SEISMIC ATTRIBUTE ANALYSIS OF THE MISSISSIPIAN LIMESTONE: NESS COUNTY, KANSAS

by

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B.S., Kansas State University. 2012

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Geology
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2014

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Abstract

Ness County has contributed 30 billion barrels to Kansas oil production since 1995, and has been an actively developing county in oil activity. The focus of this research project is to identify the reservoir qualities that make Mississippian-aged production favorable. Modern day logging techniques and seismic data allow specialists to seek out subtle heterogeneities to an oil producing formation once thought to be homogenous. Having success with horizontal drilling in other locations worldwide, large oil companies have acquired tens of thousands of acres with the intentions of drilling into the Mississippian, although some have recently backed out of the area. While some horizontal wells are producing today, complications with the compartmentalized, relatively thin Mississippian producing zones and short production longevities make horizontal drilling a high risk technique. Better understanding favorable reservoir qualities are essential for future production and development of oil fields in Ness County.

This case study utilizes different variations of post and pre-stack 3D and 2D seismic data shot on about 3,200 acres spanning over 8 sections located in northwestern Ness County. The physical and chemical properties associated with the Mississippian formation in this area can be better analyzed with different methods for processing seismic data. Raw seismic signatures show little variation within the Mississippi Lime/Dolomite. Utilizing Seismic attributes derived from raw data may bring certain featured hydrocarbon bearing zones into view. Attributes such as curvature and coherency aid in interpreting physical features within the study area while spectral decomposition, amplitude, instantaneous frequency, and instantaneous Q hold detailed signatures dependent upon rock properties.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I would like to thank George Petersen and Palomino Petroleum Inc. for making the seismic survey data available for my use. I would also like to thank my committee members for the guidance needed to make this project possible.

Chapter 1 - Intro

Since the 1970's, when the majority of Ness Country oil fields were discovered, new prospects have targeted paleostructural highs. It is true that structure is a major factor to be considered when considering drilling new wells, however, other factors that control reservoir quality can be brought into the equation by utilizing seismic attributes. With many of the large structural high zones on the decline with respect to production, further development of the Mississippi Lime in Ness County (Figure 1.1) should consist of narrowing the prospection to a smaller and more detailed scale, where subtle variances in rock properties may contain key evidence to the migration and accumulation of hydrocarbons. Seismic attributes hold information with regards to lithologic boundaries, lateral continuity, faulting/fracturing, porosity, and fluid content. With optimal resolution, direct hydrocarbon indications may be available to help further develop the Mississippi Lime Play.

Figure 1.1 Approximate study area in red

Chapter 2 - Depositional Setting

The Mississippian Lime play known today was originally deposited about 350 million years ago. During this time period the southern half of Kansas was under water in a shallow sea environment. The position of North America put Kansas at about 20° south latitude, with an equatorial climate (Figure 2.1) Transgression/regregression sequences deposited lime mud and shelly sediment, which ultimately formed the Mississippi Lime. Oldest deposited lithologies are primarily marine in origin while younger sediments exhibit evidence of marine and terrestrial environments (Goebel 1968). Present throughout most of Kansas, the limestone is often eroded on local anticlines such as the Central Kansas Uplift, but is found to be thicker in synclines and basins (Evens and Newell 2013). In Ness County, Mississippian aged rocks represent ramped subcrop ranging from the shelf margin to near shore inner shelf embayments and supratidal zones. At the shelf margin, buildup of sponge spicule sediment occurs. It is these locations where Mississippian chat is formed. The main shelf-inner shelf margin is characterized by alternating layers of echinoderm rich packstone/grainstone and sponge spicule rich wackstone/packstones. (Figure 2.2) These alternate both vertically and horizontally. The inner shelf and supratidal zone contain precursors to evaporites and mudstones/wackstones (Dubois, 2003).

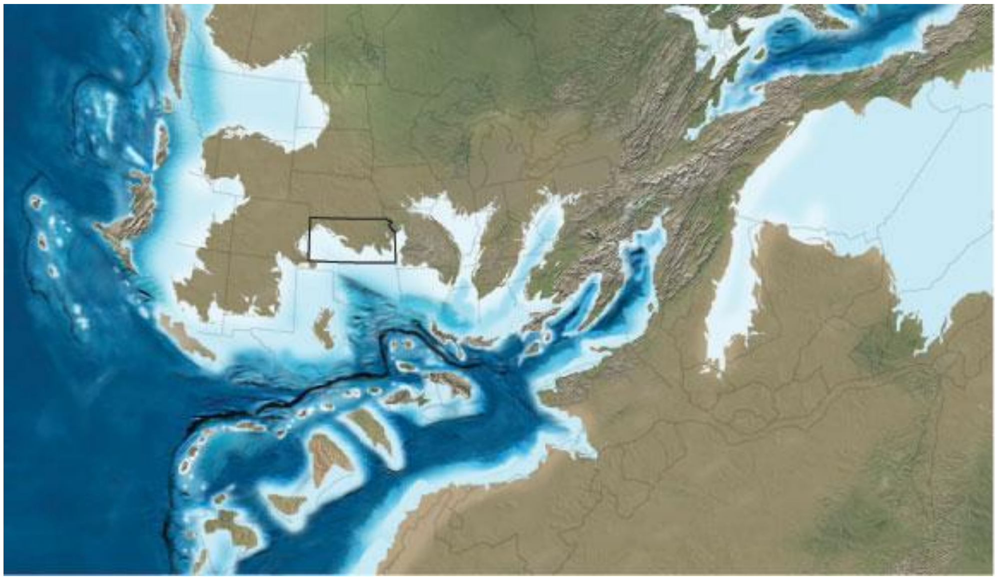


Figure 2.1 Paleoenvironment during deposition of Mississippi Lime (Goebel 1968)

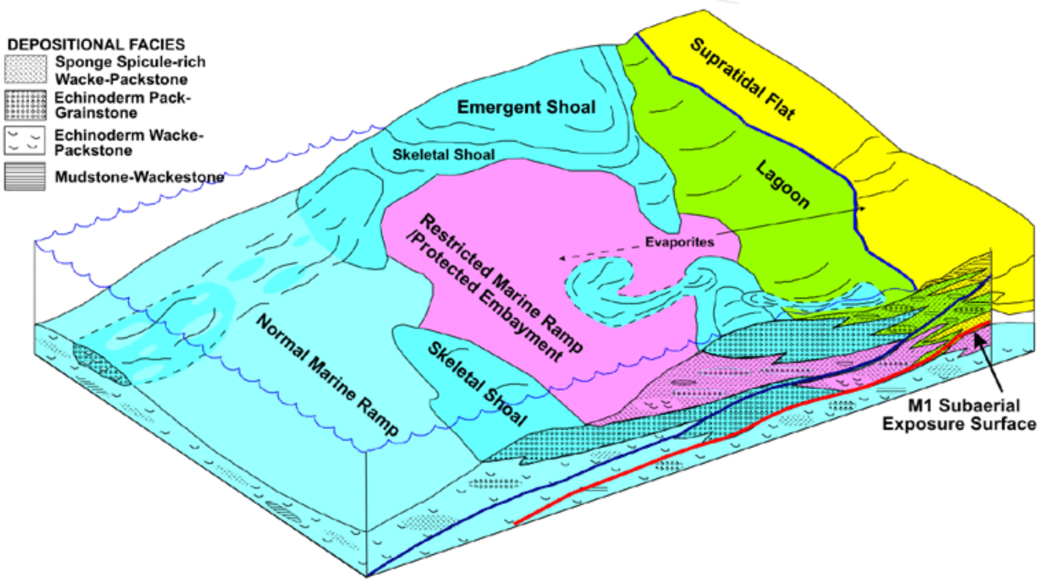


Figure 2.2 Analogue of marine ramp sediment deposition (Byrnes et al. 2003)

Chapter 3 - Stages of the Mississippian Series

Mississippian oil production comes from the upper Osagian aged rocks and the lower Meramecian aged rocks. However, it is important to consider the entirety of the Mississippian to better understand the depositional environment, and potential saline fluid/hydrocarbon bearing formations. Paleozoic erosion accounts for sporadic subcrops throughout Ness County. The researched study area falls within the Spergen/Warsaw subcrop limit, where the St. Louis Limestone has been eroded. (Figure 3.1)

Kinderhookian Stage

This stage marks the oldest unit of the Mississippian System in west central Kansas. Kinderhookian rocks lie beneath Osagian aged rocks and are separated by an angular unconformity. The tendency of the Kinderhookian rocks is to thicken northward. (Goeble 1968)

Gilmore City Limestone

Sometimes referred to the Reed Springs in the southern part of the state, the Gilmore City member begins directly above the Sedalia member and pinches out to the east along the flank of the Central Kansas Uplift. These rocks are rarely dolomitic and are characterized by oolitic limestone with localized chert deposits.

Osagian Stage

Osagian aged rocks have been described as dolomite, limestone, and cherty dolomite. In Ness County, they are separated from lower Kinderhookian rocks by an angular unconformity. While the Osagian stage has produced oil in several fields in Ness County, the majority of them are interpreted to fall beneath the oil water contact in this particular study area.

Fern Glen Limestone

Lying below the Burlington Limestone, the distributing of the Fern Glen suggests that that southern edge of the Central Kansas Uplift was undergoing deformation prior to deposition of younger Osagian rocks.

The St. Joe Limestone consists of paleosols with red and green calcareous shale, along with dark gray argillaceous shales. Some localities may include red colored crinoidal limestone beds within the paleosol. West of the Central Kansas Uplift, the St. Joe member is generally less than 20 feet thick.

The Reeds Springs Limestone Member is a cherty limestone. Blue/gray chert and sponge spicules are common among the Reeds Springs Limestone. Microscopic crusts of chalcedony may be found within insoluble residues.

Burlington-Keokuk Limestone

Varying in thickness, the Burlington is not easily distinguishable from the Keokuk Limestone. Due to pre-Pennsylvanian erosion, Burlington-Keokuk rocks are absent in the Central Kansas Uplift region, but some rocks may remain in Ness County. These rocks may consist of white tripolitic chert, dolomite, and siliceous limestone. High chert content generally exceeds 50% of the rock by weight. (Goebel 1968)

Meramecian Stage

Meramecian rocks were deposited in an environment similar to rocks of the Osagian Stage where shallow marine seas covered the western and central portion of the continent. Upper facies are usually granular, sandy, oolitic, and fossiliferous limestone. Lower facies are mainly chert bearing dolomitic limestone. (Thompson, Goebel 1968)

Warsaw Limestone

The Warsaw Limestone consists mainly of semigranular limestone with laminations of saccharoidal dolomite with interbedded chert. The chert is microfossiliferous and gray in color. Some localities of the lower Warsaw may contain glauconite while others can exhibit sponge spicules within dolomite where alteration by meteoric water has not occurred. Extensive dissolution creates intercrystaline moldic porosity.

Spergen/Salem Limestone

Known as the Spergen Limestone in Ness County, this formation lies conformably above the Warsaw Formation. Similar to the Warsaw Limestone, the Spergen Limestone is characterized by oolitic limestone and dolomite, but contain significantly less microfossiliferous chert. The character of the dolomitic limestone tends to be semi-granular to granular.

Chesteran Stage

Chesteran rocks are unconformably separated from overlying Pennsylvanian rocks. Most Chesteran rocks have been removed on local anticlines such as the Central Kansas Uplift and are not believed to be found within the given study area. Where they are present in Ness County the lower beds are usually silty, grey to red limestone. Upper Chesteran rocks are characterized by discontinuous lenses of sandstones interspersed within shale beds. (Goebel, 1968)

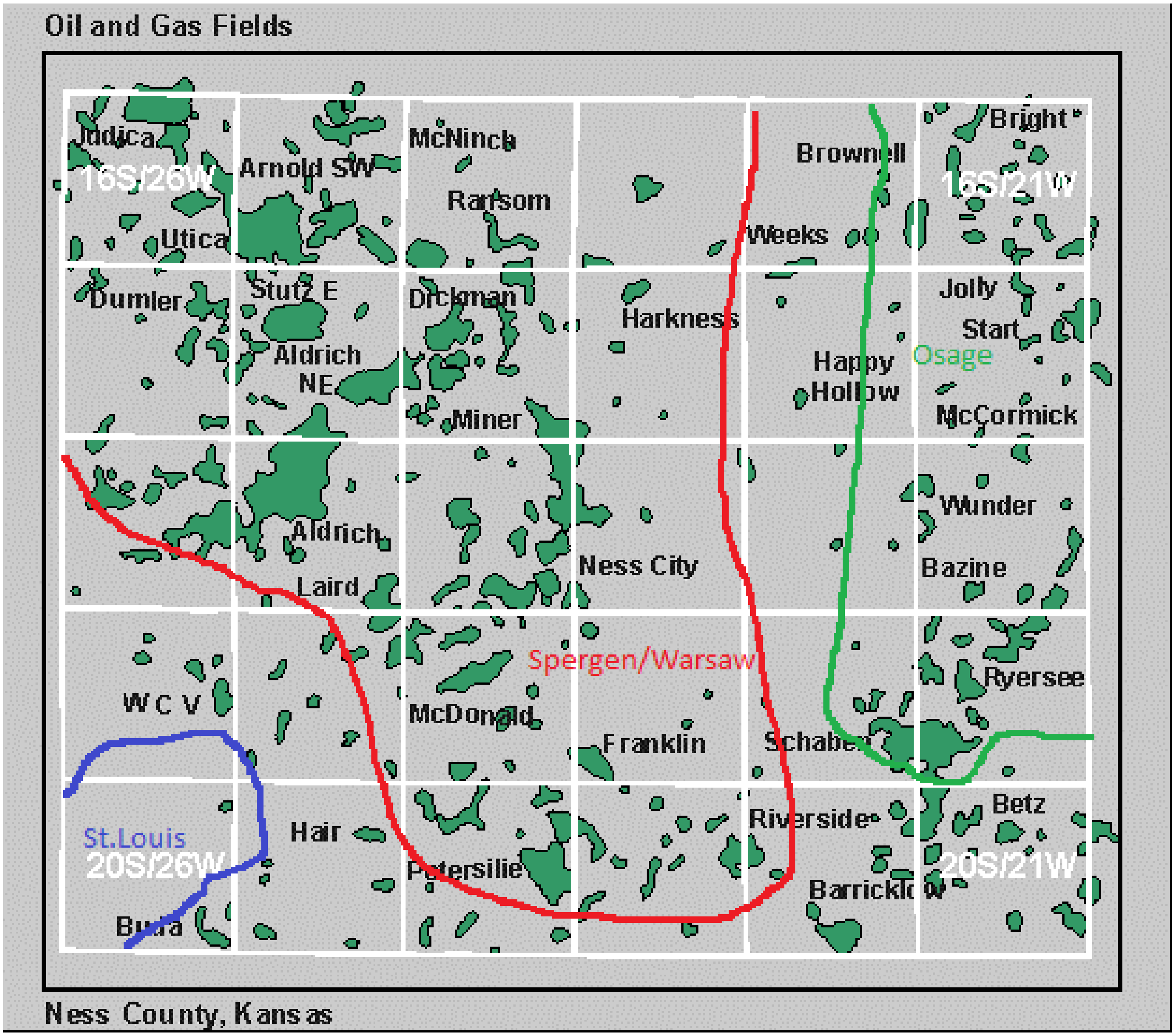


Figure 3.1 Approximate Subcrop Limit of Ness County Production (Green patches are producing fields-red, green, and blue lines represent extend of subcrops) (Dubois et al. 2003)

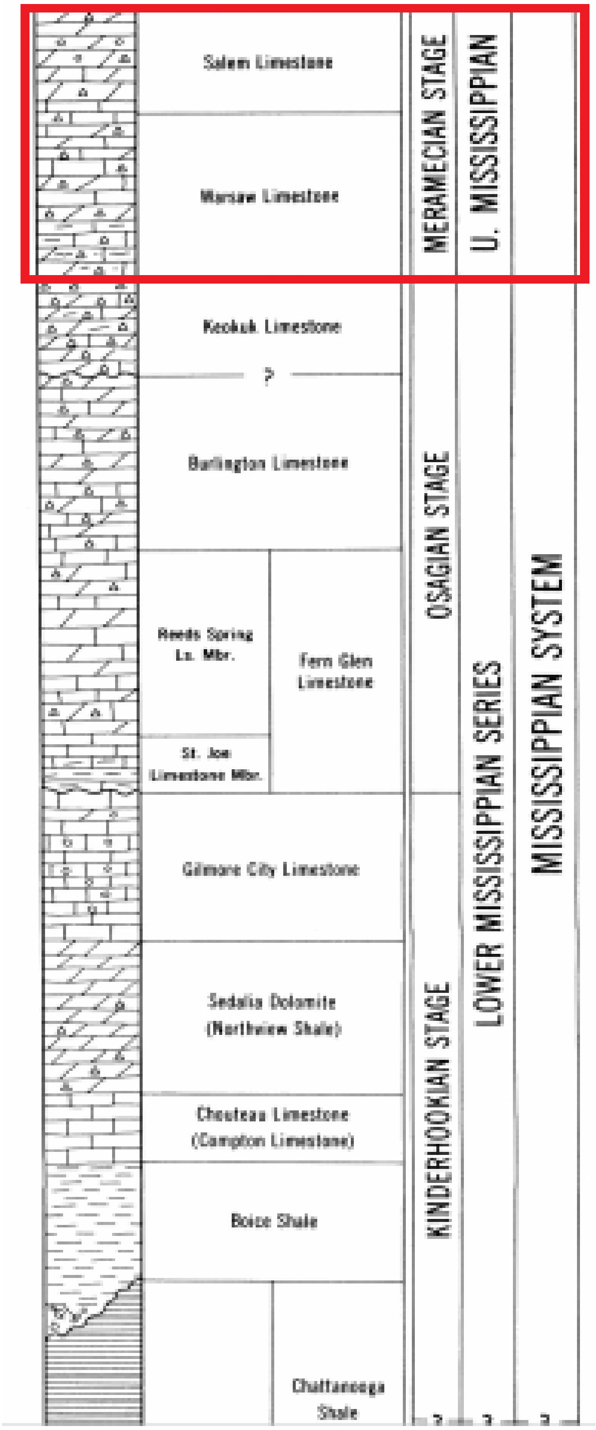


Figure 3.2 Straticgraphic column with expected range of production highlighted (Thompson and Goebel 1968)

Chapter 4 - Reservoir Charactarization

Reservoir Facies

Most production in Ness County occurs within the Spergen/Warsaw interface, although some is produced where Osagian rocks lay directly beneath the post Mississippian unconformity. Pay zone rocks of Ness County are associated with a gently southwestward dipping shallow sea ramp and are part of the upper main shelf to inner shelf interval. Slight variations in seawater stands created varying sediment textures from fine carbonate mud to coarser carbonate sands. (Figure 4.1) Subsequent dolomitization is considered to be the main control on reservoir quality.

Reservoirs of the Mississippian range from 20 to 40 feet thick but consist of thin layered facies with varying pore geometries. Porosity, permeability and capillary pressure are dependent upon primary facies. Typical of Ness County reservoirs, dolomitic grainstone/packstone/wackstone are the pay zones within a given reservoir. These are often interbedded with tighter carbonate mudstones, which are perceived as non-pay zones. (Franseen et al. 1998)

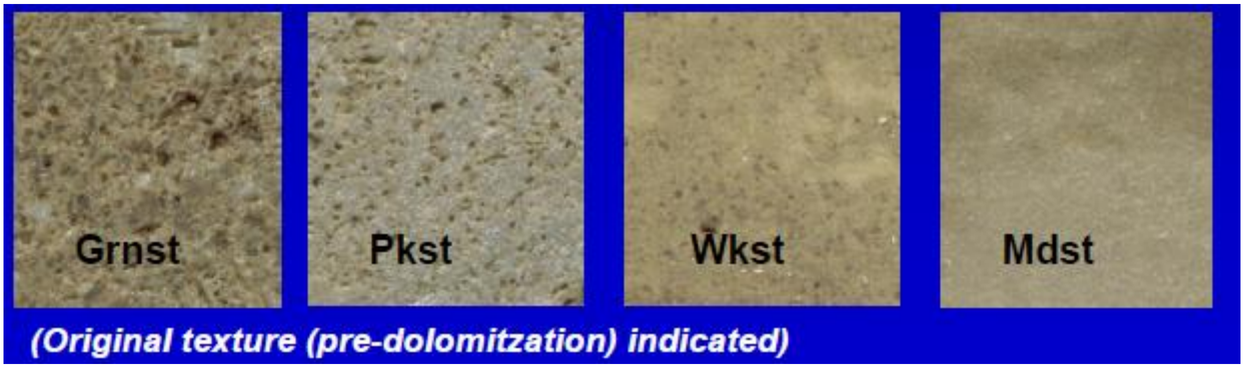


Figure 4.1 Common rocks of similar porosity common to Ness County(Dubois et al. 2003)

Reservoir Pay Facies

Sponge Spicule Rich Wacke-Packstone:

Cores taken from the Schaben field of Ness County contain an aboundant amount of the Sponge Spicule Rich Wacke-Packstone, especially among the uppermost strata. (Figure 4.2) Sponge spicules are often found in concentrated zones where paleocurrents constrained them. This facies is mottled from burrowing, dominated by sponge spicules and their molds, and has undergone extensive dolomitization. Siliceous fluids resulted in silica replacement of matrix in addition to the replacement of evaporate grains, resulting in matrix, moldic, and vuggy porosity. (Franseen et al. 1998)

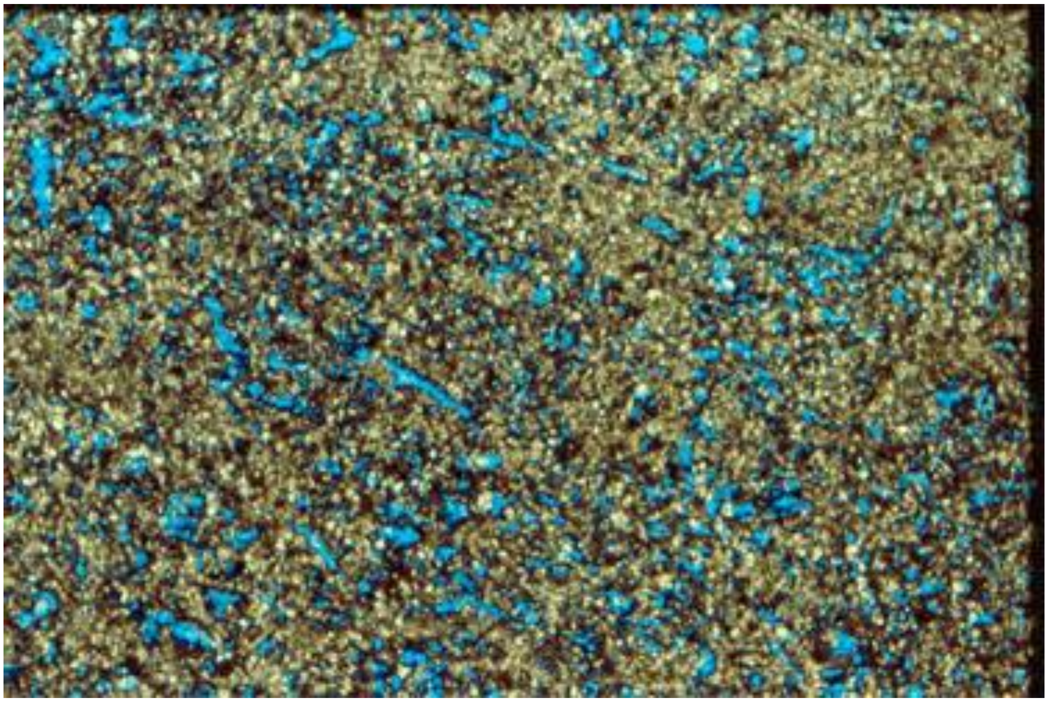


Figure 4.2 Sponge Spicule-rich packstone/grainstone facies (5mm field of view) (Byrnes et al. 2003)

Echinoderm Wacke-Pack-Grainstone-

This facies is typically wispy laminated or mottled. Dominated by echinoderm skeletals, gradational coarsening or fining is common. In dolomitized localities, grains are preserved as moldic, intercrystalline, and vuggy porosity. (Figure 4.3) Where siliceous fluids have infiltrated, grains have been preserved or their molds have been lined with silica cement. (Franseen et al., 1998)

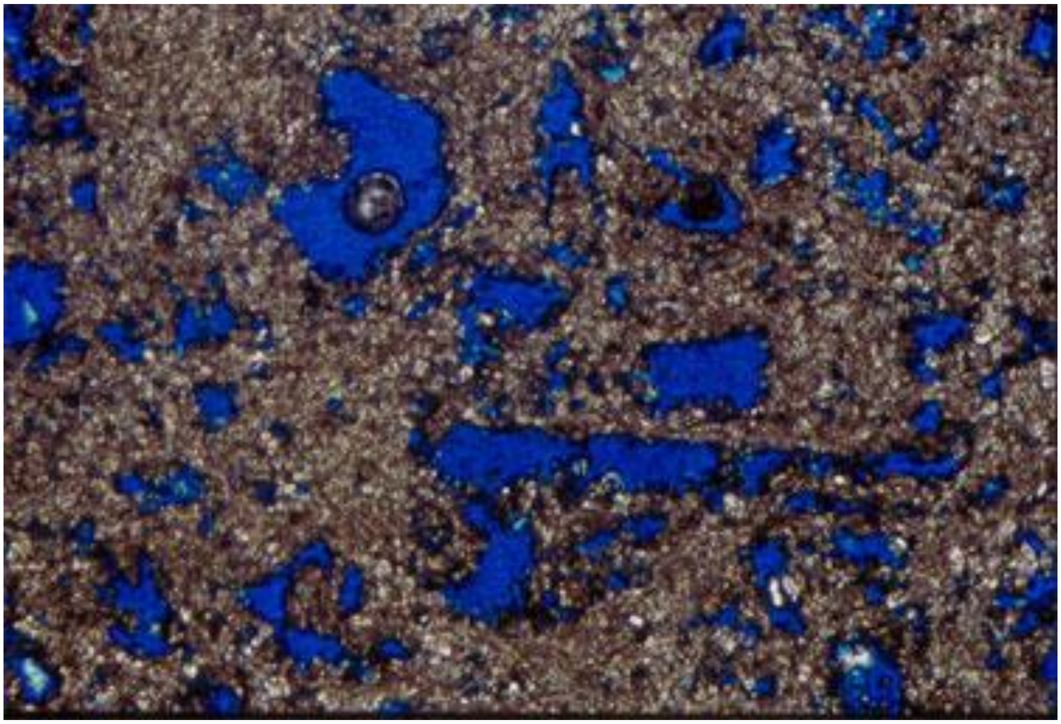


Figure 4.3 Echinoderm-rich wacke-packstone facies (5mm field of view) (Byrnes et al. 2003)

Tight Reservoir Facies and Localities

Mudstone-Wackstone-

This facies does not exhibit the abundant skeletal grains of echinoderms or sponge spicules common to pay zone facies. Dolomitized mudstones are dominated by microporosity. (Figure 4.4) The finer grain size makes this facies very tight. (Franseen et al. 1998)

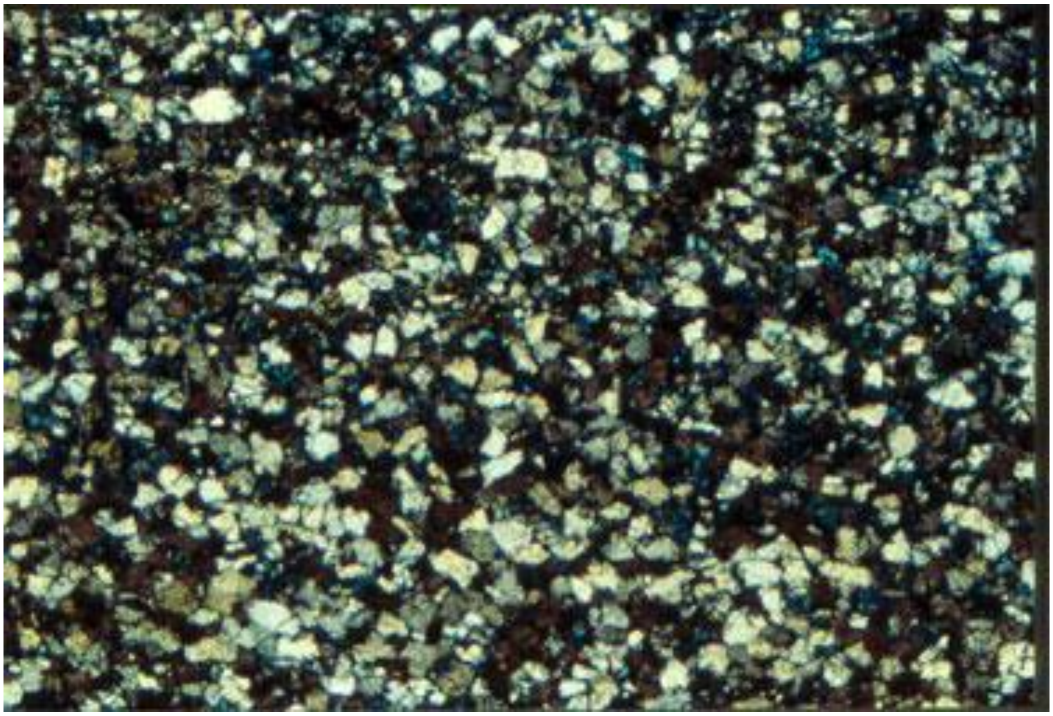


Figure 4.4 Wackstone/mudstone facies (5mm field of view) (Byrnes et al. 2003)

Sources of abundant silica have been traced to the abundance of sponge spicules. Silica replacement cementation can be supported by silicification closely matching borrowing networks, displacive silica nodules and the deformation of surrounding dolomitic sediment. Silicified zones that contain preserved, radiating bladed evaporate crystals indicate early silicification that create pervasive, impermeable barriers common in the echinoderm rich facies. These tight zones often exhibit vertical heterogeneity, and may be support indications of reservoir compartmentalization.

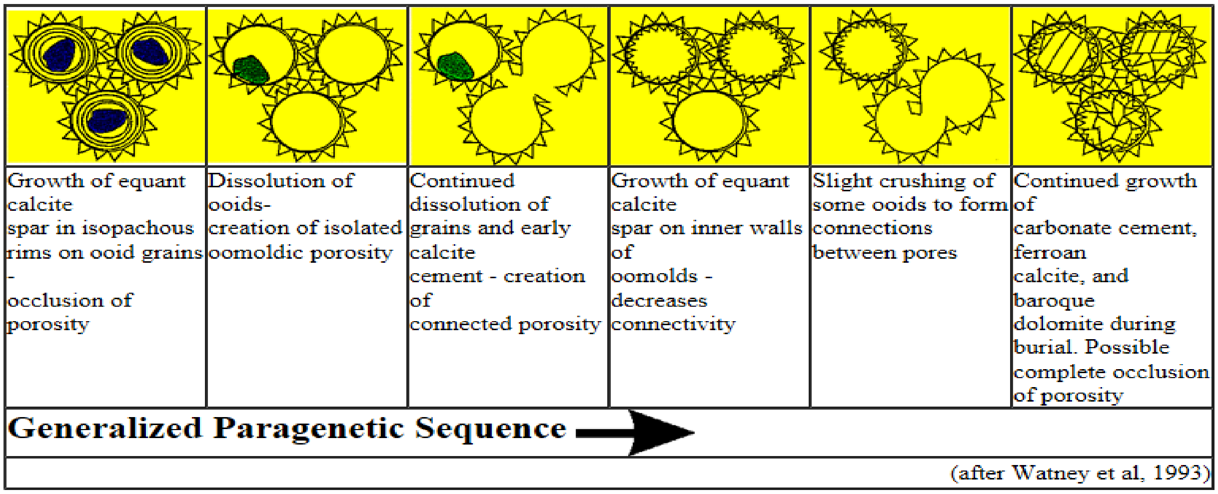
Occlusion of porosity can also result from calcite cementation and replacement by downward leaching into underlying strata. Data collected from calcite cemented zones returned low minipermeater readings and lack of oil staining. Some porosity occlusion even occurred in favorable structural highs that were presumed to be oil bearing.

> “Fracture and breccia matrix porosity that remained open results in vertical communication among the thin intervals with favorable reservoir characteristics controlled by depositional facies and early diagenesis.” (Franseen et al. 1998)

Local fracturing and brecciation were the result of several possible processes occurring at differing times. Differential compaction of silicified zones produced brittle fracturing and sediment deformation. Subaerial exposure occurred during deposition and after deposition which brecciated previous diagenetic events. Burial and structural uplift also aided in fracturing and brecciation. Fracture fills taken from cores vary at macroscopic and microscopic scales. Common types of fill matrix include: shale, subangular to rounded, silt- to coarse-grained size detrital quartz, chert, megaquartz, chalcedony grains, carbonate micrite, carbonate grains, and skeletal grains. Clastic fill may include: chert, original carbonate facies, replacive calcite clasts, course fragmented calcite cement, and red to green limy clay. (Franseen 1998)

Controlling Factors on Reservoir Properties

Original depositional facies from grainstone to mudstone are the dominant control on reservoir quality for systems with varying differences such as: varying early and late dolomitization, biotic constituent differences, warm/cool water environments, karstification, and burial overprinting. Porosity and permeability is significantly reduced with decreasing grain size, but one exception is common with the echinoderm grainstone facies, which often exhibits replacement or calcite/silica cementation resulting in occluded porosity and permeability. Porosity and permeability is enhanced by moldic porosity, and dolomitization (Figure 4.5). Stratigraphy also has control on reservoir quality where high frequency cycles at a shallowing upward ramp commonly deposit sediment of larger grain sizes. Extensive dissolution of carbonate grains helped connect moldic pores and enhance permeability. Diagenetic processes were accentuated by the relief resulting from paleotopography. The burial of Missississipian rocks created fractures that helped establish pore connectivity. (Byrnes et al., 2003)



Growth of equant calcite spar in isopachous rims on ooid grains - occlusion of porosity

Dissolution of ooids- creation of isolated oomoldic porosity

Continued dissolution of grains and early calcite cement - creation of connected porosity

Growth of equant calcite spar on inner walls of oomolds - decreases connectivity

Slight crushing of some ooids to form connections between pores

Continued growth of carbonate cement, ferroan calcite, and baroque dolomite during burial. Possible complete occlusion of porosity

Generalized Paragenetic Sequence

(after Watney et al, 1993)

Figure 4.5 Moldic porosity model resulting from diagenesis (Byrnes et al. 2003)

Quantification of Porosity and Permiability

The relationship of permeability and porosity exhibits a subparallel trend for all lithofacies within the Missississippian where permeability decreases with decreasing grainsize for any given porosity. This relationship is best modeled by the equation:

$$K=A\Phi^{3.45}$$

K = the in situ Klinkenberg permeability, Φ = porosity, and coefficient A (dependent upon grain size and Archies packing index) varies with different lithofacies: (Figure 4.6) (Table 4.1).

Lithofacies	Coefficient A
Packstone	0.00525
Pack-Wackestone	0.00150
Wackestone	0.00043
Wacke-Mudstone	0.00012
Mudstone	0.00004
Shaly Mudstone	0.00001

Table 4.1 Lithofacies with associated A coefficient value

For all facies, matrix properties constrain the degree of permeability. Diagenetic overprints can be seen by varying trends of the permeability- porosity relationship. While some rocks may exhibit high moldic porosity, permeability can still be low due to small pore throat diameters. With increasing grain size, matrix pores also increase. Dissolution, crushing, and fracturing increase connectivity of pores in all facies and create parallel flow fluid flow systems. The range of permeability varies more than that of porosity for facies common to the Mississippian. While matrix geometry is the main control on permeability factors such as connective index, packing index, and size also play a role. (Bhattacharya 1983)

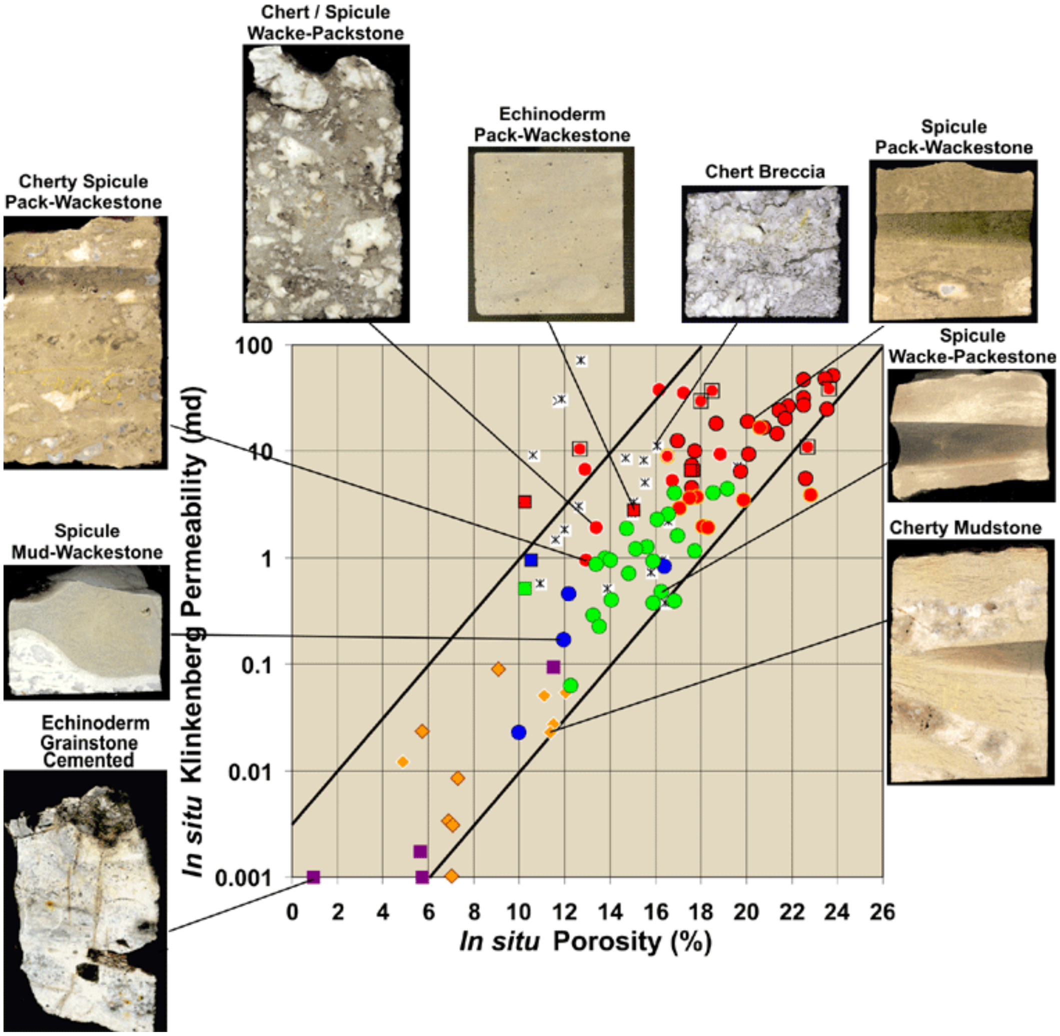


Figure 4.6 Porosity/permeability relations among local lithofacies (Byrnes et al. 2003)

Chapter 5 - Seismology

With technological advances have come increasingly important roles of geophysical exploration in the last 25 years. As the case of many surveys in Ness County, seismic data have been acquired to better understand the subsurface and the rock properties unique to hydrocarbon presence. With hopes of eliminating dry holes, seismic surveys are intended to be more cost efficient with regards to production development.

Seismic surveys are executed at the surface, but give interpreters a visual model of the subsurface. A source of energy in the form of acoustic waves is generated by air guns or thumper trucks that rumble the ground. As the waves propagate through the subsurface, some energy is reflected back to the surface and recorded by geophones. The recorded signal is called a seismic trace and has a unique travel time from which the wave left the transmitter and was recorded at the surface. Depending on the size and desired resolution, a seismic survey is gridded and contains numerous traces.

Seismic traces contain information unique to the character of the subsurface, of which can be analyzed with various seismic attributes. Attributes have different purposes, and break down seismic traces into the unique components such as, frequency, velocity, and amplitude. Seismology has its niche in the petroleum industry, where geologists and geophysicists seek to identify the components (source, reservoir, migration path, seal) of the petroleum system for a given study area. In some cases where seismic resolution is optimal and conditions or ideal, direct hydrocarbon indications may be present. When this phenomenon happens, hydrocarbons can be seen in seismic models and may exist as bright or dim spots.

Chapter 6 - Methodology

Data Loading

In July of 2002, the Lonestar Geophysical Crew #101 conducted a 3D seismic survey on the study area. A total of 190 in-lines and 250 cross-lines span the study area. The specifications pertaining to data acquisition included:

Cross Line/In Line- 82.5 ft
Sample Rate- 2 ms
Receiver Interval-165 ft
Reciever Line Separation- 495 ft

Record End Time-2 sec
Shot Interval- 165 ft
SP Line Separation- 990 ft
Source-Vibroseis 16-128 hz 3 db/octave 2 Vib 8 Sweets 12 sec

The Data Processing was performed by Sterling Seismic Services, Ltd. Once formatted to .sgy file conversion (SEG-Y seismic data), data was tuned by means of: gain recovery, surface deconvolution, spiking, spectral enhancement, and refraction and datum correction. The final product tuned for a focus on the Mississippi Lime consisted of an enhanced post stack, spectral enhanced (12-128 hz), migrated seismic survey.

To import the SEGY file, the boundary specifications had to be entered as four corners that covered the span of the survey. In order for the Kingdom Software to relate to the correct seismic vales of each trace, header information was entered that designated each trace signal to a specific shot point. To ease in location referencing, a shape file was imported from the Public Land Survey System (PLSS) which consisted of location survey lines. An overlay containing the Township/Range/section lines could then be viewed in their position with respect to the survey bounds by importing into the kingdom software under the *culture* tab.

Once imported in the IHS Kingdom Software, the seismic data was coupled with the only LAS digital well log file available within the study bounds. From the LAS file, a synthetic seismogram was created in order to the seismic data to the well log. First, a time to depth chart needed to be integrated considering the 2-way travel time of the seismic wave from the datum to the top of the first log sample. A velocity model was then computed from DT log pertaining to the Sherwin Trust well. Frequency matching computation gave a synthetic wavelet from which horizon tops were able to picked. (Figures 6.1and 6.2)

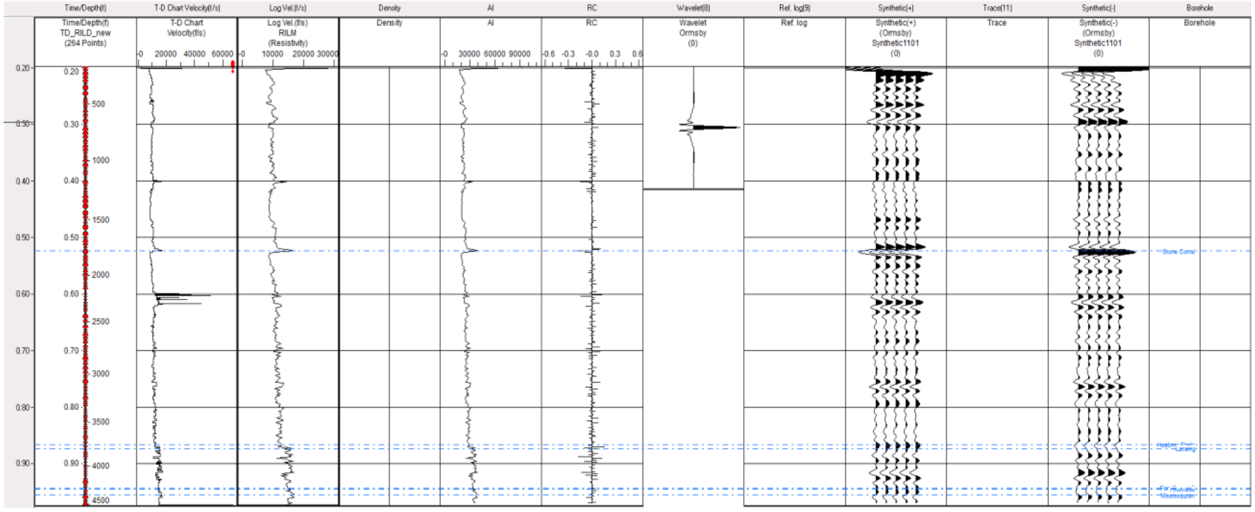


Figure 6.1 Synthetic seismogram

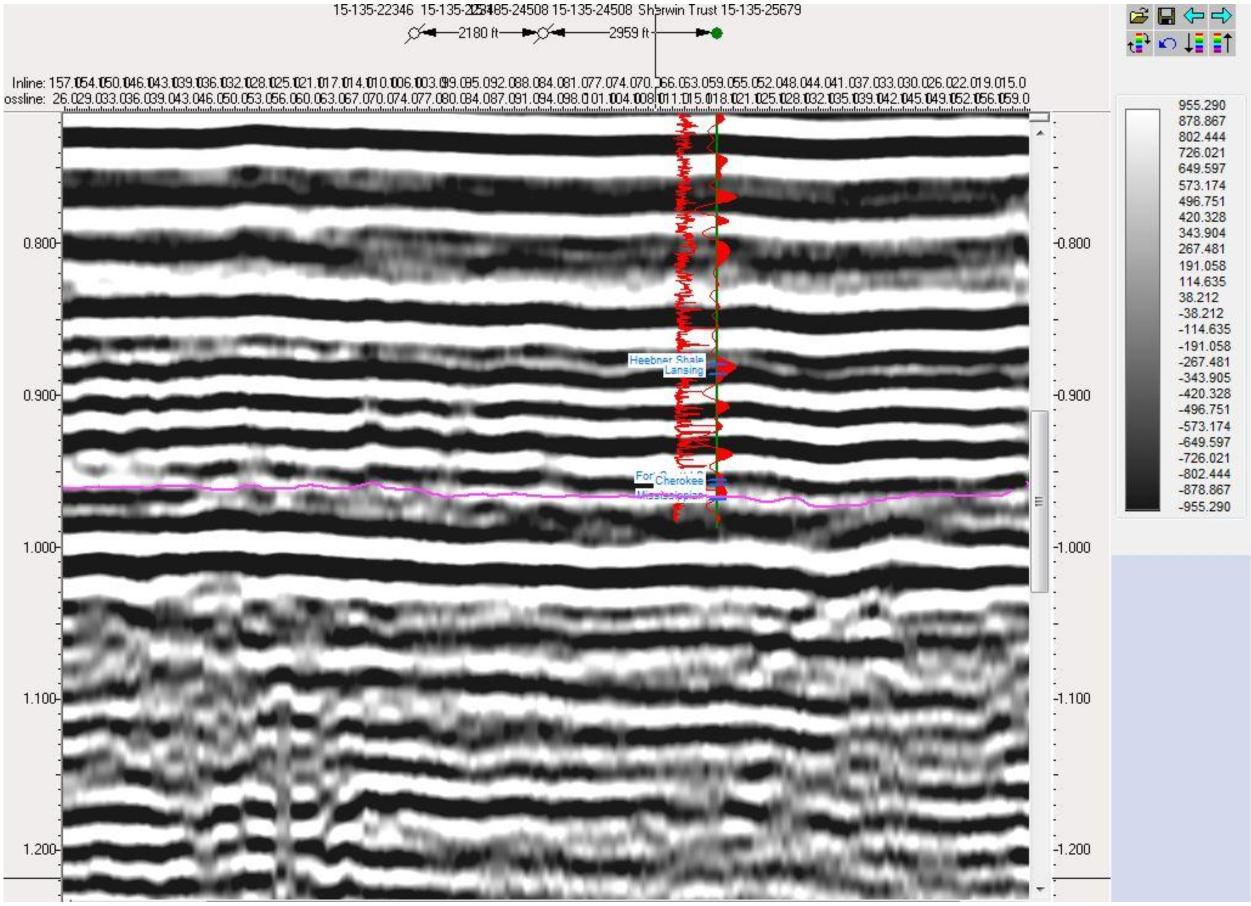


Figure 6.2 Cross section through wells with gamma log displayed at producing borehole

Data Conditioning and Attributes

Introduced in the 1970's, seismic attributes allow the user to view the constituents of seismic data that can be measured. Seismic attributes are designed to be an interpretational tool in reservoir characterization and quality control. A systematic approach begins with conditioning the raw seismic data in way that has the most use for the particular study of interest. Attribute techniques can then be incorporated within their unique limitations to yield quantifiable properties of seismic data.

Frequency Filtering-Bandpass filtering (Figures 6.3 and 6.4) is a useful technique for improving seismic resolution of a target zone by increasing the signal to noise ratio. Attenuation causes high frequency interfacies at deeper depths to be undistinguishable. This seismic data set is assumed to be of zero phase, thus variations of the Ormsby Bandpass Filter are used. Four corner frequencies make Ormsby filtering unique. Utilizing trial filters with varying frequency cutoffs aid in selecting the ideal configuration for displaying the optimum level of detail. (Hardy 2002)

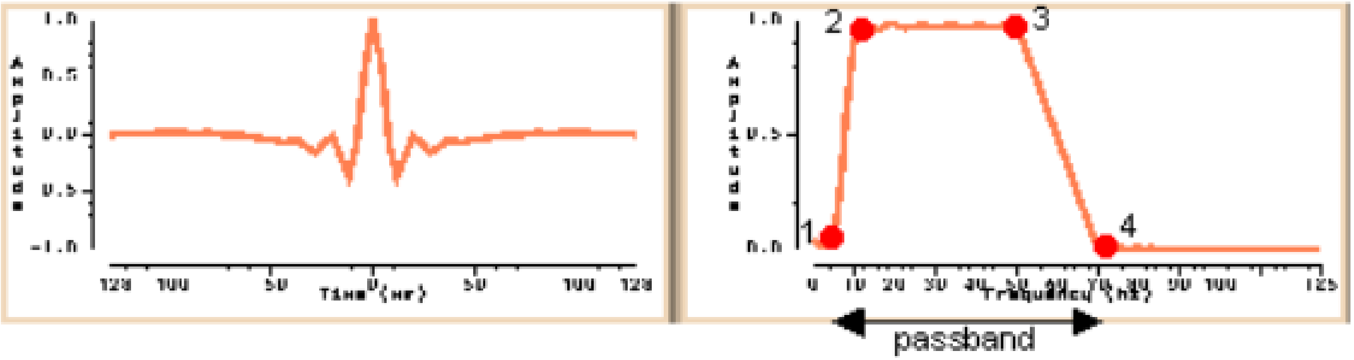


Figure 6.3 Ormbsy filter with 5-15-50-70 Hz cut off (Hardy 2002)

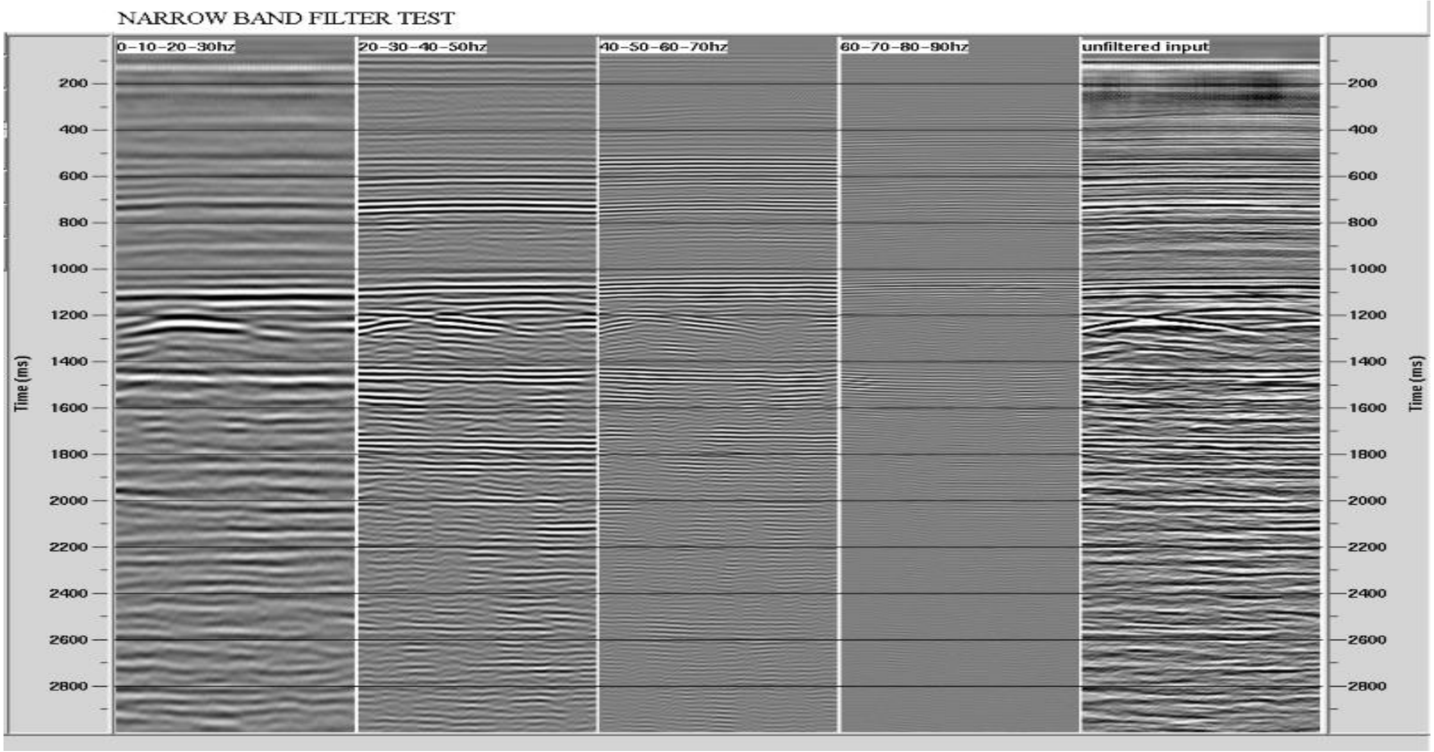


Figure 6.4 Narrow filter ranges and associated resoltion (Hardy 2002)

Spectral Whitening-Spectral Whitening (Figure 6.5) is yet another technique used on migrated seismic data to overcoming frequency attenuation, resulting in desired resolution for a given target zone. In theory, spectral whitening should create a balanced spectrum of amplitudes, although a perfectly balanced spectrum will cause complications as noise will be accentuated at the low and high ends of the spectrum. To overcome this complication, applying whitening for several specified frequencies within a bandpass filter, and then combining those results is ideal. (Hardy 2002)

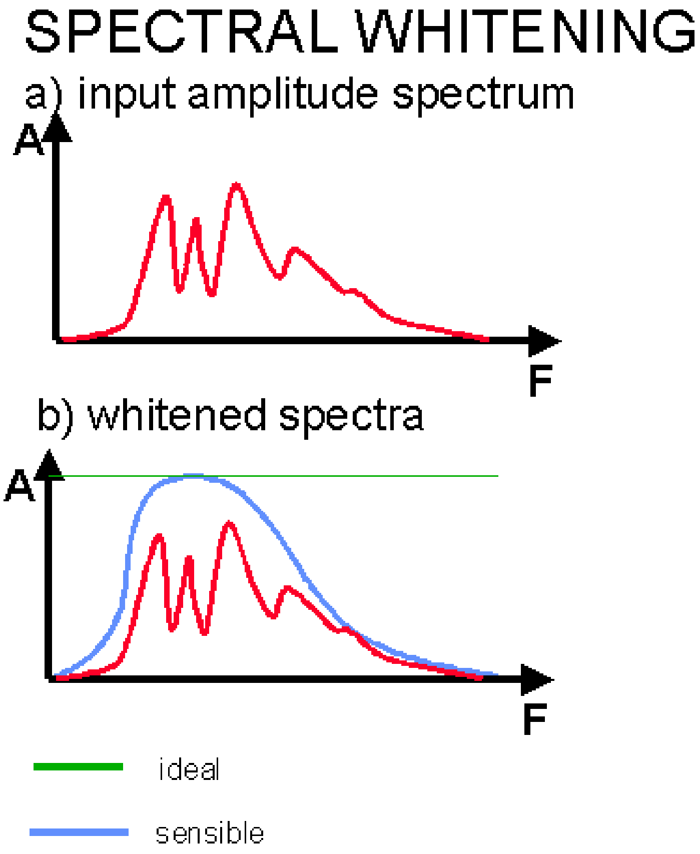


Figure 6.5 Spectral whitening logic (Hardy 2002)

Curvature- Curvature is a quantitative measurement of how deformed (bent) a surface is at a given point. The curvature attribute is most useful for delineating faults, showing karstified zones, highlighting fracture orientation and also aids in interpreting conventional structures such as: domes, valleys, ridges, and bowls. Maximum curvature can be defined as 1/radius of feature with most deformation. Minimum curvature is 1/radius of feature but is perpendicular to the maximum curvature axis. (Marfurt, 2013)

Spectral Decomposition- Spectral Decomposition utilizes the Discrete Fourier Transform (DFT) as raw seismic data is converted into the frequency domain. The amplitude spectra delineate variance in temporal bed thickness while the phase spectra detect lateral discontinuities. Then beds have a unique expression that is predictable, taking the peak to trough time separation in conjunction with amplitude. Because seismic wavelets often span throughout many thin beds, this method requires tuning to display the desired results. Finding the ideal amplitude spectrum is crucial. Transformation of long seismic traces approximates the spectrum of the wavelet; while transform of short seismic traces overprint acoustic properties bed thickness. A short window amplitude spectrum is desirable because it better takes into account not only the wavelet but geologic layering as well. Short spectrum window responses differ depending on acoustic properties and bed thickness. Tuning is achieved by analyzing a time slice or flattened horizon at different frequencies and choosing one that gives an image indicative of the geologic patterns known to the area. (Partyka et al. 1999)

Instantaneous Q-Instantaneous Q is computed from the formula:

$$Q = \Pi * \text{instantaneous frequency} * \text{envelope/envelope derivative}$$

Q is a quantative factor that measures high frequency attenuation. This attribute is similar to instantaneous frequency and should be viewed at a spectral window designed for long wavelengths. Instantaneous Q is often used as an indicator of fluid content as it accounts for the ratio between shear velocity and rock pressure. With this information one can get idea absorption properties of beds. (Rock Solid Images)

Chapter 7 - Interpretation

Local geology

Review of numerous literature sources pertaining to the regional geologic trends provided much support in the interpretation of the given study area. Publications by Marfurt, Nissen, Dubois, Wattney, and Byrnes contained much needed information on the petroleum system of the Mississippi Lime. With and understanding the local and regional structures and lithologies combined with seismic data, hypotheses were made shedding light on the subsurface geology of the given study area. Although closely trending to the regional character of the Mississippi Lime, a unique nature can be perceived via seismic analysis. It may be possible to relate fractured zones as fluid conduits, resulting in lithologic transformation from diagenetic overprinting.

Based on paleotopagraphic structure, many important features stand out. These physical features are best analyzed with the curvature and coherency attributes. Local high areas are present at the southeast and northwest boundaries of the study area. The time structure map is color shaded to represent high areas with green to reds and low areas with blue. Moving from the SE quarter of section 36 north to the NW quarter of section 21: (Figure 7.1) Local highs abruptly transition into a faulted graben (Figure 7.2) trending NE-SW through the middle of section 35. From here, the terrain gradually increases elevation in a north westerly manner before another abrupt transition into a local high beginning in section 21. Coherence and curvature are considered as physical attributes. Curvature maps not only highlight the graben that cuts through section 35 but delineate many other major fault and collapse features associated with limestone dissolution. The graben feature was picked on the basis of the constraining faults at the edge trending in a manner consistent with regional faults. Although resembling a possible channel, it is unlikely that a channel would gorge into such underlying strata. An incised channel would also be accompanied by sediment fill with a different seismic signature to that of surrounding rocks, which was not seen at this location. Faults/fractures in the study area are consistent with regional geologic character, trending at NE-SW and NW-SE azimuths. Highly fractured zones as seen where the northwest quarter of section 27 meets the southwest quarter of section 21 are interpreted as karst features resulting from subaerial exposure. Interpretations of karsted areas were based upon abrupt transitions from negative (red) to positive (blue) or vise versa curvature analysis. (Figure 7.3) It is unlikely for depositional or erosional events to occur in such a small scale localized fashion. While the most of the perimeter of the study area appears to be highly fractured, this phenomenon is most likely due to the lack of seismic resolution at survey boundaries, for this reason interpreted faults have not been extended to survey edges. Coherence analysis of the study area also portrays the same faults seen by the curvature attribute. Areas of high coherence are white in color on the time slice cutting just under the picked top of the Mississippian. (Figure 7.4) These white areas represent zones of similar rock properties and are said to have high coherence values. Spectral decomposition and normalized amplitude also shed light on lithologic variance but with much greater detail. (Figure 7.5)These maps portray post Mississippian erosional over prints throughout the middle section of the study area. Here, overlying strata have been removed, exposing underlying strata. This should be taken into strong consideration as these surface rocks throughout the study area will have different associated rock properties, and may have an impact on production.

Recommendation

Previous hydrocarbon exploration has highly favored topographic highs within the Mississippi Lime. While structure should be strongly considered when seeking new prospects, many other properties that can be quantified by seismic attributes also need consideration. In this study, techniques used to reconstruct structure and the underlying heterogeneities were used to highlight ‘favorable’ zones of interest with regards to hydrocarbon accumulation. Ideal scenarios are expected to consist of single or multiple dolomite pay zones above the oil water contact within Mississippian. While seismic attributes do help distinguish areas of contrasting rock properties, they do not provide a perfect replication of subsurface detail. Some thin bedding is too thin to be picked with the given seismic resolution. In some cases, resistivity logs can be used to pick thinly bedded areas of ideal porosity with higher confidence.

Not only are seismic attributes useful in the search for porous rocks, they also have a niche for identifying areas not so favorable for drilling. Highly fractured and karsted areas that can be highlighted by seismic data should be lastly considered for drilling amongst other lithologies. In the study area, there are two current producing wells represented by a green dot and several wells that have been plugged and abandoned that are displayed as a black circle with a line through it. The properties unique to the producers, combined with those pertaining to dry holes are the basis of the recommendation. Because the Sherwin Trust well in the northeast corner of section 34 produces in what appears to be different strata then the producer in section 35, they must be interpreted separately. The Sherwin Trust well was drilled in a locality where the uppermost strata have been eroded which can be seen on the normalized amplitude time slice. (Figure 7.5) Considering the series of NE trending fractures and compartmentalization seen in the curvature and coherency maps, a parallel fluid flow channel model must be considered. This may provide support to the numerous abandoned wells to the north west of the Sherwin Trust well as fluid barriers may exist as brecciated fill in fractures. For hydrocarbons to accumulate, all four components of the petroleum system need to be present, and with pinpoint accuracy to exploit production of the Mississippi Lime. White areas shown on the coherence map are interpreted as areas of like lithologies. Because the two producing wells both lie within a white zone, they are assumed to be fluid bearing lithologies. While these areas of high coherence do have wells producing within, interpreting the entire zones as a reservoir rock would be a fallacy. There must be some other rock quality to further distinguish fluid bearing rocks from non fluid bearing rocks. Further analyzing areas of high coherence, some exist through the middle of section 25, but these have been disregarded as they closely follow the path of a northeast trending graben and are assumed to be below the oil-water contact. (Figure 7.6)

Narrowing the search, we now are now looking for a small homogenous reservoir within a heterogeneous system with entrapments accredited to stratigraphy and structure. To further characterize this potential play, the instantaneous Q attribute was analyzed taken into consideration. Because this seismic attribute is dependent upon the shear velocity and density of rocks, it can be an indication of absorption properties and/or fluid content. For this study, two time slices representing the instantaneous q attribute were analyzed: one intersects roughly 50 feet below the top of the Mississippian, the other roughly 5 feet below the top. This procedure was carried out with the goal of modeling how fluid may have migrated about the formation, and to possibly get an understanding of the degree of vertical communication between different strata of the Mississippi Lime. Taking a look at the slice intersecting 50 feet below the surface (Figure 7.7), one will notice that the majority of the study area contains high values of the instantaneous q attribute. This occurrence is accredited to the vast amounts of saline formation water within the Mississippian. When considering the other time slice slightly below the top of the

Mississippian (Figure 7.8), the majority of the high instantaneous q values no longer exist. This time slice represents the uppermost strata with either high fluid content or high absorption properties. What existed as a large saline aquifer below may be traced upward into smaller accumulated localities. If any oil was present at oil within the network of vertical migration pathways, it would presumably accumulate near the top of the formation, above the oil/water contact. To help solidify this hypothesis that the instantaneous q attribute it associated with fluid content within the Mississippian, the linear feature seen in the NW quarter of section 27 (Figure 6.8) has been used as supporting evidence. This feature can be seen in the instantaneous q map along with the coherence and curvature map. At this location, there may be an impermeable fault plan which serves as a trap for fluid accumulation, hints the linear features seen on the maps. Here we see physical attributes in cross correlating with attributes designed to highlight fluid bearing rocks.

From a petroleum geologist's standpoint, one would need to compare seismic facies to those found in core samples. Without core data, seismic data is still a vital tool, but must be used with a humble degree of confidence. While seismic attributes useful in the search for porous rocks, they also have a niche for identifying areas not so favorable for drilling. Highly fractured and karsted areas that can be highlighted by seismic data should be lastly considered for drilling amongst other lithologies. Of all possibilities, highlighted areas in figure 6.8 are the most favorable prospect locations. They lie amongst a window of rocks where the uppermost strata seen in the study area have been eroded, and may not seem favorable to an old fashioned prospector only looking for structural high zones.

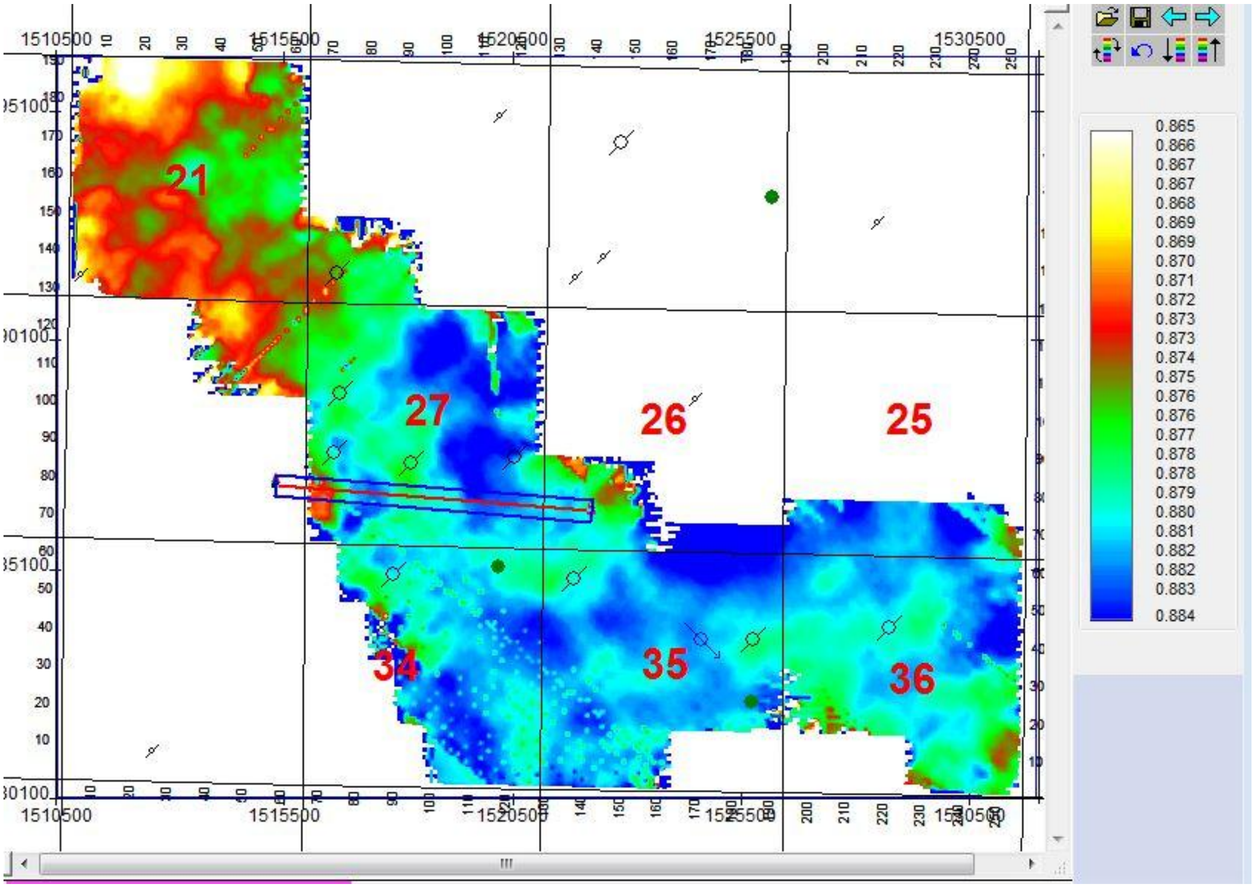


Figure 7.1 Time/Structure Map showing 2-way travel time in milliseconds (blue being deepest and yellow being shallow)

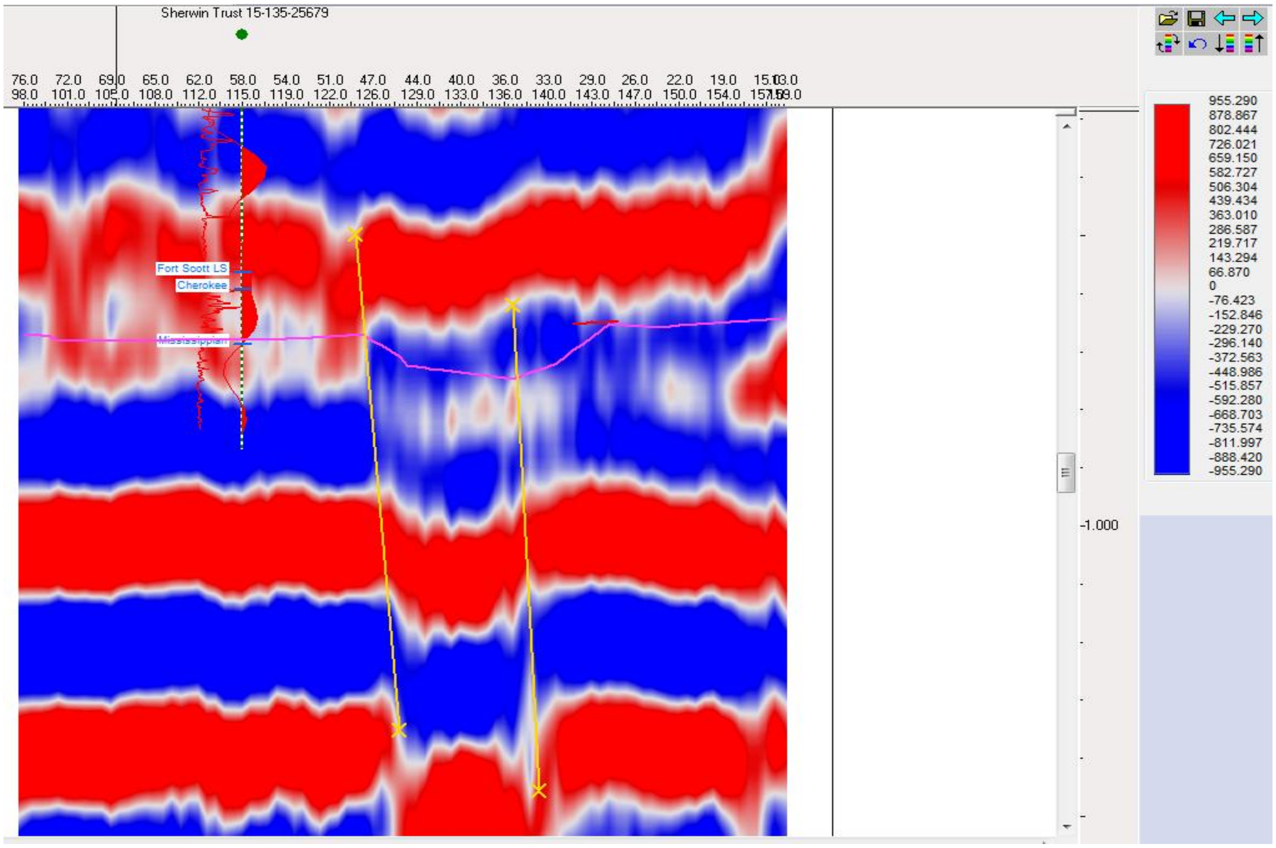


Figure 7.2 Cross Section through Sherwin trust well and graben in section 35

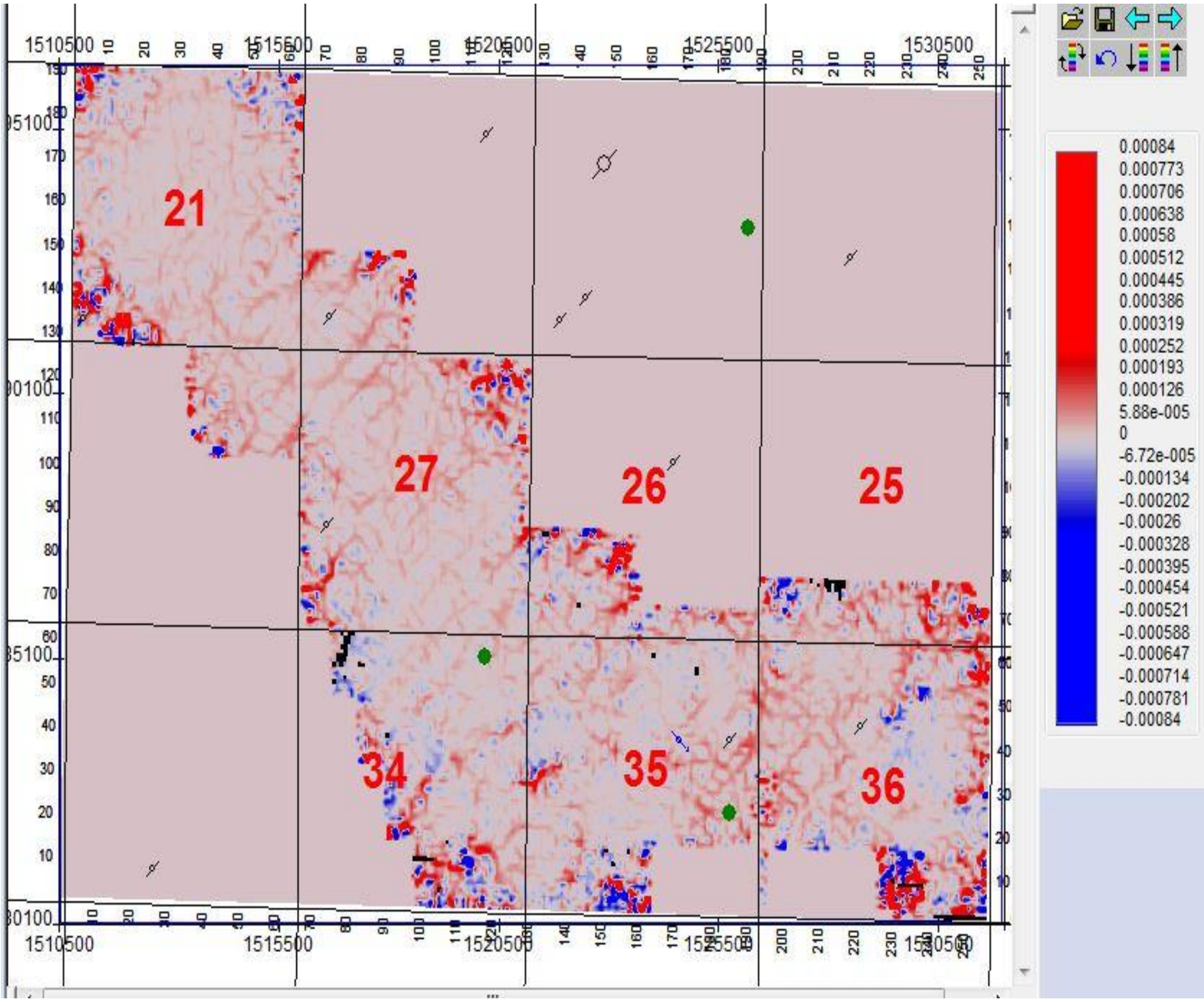


Figure 7.3 Curvature map with indications of fracture trends and fracture density

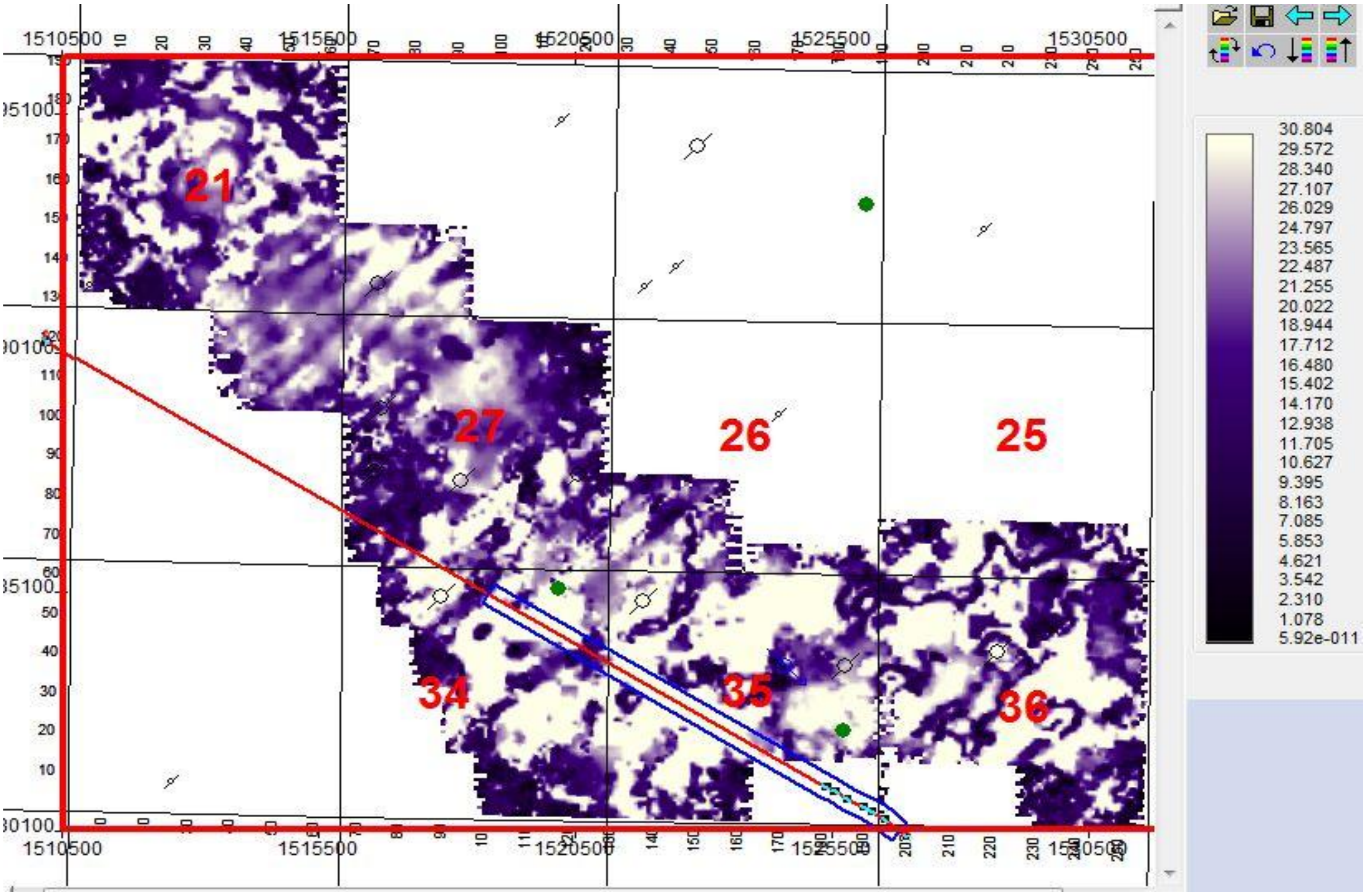


Figure 7.4 Coherency map showing lateral continuities and faults

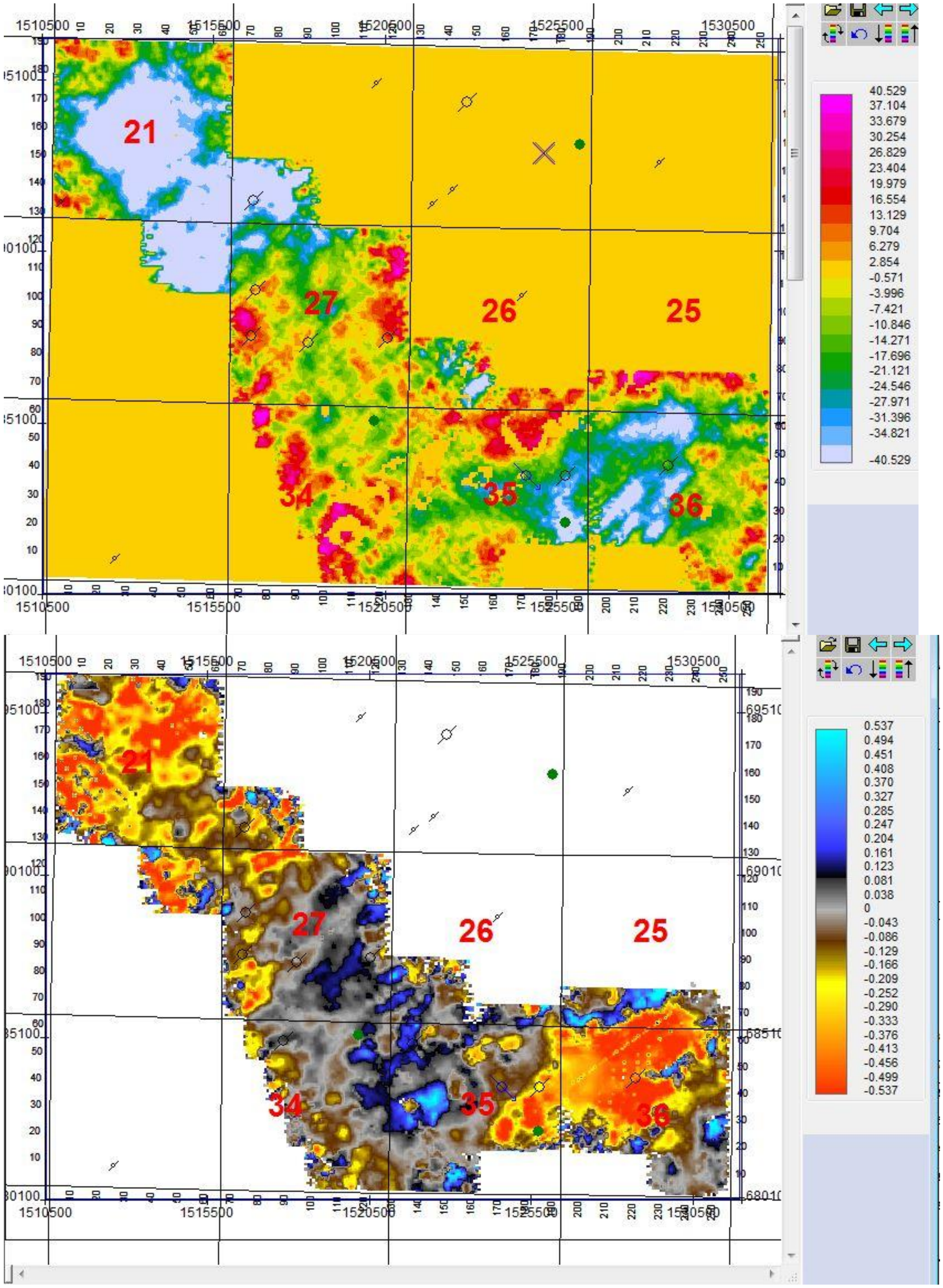


Figure 7.5 Spectral decomposition (top) and normalized amplitude (bottom) both indicate varying surficial lithologies throughout survey area

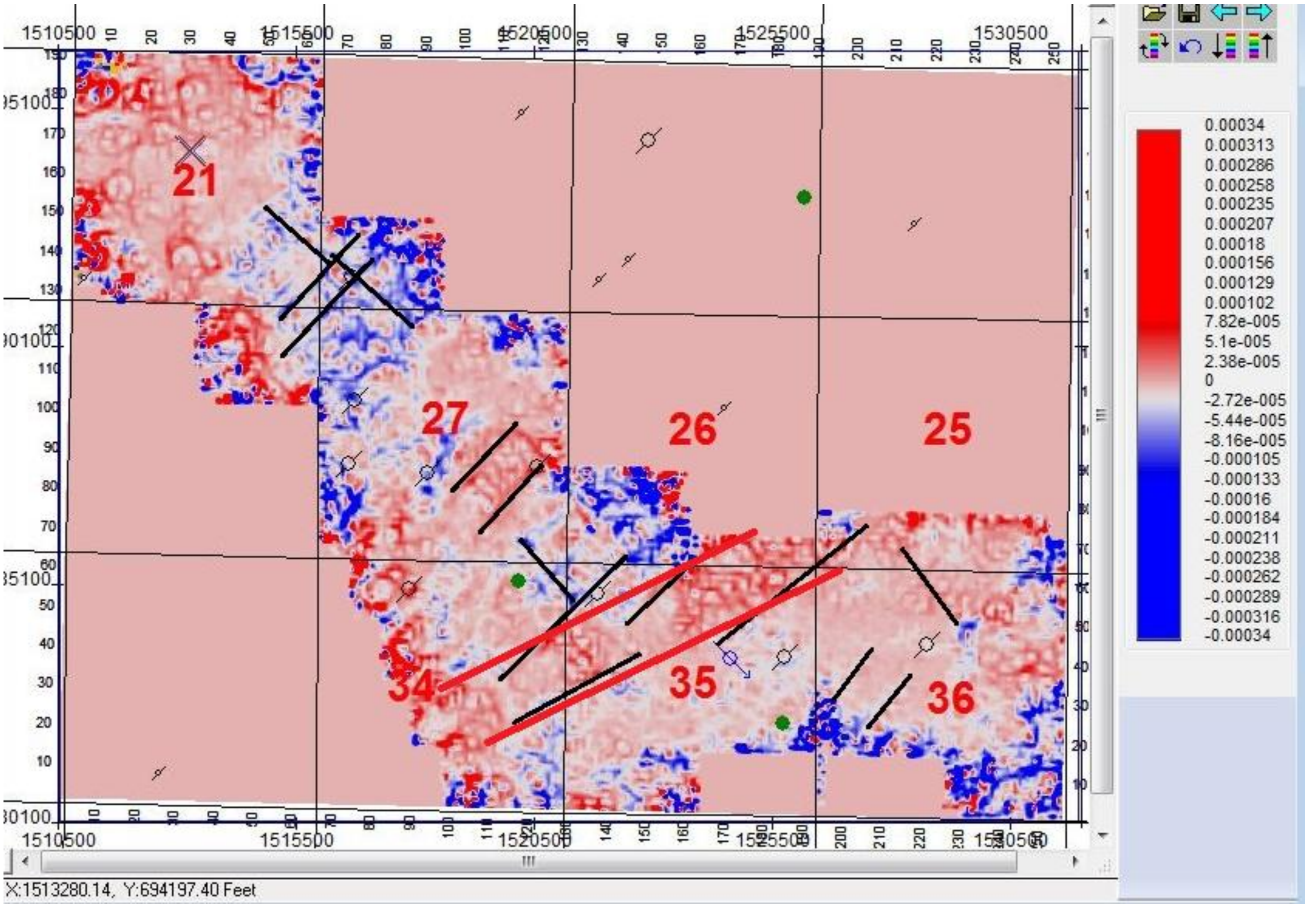


Figure 7.6 Curvature map with showing indications of major faults and karsted areas

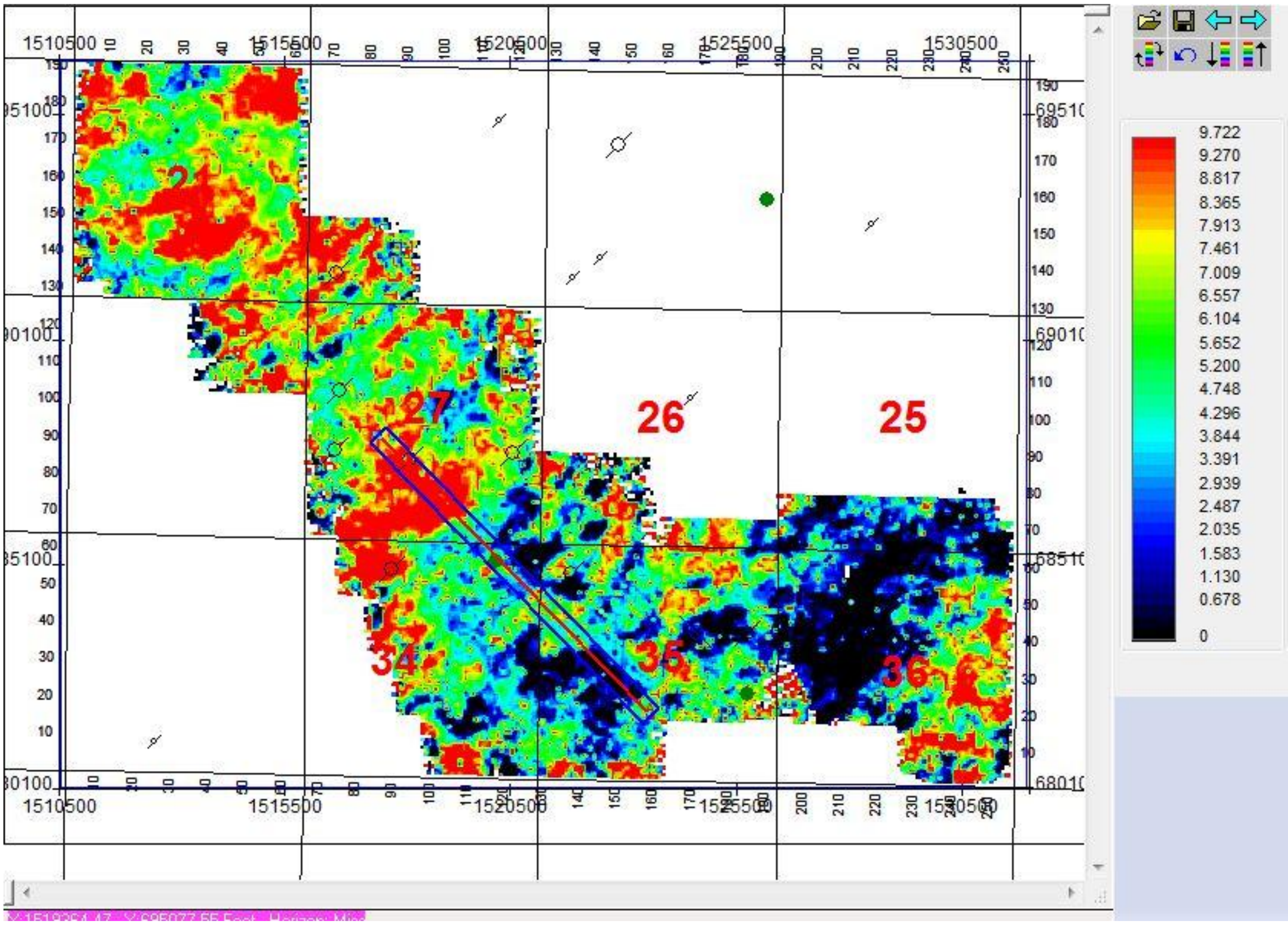


Figure 7.7 Instantaneous Q time slice 60 feet below the top of the Mississippian

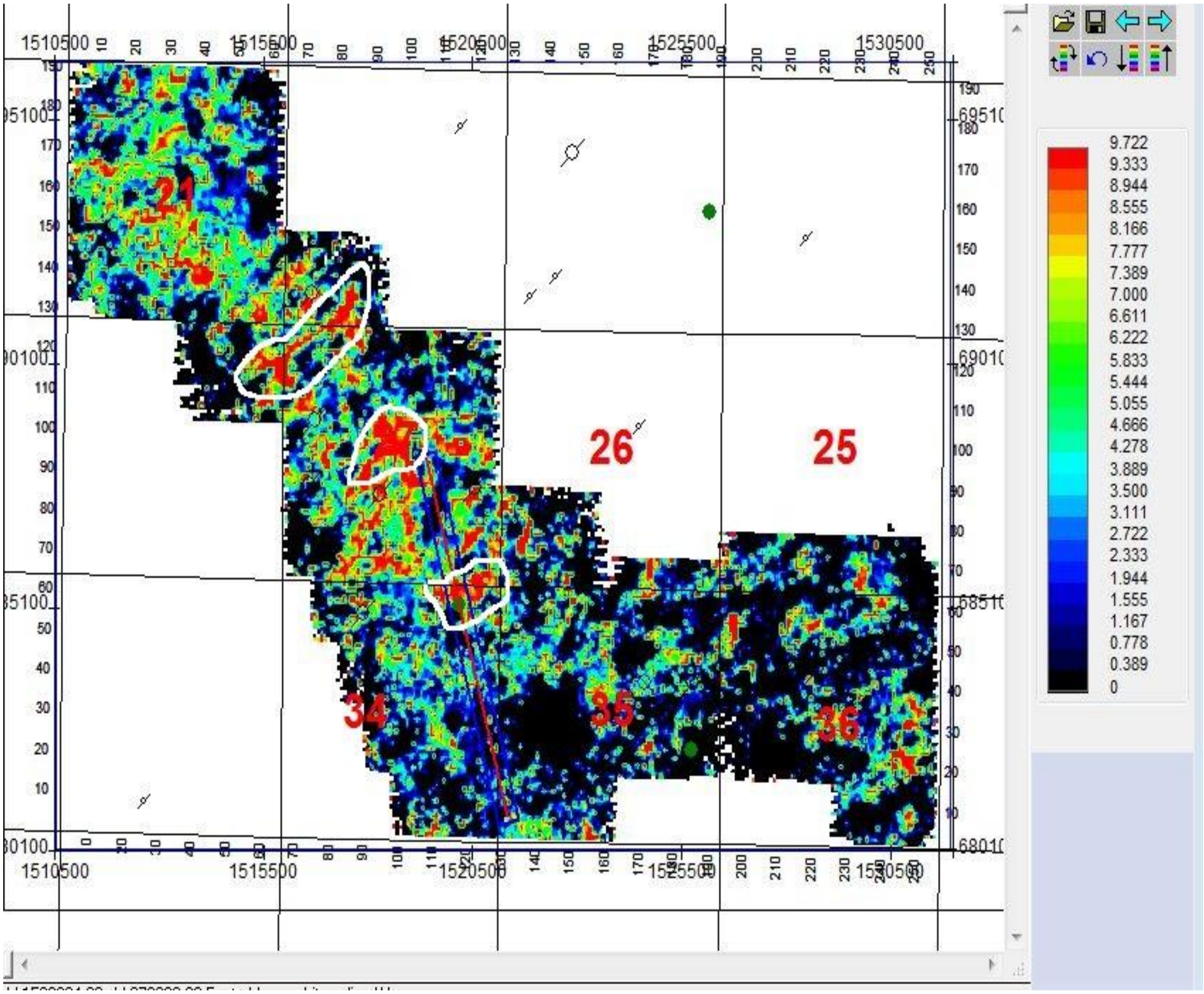


Figure 7.8 Instantaneous Q slice at the top of the Mississippian shows localized areas of high Q factor values

Chapter 8 - Conclusion

The Mississippi Lime has been an actively developing oil play in recent years. With many major fields showing rapid declines due to the decades of production, the need for exploration of new fields and enhanced recovery is important. Technological advances of seismic attributes beginning in the 1970's have provided new impactions on hydrocarbon exploration of the Mississippi Lime. Most of the large oil fields of this complex reservoir system have already been discovered. With aid from seismic data, interpreters may be able to accurately seek out smaller yet still economical producing compartments. By measuring, maneuvering, and quantifying raw seismic data, one may be able to model the subtle lithologic variances resulting from deposition, regional deformation, and diagenesis. These techniques should provide better means for drilling that those based primarily upon the structure of the Mississippian.

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