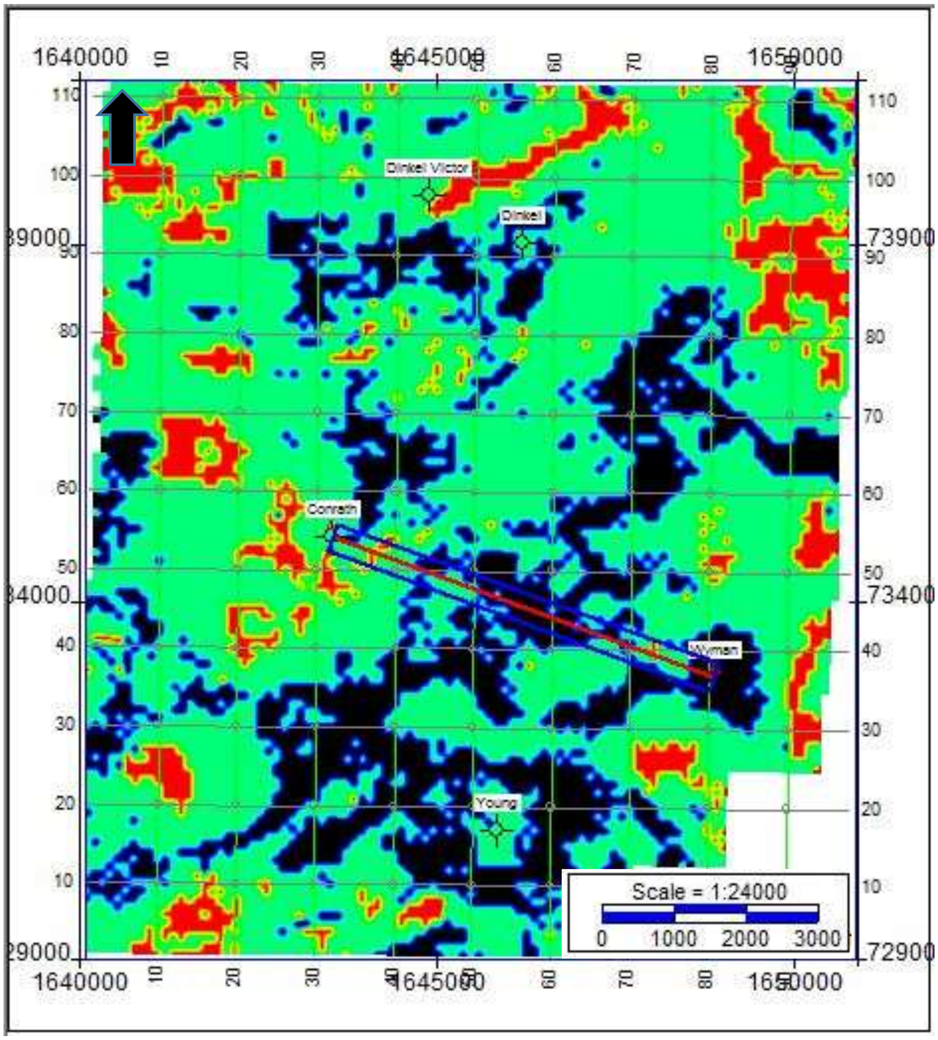


Figure 18. Event continuity map. Red indicates a value of positive 1, green indicates a value of 0, and blue/black indicates a value of negative 1.

Similarity Variance

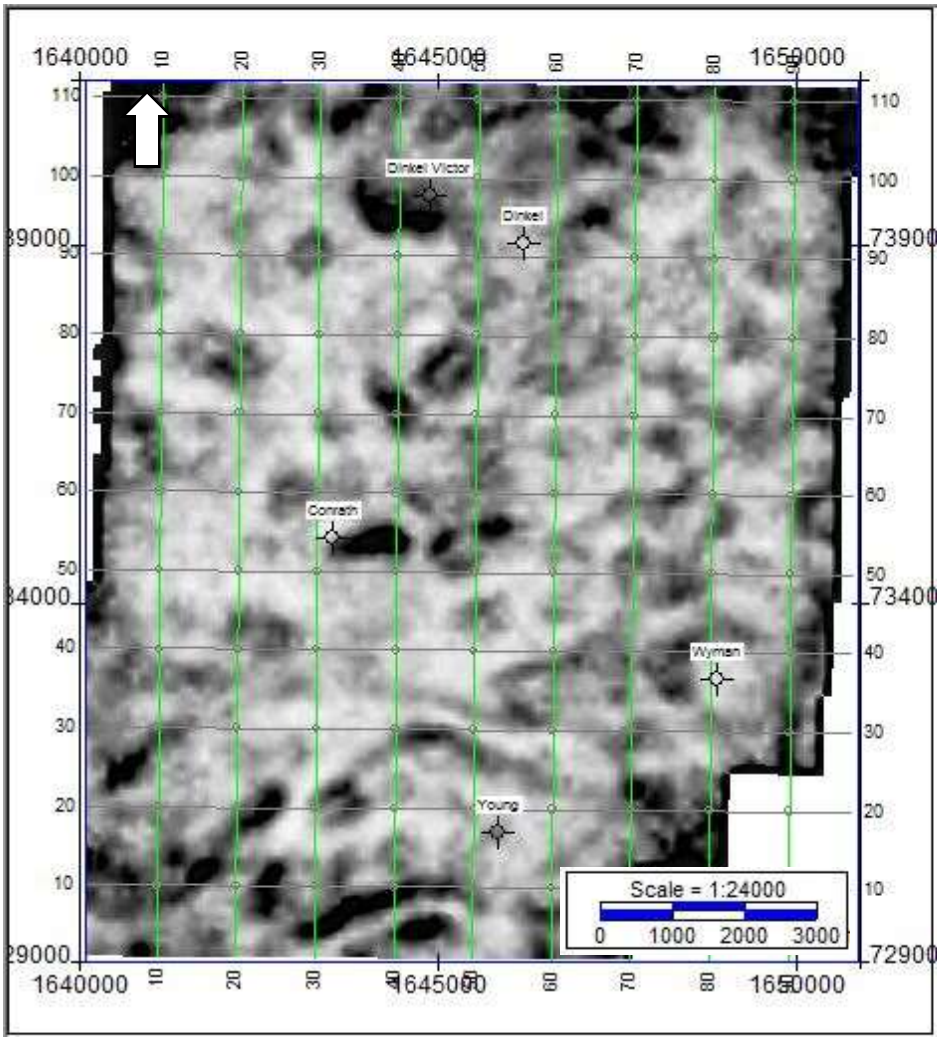


Figure 19. Similarity variance map. Darkening is an indication of local depositional anomalies.

Chapter 5 - Discussion and Conclusions

Discussion

Analysis of an isochron map for the Cherokee formation, and time structure maps for both the Mississippian horizon and the Cherokee horizons, reveals that placement of the wells within this study area largely corresponds to Cherokee/Mississippian topographic highs and indications of structural closure (see figures 12, 13, and 14). This is likely the reason that these wells were initially drilled in these locations. However, the log signatures for Conrath 1-10 and Wyman 1-11 indicate that poor production from these wells could possibly be attributed to a lack of sand development. The gamma ray and porosity curves shown in figures 6 and 7 indicate that the sands with adequate porosity in these locations are thin, and inter-bedded with shale. However, the appearance of these sands, nearby oil shows from the Cherokee group, and the fact that drill stem tests were run in the first place are all encouraging indications that a thicker, properly developed reservoir may be all that is necessary for a productive well.

Thickening of the Cherokee formation does appear to occur southeast of Conrath 1, and northwest of Wyman 1 (see figure 14). Taken on its own, this Cherokee thickening does not suggest that greater production success could have been found in this area. However, when coupled with the results of the attribute analysis carried out in this study, this thickening may be the first indication of a compelling prospect.

Examination of amplitude data throughout the seismic survey reveals a possible sand body reflection event located at a time-depth of roughly 0.888 seconds, as is shown by the orange (negative) reflection event in figure 20. The time-depth of this interpreted event is in agreement with Philip (2011), who suggests that the most probable location for a basal Cherokee sand body is within 10 milliseconds of the top of the Mississippian.

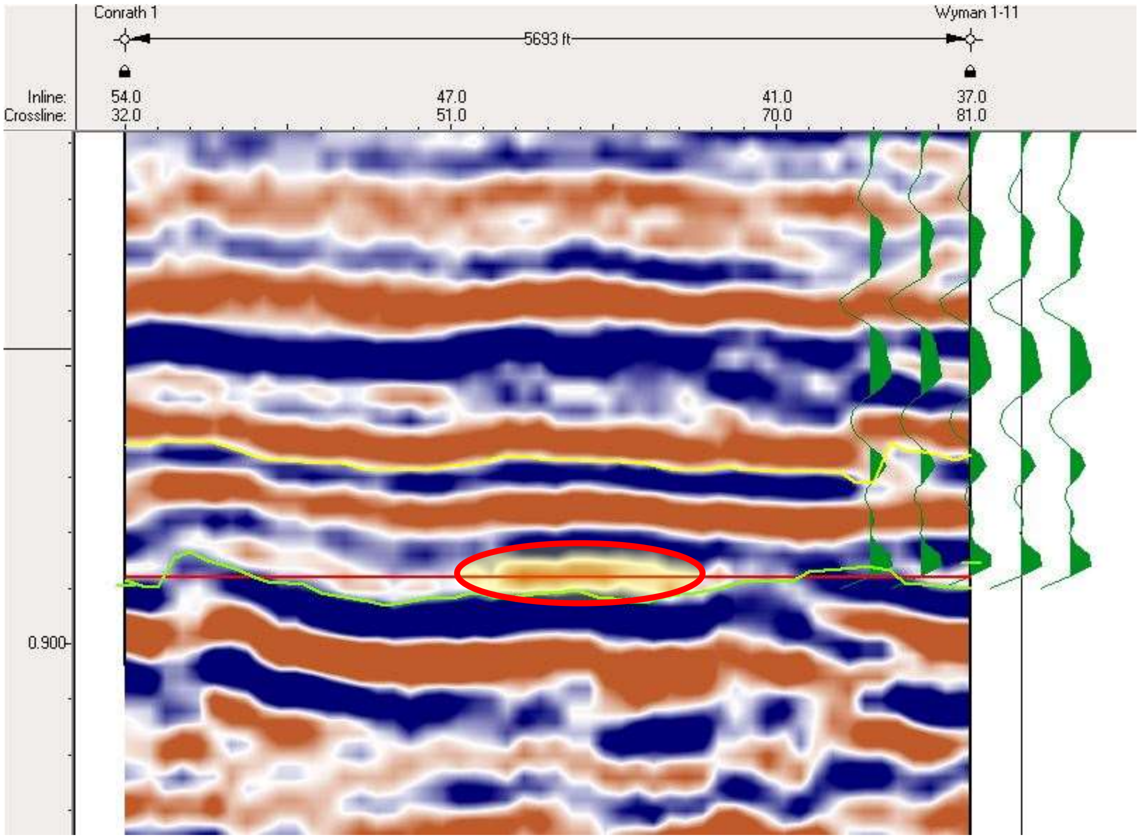


Figure 20. Interpreted sand body (yellow ellipse) found within the seismic survey. The red line indicates a seismic time slice at 0.888 seconds.

The map of amplitude attenuation (refer to figure 17) outlines a broad area of decreased amplitudes (i.e. higher amplitude attenuation) that roughly correlates to the zone of Cherokee thickening (refer to figure 14), and the reflection event shown in figure 20.

As is shown in figure 15, an increase in relative acoustic impedance coincides with the placement of the Dinkel-Victor, Young, and Conrath wells, and because such an increase could potentially represent a loss of reservoir quality rock, this information would have weighed against placing these wells in their current locations. Conversely, a NE to SW trending feature of relatively low acoustic impedance is located southeast of Conrath 1-10 and northwest of Wyman 1-11. This linear feature corresponds with the area of Cherokee thickening, greater amplitude attenuation, and an RMS amplitude increase (suggesting varied lithology within the Cherokee formation in this zone of interest).

It is an analysis of the event continuity map, however, which provides some of the most compelling evidence for a sand body with a meandering outline. A broad, meandering channel pattern can be seen quite clearly in figure 18. This channel outline is made even more compelling by the fact that it roughly coincides with the previously mentioned zones of Cherokee thickening, lower acoustic impedance, higher RMS amplitude values, and greater amplitude attenuation. Figure 21 below broadly outlines the area of greatest exploration potential, based on the convergence of multiple attributes and relatively higher Cherokee time-structure contours (see figures 14 through 17, grouped below in figure 22)

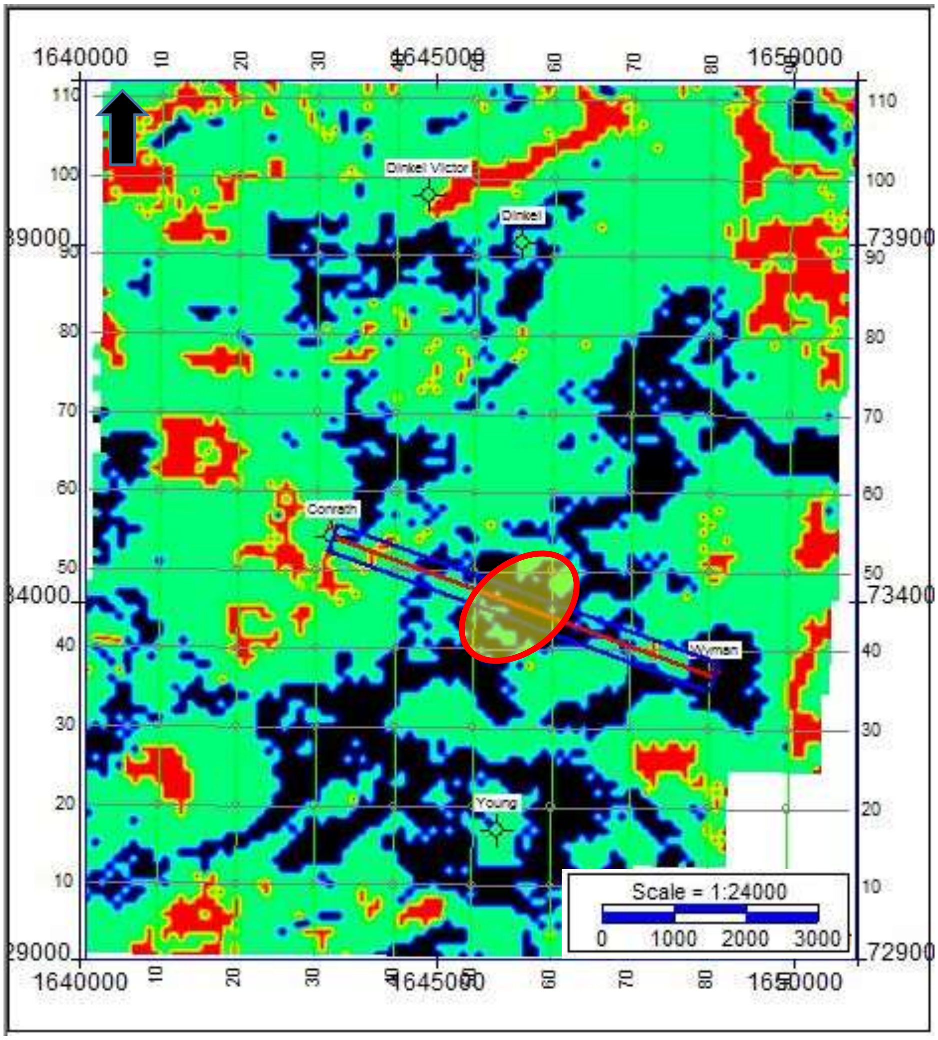


Figure 21. Event continuity map with area of greatest potential (outlined in red) based on the convergence of multiple positive attribute indications (see figure 22).

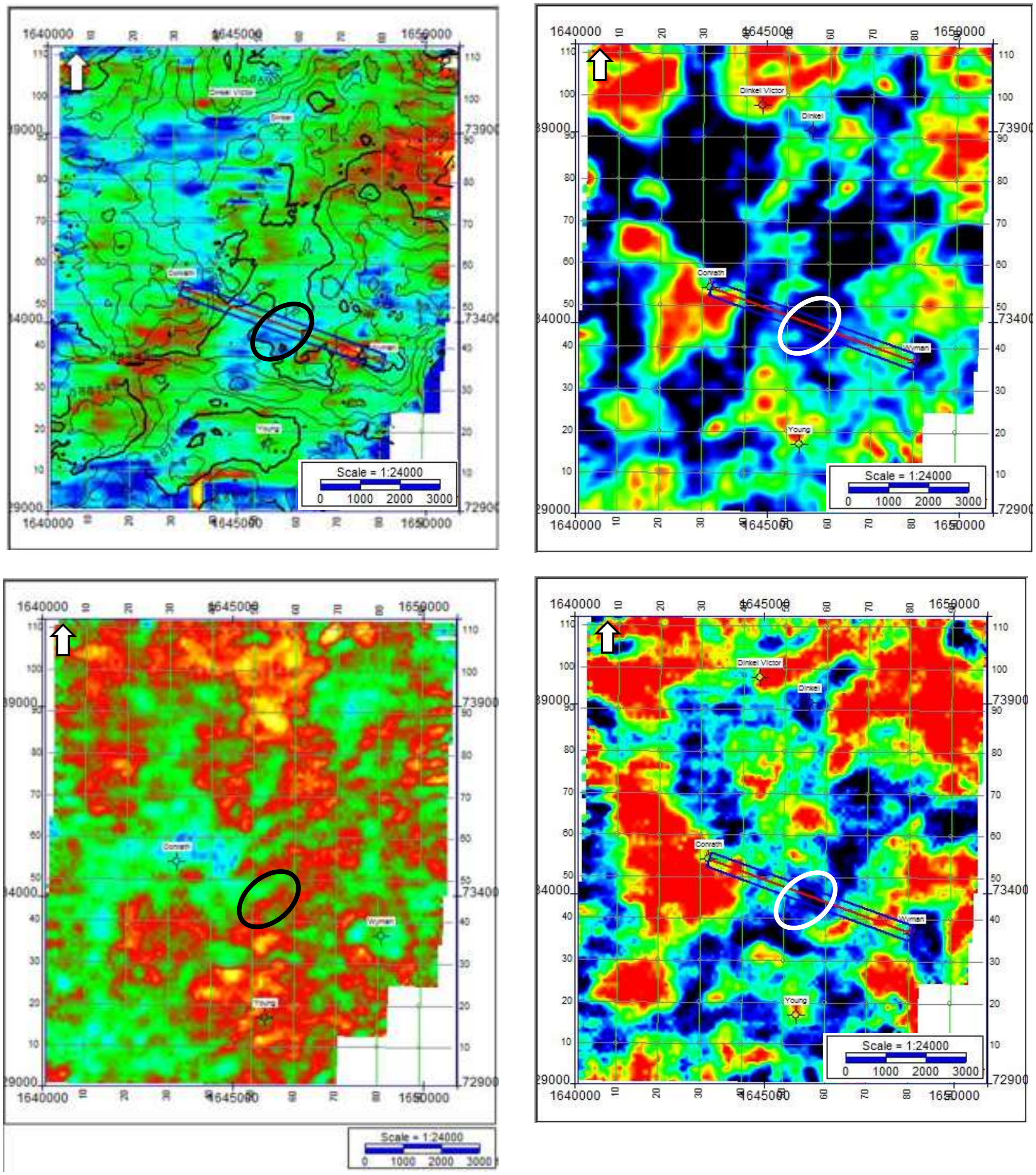


Figure 22. Grouping of figures 14 through 17, with estimated area of greatest potential indicated by the colored ellipses.

A basic paleodepositional interpretation can be made based on an examination of the Cherokee/Mississippian time-structure maps and the identified channel sand body. These maps (see figures 12 and 13) depict relative structural highs to north, suggesting this location may be a north-eastern extension of the transitional continental-marine paleo-shoreline identified in Raef et al. (in press). The structure observed in these maps may post-date the deposition of the Cherokee group, however, as stratal amplitude time slices above the flattened Mississippian horizon do not indicate a shoreline nearly as clearly. This suggests that the channel outlined in this study may be further inland, which is in agreement with the meandering, fluvial channel geometries seen here. Regardless, the interpreted Cherokee channel sand body identified in this study has a general NE-SW trend, which is in agreement with the system identified in Raef et al. (in press).

Before transitioning into conclusions, one concern worth addressing is the relatively low cross-correlation value seen in both the Wyman, and Conrath synthetic seismograms generated in this study. Low cross-correlation values for synthetics can sometimes be explained in part by ambiguity of phase as a result of large sequences of monotonous, cyclical reflectors. However, achieving values of ~0.6 for each of the wells only after both bulk shift and stretch and squeeze operations have been applied could be indicative of issues with original log data quality, or the quality control methods applied by the author. Regardless, there appears to be an acceptable tie between both synthetics and the seismic data – particularly for the Wyman 1-11 well. This is indicated, in part, by the correlation between the interpreted Mississippian time horizon in this study (~0.89 seconds) and the Mississippian horizons seen in Raef et al. (in press), Philip (2011), and Abbas (2009) for the nearby Wierman field (~.9 seconds).

Conclusions

In conclusion, the results of this study indicate the presence of a NE-SW trending channel sand located in the southeast/central portion of the study area. Slight thickening of the Cherokee formation, combined with an analysis of acoustic impedance, amplitude attenuation, RMS amplitude, and event continuity supports this conclusion. The general trend of this feature, its time-depth location, and its proximity to what has been interpreted as a paleo-shoreline all appear to be in agreement with the results and conclusions of previous studies conducted by Abbas (2009), Philip (2011), and Raef et al. (in press), for the nearby Wierman field (figure 22, below).

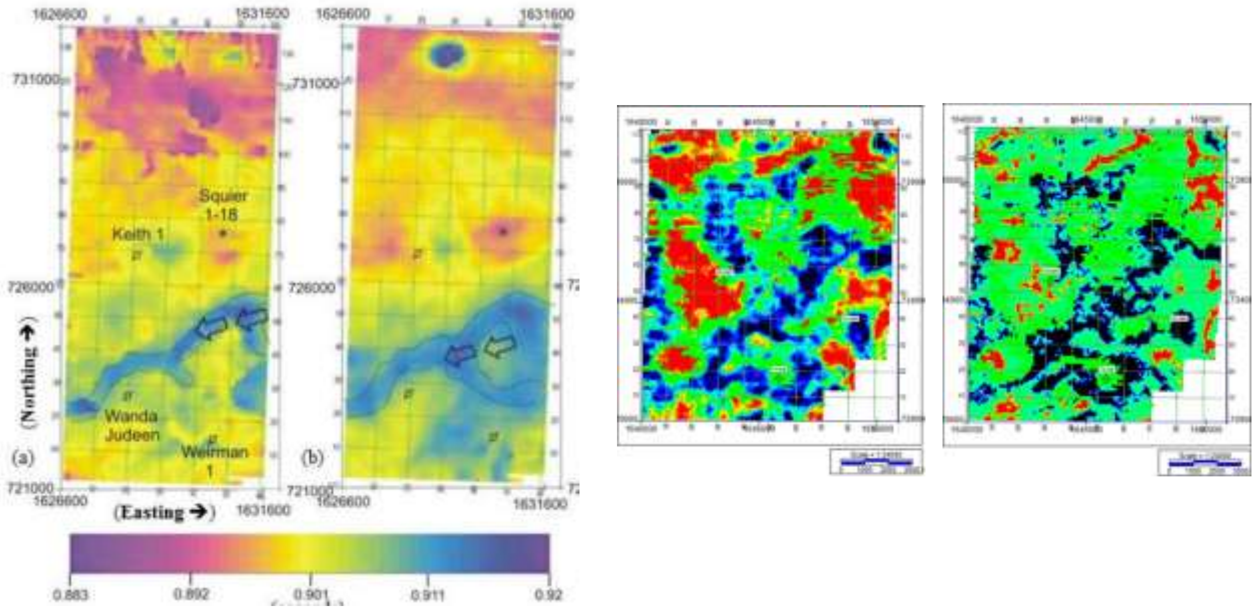


Figure 23. Comparison of channel features as seen in the two images on the left from Raef et al. (in press), and the results of this study (the two images on the right).

Finally, it is recommended that future exploration operations consider the channel feature outlined in this study when making well placement decisions. Some of the most significant concerns for the prospects identified within this channel would be the potential for lack of structural development/closure (i.e. an adequate trapping mechanism), and the possibility of reservoir compartmentalization. However, generation of additional attributes, along with further well log analysis and additional drilling may significantly contribute to a reduction of risk associated with structural properties.

While the workflow and results presented in this study may be broadly applicable to exploration efforts outside of this study area and/or Kansas, it should be noted that this study considers only a small subset of the library of seismic attributes available to the seismic interpreter. The procedures outlined in this study are relatively preliminary, and should not be viewed as an established solution for all exploration operations. A solid working knowledge of the local geology and attribute analysis techniques may assist in tailoring a more appropriate workflow to a new set of circumstances. Regardless, utilization of the 3D seismic attributes outlined in this study is highly recommended as part of an integrated workflow for future petroleum exploration operations in this area of Ness County.

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