Processing and Interpretation of Illinois Basin Seismic Reflection Data

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PROCESSING AND INTERPRETATION OF ILLINOIS BASIN SEISMIC REFLECTION DATA

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

By

KATHERINE MARY GIGANDET
B.S., Wright State University 2012

2014
Wright State University
I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Katherine Mary Gigandet ENTITLED Processing and Interpretation of Illinois Basin Seismic Reflection Data BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT


An anonymous oil company released 2D dynamite reflection data from the Illinois basin to be reprocessed and interpreted by Wright State University. The aim of the project is to exhaustively apply different seismic processing methods to the data to determine if any improvement in the imaging and interpretation may be accomplished. The data interpretation procedure convolved extracted wavelets from the final migrated section with reflectivity calculated from well log data provided. Once major formation tops were identified attribute analysis was applied to locate potential oil volumes of interest.

The raw shot records from this impulse data are dominated by guided (refracted) waves. A large number of shot records show a stationary seismic source generating coherent noise at the same receiver locations throughout the survey. Rather than simply edit the affected traces I investigated methods to filter this source of noise to maintain the fold of coverage. This investigation found that several FK filters combined with iterative application of residual statics and velocity analysis was very effective in removing both the guided waves and the stationary-source waves on the raw shot records, resulting in improvement of the imaging. Radon filtering was attempted to reduce multiples and for future marine studies. Two well logs were successful in creating synthetic seismic traces within the area of the data allowing a comparison to the migrated section and identification of the bottom of New Albany, top of Maquoketa, top of
Trenton and the top of the Knox unit. AVO volume analysis of intercept and gradient revealed a type 1 anomaly at the Trenton since it has high impedance. An anomaly of interest is seen below the Trenton of unknown origin with the same characteristics. It was concluded the seismic processing provided an interpreted stack despite the noise present and a meaningful AVO attribute analysis could be performed.
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I. Introduction

A reflection seismic line from the Illinois Basin was provided by an oil company to be reprocessed and interpreted by Wright State University. Well logs were used to aid in interpretations. The seismic survey was conducted using reflection techniques with a dynamite source. Guided waves and a stationary seismic source dominated the seismic shots prompting distinct processing methods to be used on the data to enhance reflections. Knowledge of the Illinois Basin stratigraphy was utilized for interpretation along with well log analysis.

Geology of Illinois Basin

The geology of the Illinois area has a 1.5 billion yearlong history with the oldest being buried granite and rhyolite from ancient mountain building. Illinois lies within the Eastern part of the Granite-Rhyolite Province which is a complex of basement rocks extending eastward from Missouri and eastern Iowa into Canada. The boundaries of this province are shown in Figure 1 along with the Canadian Shield to the north and the Grenville Province to the south (Kolata 2010).
Figure 1: Location of geological provinces relative to Illinois (Kolata 2010).
A basin began to form in the region during the late Precambrian to Early Cambrian as a rift occurred along the southern margin of the continent. Thermal cooling and isostatic adjustments in the crust caused the rift and surrounding region to continue subsidence through the Paleozoic. There may have been a separate area of subsidence from thickness patterns in the Late Cambrian Mt. Simon Sandstone in east-central Illinois. This basin is called the Illinois Basin or Eastern Interior Basin and it is a shallow structural depression with uplift and arches around the circumference. These arches include the Wisconsin Arch, Kankakee Arch, Cincinnati Arch, Pascola Arch, Ozark Dome, and the Mississippi River Arch shown in Figure 2 relative to the basin along with the depth to the basement rock (Kolata 2010). The basin fill covering the
igneous rocks are limestone, sandstone, and shale. Coal deposits and glacier deposits are also present from ancient swamps and continental glacial advancement from the North.

Figure 3: Cross sections of the Illinois basin in two directions with structures and rock lithologies (Kolata 2010).
The regional dips along the margins to the center are low at 30ft/mi to 70ft/mi (Hohman 1998). The main basin fill is thick Paleozoic Cambrian to Mississippian carbonate dominated sections with the largest amount of deposition occurring in the Upper Ordovician. The oval depression covers 110,000 square miles and the outline is marked by the contour on top of the Ordovician Kimmswick Limestone. Figure 3 demonstrates cross sections of the basin and the components it consist of (Kolata 2010).
In the southern part of the basin the most significant structure is the New Madrid Rift System which consists of the Reelfoot Rift and Rough Creek Graben illustrated in Figure 4. Other possible structures in the region consist of anticlines, synclines, and monoclines. Most Paleozoic
sequences thicken in the New Madrid Region making them linked to the subsidence of the basin. Faults are concentrated in southern Illinois with three types: high-angle normal faults, high-angle reverse faults and strike slip (Kolata 2010). Throughout the deep carbonate-dominated basin fill only three siliciclastic layers are present: St. Peter Sandstone, Maquoketa Shale, and the New Albany/ Borden Group. Figure 5 shows these units location in the rock record (Hohman 1998).

Figure 5: Cross section of Illinois basin from West to East with time periods and three siliciclastic formations labeled (Hohman 1998).

Dolomite and limestone make up more than half of the Paleozoic rocks and sandstones make up a quarter. The rest are shale, siltstone, chert, coal and anhydrite. The sequences thicken southward towards southern Illinois, western Kentucky, and southeastern Missouri. Cambrian through Pennsylvanian sedimentary rocks can be up to 7000m thick (Mcbride 2006).
Hydrocarbon source rocks and reservoir rocks along with structure support a strong oil and gas industry.

Production of hydrocarbons began in Illinois in 1853 when two water wells produced drift gas. Commercial oil and gas production began around 1904 meaning they were produced for refinement and profitably redistributed. In 1910 Illinois was the third leading oil-producing state in the United States. The historical high in Illinois was in 1940 at 147.6 million barrels that year. Some of the largest oil fields in Illinois were discovered in that period such as the Clay City, Salem, and Louden Fields. Oil production has changed throughout the years and it is illustrated in Figure 6 (Kolata 2010).

![Figure 6: Production of Oil in Illinois Basin through the last century (Kolata 2010).](image_url)

The main source rock is the Devonian age New Albany Shale which is organic-rich and has the volume and maturity needed. Reservoir rocks are found in the Paleozoic rocks primarily the Mississippian and Pennsylvanian sandstones and Ordovician, Silurian, Devonian, and Mississippian carbonates. The shallowest reservoirs are about 200ft (61m) and the deepest are
5,400ft (1,646m) (Kolata 2010). A significant reservoir target is the Ordovician Carbonate traps which were the focus of interpretations.

**Seismic basics**

The exploration methods for oil and gas in the early 1900’s were very primitive. The equipment used for finding oil fields was: Brunton Compass, K&E stadia handbook with Jacob’s staff, a 7ft stadia rod, a bricklayer’s hammer, and a couple of matches. (Robinson 2008) These items were part of a trial and error method to find oil and gas generally with a high rate of failure. The process involved drilling wells randomly until a reservoir was discovered. The reservoir was developed by drilling until dry holes defined the margins. This method in the modern world is not cost effective, so 2D and 3D seismic imaging with well log interpretation is utilized instead to provide the desired information with better accuracy. The most common type of seismic imaging involves reflections of waves off a boundary between layers with abrupt changes of acoustical impedance to image the subsurface. The waves first propagated from the surface are very important. The two main types of wavelets sent into the ground are impulse/min phase, and a vibroseis sweep resulting in a zero phase wavelet. The sources of these wavelets can vary as well. For min phase wavelets some examples of sources are dynamite, weight drop and air-gun. For zero phase wavelets the source is a vibroseis truck. A minimum phase wavelet has all the energy at the beginning of the wave and has a varying phase. A zero phase wavelet has the maximum energy in the middle of the wave and the phase stays at zero. It is widely accepted that zero phase wavelets are easier to interpret reflection boundaries since the boundary is at the middle of the wave. Figure 7 demonstrates the two types of wavelets in terms of time, amplitude, and phase (Basic Definitions 2013).
**WAVELET ANALYSIS**

a) **MINIMUM-PHASE**

![Minimum-Phase Diagram]

b) **ZERO-PHASE**

![Zero-Phase Diagram]

Figure 7: A visual representation of the two wavelet types (Basic Definitions 2013).

The distinct characteristic of the strata that causes a reflection is a contrast in acoustic impedance. Acoustic Impedance: $Z = PV$ ($Z =$ Acoustic Impedance of material, $P =$ density, $V =$ Velocity). Without this contrast no reflection will occur and the boundary cannot be imaged.

A 2D seismic survey involves a line on the surface of geophones that record the reflections. Seismic sources release wavelets into the ground in sequence and each geophone records the shaking up to a few seconds after each shot. The recording shows two way time for the wave to propagate into the earth and back to the receivers. All shot records are not images but rather the recorded signature of the subsurface.

**Purpose and Privacy contingencies**

When the data was first released to Wright State, the providers had questions to be answered. Quite simply these were, “We just drilled a well, what did we find? Are there any points of interest in the subsurface?” The purpose of the study was to answer these questions and to find good practices to use in the future when faced with similar data characteristics. A continuing of a relationship with the company is a top priority to encourage more correspondence. Identifying potential oil reservoirs to be extracted by the company was a hope
for the research. Improving the processing was a goal along with using well log analysis to interpret the processed seismic line.

To protect all parties involved in this study, company names are omitted along with any location information of the seismic line. All location information will be limited to the Illinois Basin and the general geology of the area. To prevent release of pertinent knowledge coordinates and specific names were kept from the author. Supporting evidence which may directly indicate the locality will be referred to in general terms rather than shown specifically. Any references to previous processing not done by Wright State are also absent.
II. Methods

The acquisition portion was performed by an unidentified company for the data providers. Additional information was obtained in the form of well logs and formation tops from the Illinois Geological Survey. Wright State’s original processing efforts involved killing the traces influenced by the stationary source and then simply determining if the processing would produce viable results. The proceeding portions of the research were performed by the author. Procedures commenced with a general processing flow followed by FK filtering and rounds of residual statics. Once processing efforts were exhausted on Promax, the data was transferred to Hampson Russell for Radon filtering and AVO analysis. Well logs were found and digitized to help interpret the seismic line. Synthetics were created from wavelets extracted from the data and well logs, to create a tie to the seismic line for identification of formation horizons. Last the finished stacked seismic line was analyzed along with the AVO analysis results to answer the oil company’s queries.

Acquisition

The seismic reflection data was acquired for the oil company by a professional acquisition company. Its purpose was to help the oil company with their drilling practices. The 2D data were collected with dynamite as the seismic source and a 240 channel recording system. The sources were 240 gram charges (0.5lb) and the shot holes had a depth of 8ft. The recording devices were 10Hz land geophones manufactured by OYO. The receiver array was 3 geophones over 15ft making the interval to be 7.5ft. Precisely 239 shots were detonated and recorded using the devices. The data were acquired by shooting through the stationary receiver spread. The sample rate was 2ms and there are 1501 samples per trace making the recording time 3 seconds. The receiver and source interval is 55ft with the first live station 2101 and last
live station 2303. The dominant frequency is approximately 25Hz. Data was received with observer notes and geometry. The data were collected with a 24 bit dynamic range. The geometry of the line is a straight line with very little elevation changes along it. No information was given in the acquisition notes to point to the cause of the outside seismic source disrupting the shots. Guided waves and ground roll at the same velocity as airblast are apparent on the raw shots from the source type.

**Processing Software and Flow**

The data were given in the SEGY format. It was originally processed and viewed on Promax since it supplies a user interface with flows which can be altered easily. Guided (surface) waves are problematic in the raw shots as is a stationary noise source of unknown origin. As the shot point progresses towards the stationary source the stationary source interference is less. Guided waves and groundroll created by the dynamite source are also apparent and initiated concern for processing. After the data were obtained from the oil company, processing was started on Promax, with the goal of improving the image by reducing the guided waves and stationary seismic source noise. To achieve this, FK filtering and residual statics were administered with a velocity analysis. Velocity analysis involved constant velocity stacks compared to the Velocity Analysis processor since there are no clear reflections in the raw data making this method inaccurate. The filtering was done to maximize the fold instead of killing effected traces in hopes of improving the image and to show the noise can be affectively processed without it being removed by deleting entire traces. The increased fold will improve AVO analysis by increasing the offsets. Previous processing by Wright State killed the affected traces in an attempt to show an initial improvement in the processing. This was seen as too drastic and large amounts of data were lost drastically reducing the fold of coverage. An
Automatic Gain Control processor was applied instead of True Amplitude Recovery when testing of both proved AGC provided increased enhancement of reflections.

Deconvolution was an option to add in the flow. If added before stacking it will attenuate short-period multiples which is not a large problem on this land data. If applied after stacking the data, it could tamper with the relative improved data (Gadallah 1994). The use of deconvolution on similar data to increase resolution resulted in a degradation of quality (Bressler 2001). Some events were lost in the seismic section and amplitude reductions occurred. For these reasons deconvolution was not used to improve the processing efforts. A migration was applied to the stacked section to mainly collapse diffractions and a phase rotation as well to change the phase from minimum to normal to produce concise reflectors more easily interpreted. The basic flow procedures on Promax in order of processors performed were as follows:

- Inline Geom Header Load
- Apply Elevation Statics
- Trace Kill
- Trace Mute
- Automatic Gain Control
- Inline Sort
- Constant Velocity Stacks
- NMO Correction
- CDP/Ensemble Stack
- Max Power Autostatics
- Apply Residual Statics
- Memory Stolt F-K Migration
Phase Rotation

The first round of processing omitted the FK filtering to provide a first look at the stacked section. Then FK filtering was added to the processors before the velocity stacks and it was determined it needed to account for the side of the shot point the filter was applied, reducing artifacts created by the filter. Five iterations of residual statics were applied to the data to improve coherency of the reflectors and improve filtering and NMO corrections. The data was then transferred to Hampson Russell software without a CDP Stack and migration to perform a Radon Filter to find effects of possible multiples suppression. With the filter applied, a super gather and stack were performed on the Hampson Russell software to compare to the final stacked line on Promax. Last an AVO analysis was performed with the software and was interpreted.

Well Selection and Interpretation

Multiple wells were considered to interpret the final stacked data. The limiting factor geographically was the wells needed to be within the same county as the line. Certain characteristics such as depth, type of logs available, point of interest, and year of scan were examined when selecting the desired logs. Depth and presence of a sonic log were the most critical factors when determining the use of a well. Depths of less than 4000ft were not thought as deep enough to show the targets of interest. One well log already digitized was used for early interpretations by making a synthetic from a Ricker wavelet. Three other well logs were digitized using Neurolog with one serving the purpose for picking formation tops only and the other two for picks and creating a synthetic seismic.

Although three of the digitized wells came with well top picks by the provider they were only used as a reference. The digitized well logs were then displayed on Hampson-Russell software to allow viewing and picks. Research of the different formations present and examples
of interpreted well logs gave the strongest evidence for the picks. To tie the wells to the seismic line three wavelets were extracted on Promax from the final stacked data at different time intervals and transferred to Hampson Russell. To extract the wavelet the Promax processor Derive Average Wavelet was used and when a spectral plot was displayed the wavelet was not saved. Therefore when extracting the wavelet the processor was used once to see the plot and another to save it under the file name ‘wavelet’ with the times it was extracted from in parenthesis. Next it was outputted as a SEG-Y to be transferred to Hampson Russell. The synthetic and the true seismic were observed and correlated to allow horizons to be picked.

**AVO**

Unstacked seismic data which included all processors except stack and migration was transferred to the Hampson-Russell GeoView software for AVO analysis. The CGG website offered an AVO Guide used in the procedure (CGG Veritas 2006). AVO shows anomalies of amplitude versus offset which can be indicative of oil reservoirs and lead to characterization of those reservoirs. After the data was loaded and displayed on the program a Radon Filter or Invest Filter was applied to decrease multiples. Then a Super Gather was done and then a stack, this was compared to the stacked section on Promax. From the Super Gather an AVO Volume was created with the attributes gradient and intercept. Well 2 was used to create the AVO analysis since velocities needed to be put in the processor along with density. To compute the density from the logs available the density transform S-wave Castana’s was used.
III. Processing

The processing portion of this research was accomplished on Promax and involved several steps. The Promax software uses the Solaris operating system. The data was given as a standard fixed trace length SEG-Y with a tape management system. The storage used was disk image and the maximum data block size is 65535. Prior to the processing performed by the author preliminary processing was performed by Wright State with trace kills on all channels affected by the outside seismic source. This is a brute-force way of processing this data since it severely cuts down on the fold of coverage. The result of this processing procedure is compared to the author’s method of applying FK filtering and keeping most traces to increase fold. Multiple loops of residual statics were also applied as a way to increase continuity of reflectors.

The first step when looking at the data was to perform quality control on the geometry already loaded into the data. Using the 2D Land Geometry Spreadsheet processor this was accomplished by displaying the Basemap and looking at the database. The first correction was a station which had an offset incorrectly put in. It was discovered the shot point corresponding to FFID 126 was out of place, and when investigated the skid direction was determined to be the opposite sign. This was changed and then the geometry was reloaded into the data by Inline Geom Header Load. With the geometry loaded into the data the flag showing the shot point of the FFID was centered with the wave propagation. Figure 8 shows the station geometry and numbers along with a histogram of the elevations. Figure 9 shows the Basemap of the common depth points, the fold of coverage and a histogram of elevations in an arbitrary coordinate system with a length of 3 to 4 miles.
Figure 8: Basemap of the station locations, source number and a histogram of the elevations.
Figure 9: Common depth point locations with fold of coverage in color and a histogram of elevations below.

**Rawshot Gather**

The raw data has many characteristics of a land, impulse source data set. Dynamite land data typically contains ground roll, surface waves and air blast from the energy being dissipated in different mediums. Since the acquisition was performed in a straight line the refractions are almost linear in the raw shots. The kind of noise which can be seen on reflection data is shown in Figure 10 with their approximate location and angle after a NMO correction. Figure 11 shows how noise is identified and how it looks on an example of a shot gather (Gadallah 1994).
Figure 10: Shot gather location of different wave types and noise after a normal moveout correction applied (Gadallah 1994).
In the shot gather in Figure 12 the air blast are present but are obscured by guided waves which disperse and are approximately the same velocity which dominate the gather. The high amplitude and high velocity ground roll will cause the most difficulty with processing since they totally obscure the reflections compared to the refractions and will be spatially aliased in the FK domain. When the acquisition was done it started with shots towards the middle of the line moving to the left and then from the middle to the right which is why in the raw shots the first FFID does not have a source at the first channel. It is apparent there is a stationary noise source centered on channel 203. The stationary source creates waves throughout the recording time as a stationary source opposed to the dynamite which emits a pulse of energy. As the source point moves closer to the stationary source (illustrated in Figure 13) the effects of it are
not apparent since the seismic source applied by the survey overshadows it in intensity.

Information was not given to the cause of the static source but possibilities include: farm equipment, vehicles, or machinery. Reflections can be seen on the line but are obscured enough to give concern. Two shot gathers are displayed below in Figure 12-13 with only geometry loaded.

Figure 12: Field file identifier (FFID) 23 with geometry applied. It is a good representation of the stationary seismic sources influence on the data at channel 203.
Figure 13: Field file identifier (FFID) 135 with geometry applied. Indicates the shot points influence on the interfering source and the large amounts of guided waves in the original data. As the two locations converge the dynamite source’s waves are less affected because its intensity is greater.

To show the extent of the stationary seismic sources influence a list was made in Table 1 of the FFID’s and the channels on each which were affected. The original processing performed by Wright State when the traces affected by the stationary source were killed the amount of fold was drastically diminished by this amount. This large amount of data lost can be significant to the interpretations. The loss of this amount of data was compared to processing which kept it present done by the author.
Table 1: Channels on each FFID which were affected by the stationary seismic source on the shot gathers.

<table>
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<tr>
<th>FFID</th>
<th>Channel</th>
<th>FFID</th>
<th>Channel</th>
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</tr>
</tbody>
</table>

Trace Editing

Once geometry was determined to be perfectly loaded into the data trace editing was applied. Since the author wanted to keep the fold at its peak the previous kills of affected traces
were reversed and only traces with typical noise such as 60Hz remained in the kill file. Kills also included traces recorded at near offset to the shot which were filled with ground roll and guided waves. These near offset kills might lower the amplitude of shallow reflections after filtering but may decrease noise. Mutes were also picked to zero above the first breaks and to zero the area obscured by the guided waves and ground roll. The area above the first breaks was zeroed using a top mute and was adjusted after FK filtering when it was determined the mute dug into some reflections revealed by the filter. The mute applied for the ground roll at the same velocity as airblast was a bottom mute and used the same processor as the top mute with changed parameters. Below are the results of the kills and mutes on two FFID’s in Figures 14-15. The mute picks were not originally picked by the author but checked from previous processing and adjusted after filtering.
Figure 14: FFID 23 with geometry and trace editing.

Figure 15: FFID 135 with geometry and trace editing.
Elevation Statics and Automatic Gain Control

Although the terrain was subdued throughout the line, Elevation Statics was applied to the data to correct for the small variations. The final datum elevation was chosen to be 700 and the replacement velocity was 12000. To correct for the decrease in amplitude down the record due to spherical spreading and absorption of the source wave Automatic Gain Control (AGC) was applied. The window chosen on this data was 250 ms. This shorter gate size was chosen for higher amplitude. The AGC was applied after the Elevation Statics and might be the most significant processor. Another amplitude correction was added to the flow in place of the AGC, True Amplitude Recovery, but when applied and the flow was continued, the quality of the data decreased. It was determined AGC was the best amplitude corrector. The main reason for experimenting with True Amplitude Recovery was to use it before a Radon Filter on Promax. Figures 16-17 show the effects of the Elevation Statics and AGC after the trace editing was applied. The addition of a gain control increases the appearance of deeper signal and the air blast seems to be more intense after the AGC.
Figure 16: FFID 23 with geometry, trace editing, elevation statics, and automatic gain control.

Figure 17: FFID 135 with geometry, trace editing, elevation statics and automatic gain control.
FK Filtering

To deal with the guided waves and the stationary source FK filtering was applied to the data. FK filtering involves applying a filter for the events in a FK plot by choosing a polygon to indicate the region to which they are applied. The advantage of filtering in the FK domain is that whereas in one dimension, signal and noise may overlap rendering multiplicative filtering impossible, in the two dimension they do not overlap in both the F and K. Since a dipping straight line in t-x transforms to a dipping straight line in FK, events having certain dips between two values in the t-x domain can be removed by multiplying the FK transform of the data with a transform which is zero between the corresponding dips in the FK domain and one elsewhere.

The groundroll at the airblast velocity in the data have a distinct dip and the refractions do as well making them acceptable to a dip, fan, or pie-slice filter (Hatton 1986). The type of FK Filter used was a reject for the event the polygon (pie slice) encompasses. Four polygons were chosen with two on each side of the shot point for the opposite sign wave numbers of the groundroll and refractions using the FK Analysis processor. It can be seen there is two events on each side not corresponding to reflections. Steepness in the t-x domain or large values of dt/dx corresponds to shallowness in the FK domain. Therefore the steeper air blast velocity groundroll in the shot gathers corresponds to the more horizontal FK values. Each polygon chosen was to lower the guided waves and groundroll still present on the data after trace editing, elevation statics and amplitude corrections. Figures 18 and 19 shows the four reject polygons chosen.
Figure 18: FFID 200’s FK analysis with the two FK filter polygons with a negative wavenumber.

The lower angle one is the filter which corresponds to the steep groundroll and the upper is the most disruptive refractions.
Figure 19: FFID 23’s FK analysis with the two FK filter polygons with a positive wavenumber. The lower angle one is the filter which corresponds to the steeper groundroll and the upper is the most disruptive refractions.

A FK filter artifact of diagonal interference was evident at first when the filter was applied with only the FK Filter processors in the flow for each polygon and the processing
performed up to a stack. This might have been caused by the survey being a split spread geometry and the filters not being correctly applied to the portion of the shot gather. The outside seismic source disturbance is visible as well leading to poor FK filtering procedures.

Figure 20: Stacked section after FK filtering with no contingencies as to where the filter is applied. Shows massive amount of a FK attribute with the direction from the top left to bottom right.

Therefore the flow control IF and END IF was added. For the right filters that needed to be applied to the right of the shot point the following flow control was applied.

IF Include

FFID number

Signed S-R offset

2-300:1-20000/
Then the two FK filters processors to the right of the shot.

END IF

The filters on the left of the shot point were applied by:

IF Include

   FFID number

   Signed S-R offset

   2-300:1—20000/

Then the two FK filters processors to the left of the shot.

END IF

This made sure the correct polygon filter was applied on the correct side of the shot point and lowered the attribute observed from the FK filtering process. Figures 21-23 is the individual shot gathers after the filtering which shows decreased guided waves and groundroll.

Figure 21: FFID 23 with geometry, trace editing, elevation statics, automatic gain control and FK filtering.
Figure 22: FFID 135 with geometry, trace editing, elevation statics, automatic gain control and FK filtering.
Figure 23: FFID 200 with geometry, trace editing, elevation statics, automatic gain control and FK filtering.

It can be seen in all three shot gathers the refractions which had a higher slope were diminished the most, with the remaining amount of groundroll at airblast velocity lessened but not to the same degree. The filters chosen did affect the stationary seismic sources interference after the flow control but it still had some influence on the shot gather. A CDP Sort was performed so the following processors could be performed creating a gather of common depth points.

**Velocity Analysis and NMO Correction**

Once the geometry, Elevation Statics, trace editing, AGC, FK Filter, and CDP Sort were applied the next step for this data was to correct the hyperbolic move out of the primary reflections so when stacking is done each trace for one CDP will be set to zero offset and have
the highest amplitude. To choose the velocities and time zero to perform the correction, the Constant Velocity Stack processor was applied. The velocity intervals for the stack were chosen to be varied since this would give a good first look at the velocities. The Constant Velocity Stack was used since the noise still in the data would be attenuated and a Velocity Analysis processor with a velocity spectrum would not be appropriate since most reflections would not be detected in the semblance. The results of the first velocity stack had picks which were much lower than appropriate. Then previous picks by Wright State were viewed influencing higher velocities to be chosen. These picks were zero offset velocities pairs with the time and velocity: 0-12250, 400-12195, 450-13855, and 700-15648 at ms and ft/s. After many rounds of statics the final velocities were: 150-9000, 350-10915, 400-14624, 500-15321, and 700-16816. These were placed in the NMO Correction processor and a stack was made.

Residual Statics

To make the processing more robust residual statics was applied using Max Power Autostatics and the Residual Statics processor. A horizon was picked from the stacked NMO corrected data at around 700ms where the most coherent reflector appeared and was put into the Max Power Autostatics processor along with the unstacked data. The stacked gather below in Figure 24 shows the results of one round of statics with a Stolt FK migration and phase rotation. The phase rotation applied was a change of 90° to transfer the minimum wavelet to zero phase to increase the success of interpretation. Multiple migrations were applied to find the one which would enhance the data. Memory Stolf F-K migration was determined to give the best result with the lowest run time. The single round of statics stack, Figure 24, is not effective at imaging shallow reflectors. The coherency of some reflectors was low such as at 500ms where the reflector disappears towards the middle of the line and seems to converge with the
reflector above. There is an anticlinal dip throughout not caused by true structure and the static
source point can be seen but it does not appear to harm the reflections below.

Figure 24: The processed stacked section with FK filtering, velocity analysis, residual statics,
migration, and phase rotation.
Figure 25: Processed stacked section with 5 loops of velocity analysis, residual statics, and FK filtering. A migration and phase rotation has also been applied.
Figure 26: Final stacked section with multiple rounds of statics and fold given in the header.

After five iterations of residual statics the reflector at 450ms is more coherent and separated from the prominent reflectors above and below it. The shallow reflections are better resolved and became easier to distinguish. The reflections seem to extend farther to the lower fold edges. The times between 500 and 700 seem to still have a loss of reflections toward the middle of the gather. The decrease in the coherency of the shallow reflections may be caused by the noise or loss of close offsets by the kills made to decrease noise. There is now a synclinal form compared to the single residual statics stack caused by processing. This shift may be caused by a better static solution after multiple loops. In Figure 4 a syncline is shown to be close to the survey location but is not imaged since the dipping shown is not true structure since it centers on the middle. The intermediate loops are displayed in the appendix.
The processing performed by the author with the kills of the traces affected by the stationary seismic source no longer in place is compared to the processing with those kills done by Wright State University. The processing done with the kills of traces affected by the stationary seismic source contained three FK filters with a velocity correction and statics. The stack produced has a loss of data where the static source is and has definite lower amplitudes. The coherency of the reflections is well across the section with very little of them converging. It has the anticlinal form like the stack in Figure 24 from similar processing.

Figure 27: Stacked data of processing done by Wright State with all of the same processing types as the author but with the traces influenced by the stationary source killed.

When comparing all three stacked data sets the one with the kills applied to the portion of the data affected by the stationary seismic source had the least noise and most coherent reflections. It has more reflections imaged and resolution seems to be better. The traces with the affected data kept, the section has more incoherent reflections but with higher amplitudes.
The use of traces affected by the stationary noise does not necessarily improve the image but maintains the data’s signature and has reflections which can be interpreted. For AVO analysis the greater fold data is the one which would be used. Of the two stacks with the data kept the one with more loops has a better appearance of important reflectors and coherency. Although the stack with the kills appears to be the most coherent it can be concluded a usable stack can be created with those traces intact. This will help in analyzing far offset traces in the AVO exercise.

Radon Filter

Radon filtering was done on Hampson Russell from the data transferred from Promax with all the previous processors except migration and stack. The filter on Promax requires velocity picks and is a potential source of error. In the Hampson Russell software Radon Filter has the name Invest. The Invest Quick Guide downloaded from the CGG Veritas website was very helpful in finding the right input for the variables (Fernandez 2008). The object of the filter was to attenuate multiples and suppress noise. The technique is to model multiples and subtract them from the input seismic trace data and the filter is applied to pass the primary energy.

There are two actions which can be done: Multiple Suppression and Noise Reduction. Multiple Suppressions eliminates coherent noise and enhances traces through radon transforms and Noise Reduction eliminates random noise. Two main outputs can be displayed: Primary, and Model. The Primary is the results of the filter and the model is the removed noise. In the modeling parameters the frequency range is chosen. This must remain large to encompass all the frequencies but not too large to increase run-time to be inappropriate. The delta T sets the range of parabolas since it is the time difference in milliseconds from near trace to far at a specified offset. For the span of the delta T range the number of curves must be chosen as well. With the modeling type, parabolic must be placed when a pre-stack is undergoing the filter.
Linear is for attenuating noise on post-stack data. The noise reduction has only one parameter which needs to be adjusted. This is the Noise to signal ratio which controls the strength of algorithm. A smaller number means a stronger noise reduction. Figure 28 shows what the parameter window for a radon filter in Hampson Russell.

![Image of parameter window for a Radon Transform](image)

Figure 28: Parameter window of a Radon Transform (Fernandez 2008).
Both a multiple suppression and noise reduction was done with a model being displayed. The parameters chosen after experiments of different variables are:

**Modeling Parameters**

Low Frequency= 0

High Frequency=100

Low delta-T=-10

High delta-T=50

Offset=8497

Number of curves=20

Parabolic (since not stacked)

**Multiple Suppression parameters**

From low Delta-T=30

To high Delta-T=50

**Noise Reduction parameter**

Noise/signal ratio=0.01
Figure 29: The CDP gathers before the radon transform.
The sorted data is displayed before and after the Radon Filter in Figure 29-30. The data after the Radon Transform has more linear reflections and it was observed the middle CDP’s were still left with noise and the lower fold CDP’s benefited the most. To increase the coherency of the reflectors a Super Gather was done after to bring higher amplitudes with the following parameters:

Type=mean stacked

Rolling window set at 5

Number of offsets set to 10
The result of the Super Gather increased coherency of the reflectors but the more shallow reflectors seem to have loss of intensity and appear weak. Finally a stack was done to be compared to the ones produced on Promax. The stacked data in Figure 32 displays reflections but they are very faint, especially shallow reflections. This data did not have the static sourced waves killed, possibly causing the lost in coherency after the stack in Hampson and Russell.
Stacking the data without the Radon Transform and without the super stack decreased the coherency of the reflectors resulting in poor visualization. The processing applied to the data on Promax before transferring to Hampson Russell possibly contributed to the poor stacking results. The stationary seismic source might have played a role in the appearance since the stacking processor on Promax was the main component to its attenuation and the Hampson and Russell software did not accomplish this as well. This might explain why the shallow reflections were affected the most since they would have the most noise from that source. The low quality of shallow reflections could be caused by the CDP spacing not being close enough decreasing coherency. Some processing diagonal attributes from FK filtering have also made their way into the stack.
IV.  Well Logs

Four well logs were examined in this research with different sources and purposes. The first one was useful for preliminary results since it gave the parts necessary to make a synthetic to compare to the true stacked data. Three others gave enough detail to pick formation tops and to create synthetics which could be tied to the seismic line aiding in the interpretations of stratigraphic units. To make these picks in the well log lithologies and thicknesses were investigated.

Stratigraphic Setting

The main basin fill of the Illinois Basin is carbonates with intermittent shale. Beds of siltstone, sandstone, limestone, and dolostone are also present but are limited in extent and thickness. Throughout the deep carbonate-dominated basin fill only three siliciclastic layers are present: St. Peter Sandstone, Maquoketa Shale, and the New Albany/ Borden Group. The New Albany Group is the shallowest of the three and is a very dark, gray to black, brittle, highly fissile, siliceous or finely silty shale. There is very thin sandstone or sandy zone at the base of the Albany and it has an average of 55ft in thickness (Nelson 1995). The New Albany reaches more than 90m in thickness with less than 30m thickness at the Illinois Basin edges. The layer is enriched in trace metals especially towards the top. New Albany has five members (from youngest to oldest): Clegg Creek, Camp Run, Morgan Trail, Selmier, Blocher. These members have different names depending on the location of the group. The most useful information when picking this group’s horizons is the interpreted well log in Figure 33(Cluff 1981). The gamma has distinguishable boundaries which can be compared to the well logs used in the
interpretation of the stack.

Figure 33: Interpreted well log of the New Albany Shale and adjacent rock units (Cluff 1981).

The next siliciclastic is the Maquoketa Shale which was named by White (1870) for outcrops near Maquoketa Iowa where the unit consist of shale with interbeds of limestone. It is classified as a formation and is divided into 4 members in most areas (listed from oldest to youngest): Cape la Croix shale, Thebes Sandstone, Orchard creek shale, and Girardeau limestone (Nelson 1995). In Illinois it is a group and in the seismic lines vicinity it has three members: Brainard Shale, Fort Atkinson Limestone, Scales Shale (Hohman 1998). The Kope formation in Ohio is equivalent to Scales Shale member. The Maquoketa corresponds to the Point Pleasant formation to the east of the basin and the Utica Shale which has gotten attention lately for its production of natural gas. There is an unconformity above the formation recognized by a sharp scoured surface that caps a dolomite zone as much as 20 feet thick. The formation has an
average thickness around 140-200 feet and can be 300 feet thick (Hohman 1998). An interpreted well log was found for the Maquoketa, Trenton and Black River shown in Figure 34. It can be seen that the Maquoketa is surrounded by lower gamma layers and is a higher gamma shale which is a good indicator of its location.

Figure 34: Interpreted well log of Maquoketa, Trenton and Black River in multiple locations (Hohman 1998).

Table 2 shows the sequence of units between the New Albany Shale and Maquoketa Shale.

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Devonian
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</tr>
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</tr>
<tr>
<td>Bain bridge</td>
<td></td>
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<tr>
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<td>Leemon</td>
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<tr>
<td>Maquoketa</td>
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</table>

Table 2: Positions of formations between New Albany and Maquoketa with their time divisions (Nelson 1995).

Below Maquoketa is the Trenton formation which is a pure carbonate package. There is dolomitization in the top of the Trenton which is 20 feet thick. Between the Maquoketa and Trenton formations there was noted a sharp, irregular contact with abundant mineralization by Rooney (1966). The unconformity between the two has many causes investigated such as subaerial exposure. The contact between is characterized by pervasive pyrite and phosphate mineralization developed along a very pronounced hard ground. The Trenton formation or Galena Platform corresponds to the Lexington Platform to the east. The Sebree Trough separates these two platforms and is filled with the Maquoketa Shale package (Hohman 1998). Figure 35 shows how the Sebree Trough separates the Lexington Platform and the Galena. Across the cross-section line in the Figure 37 the Trenton package can be related to the Kimmswick Limestone to the west and the Curdsville Lexington to the east. Below the Trenton is
the Black River and it relates to the Decorah Group to the west and the High bridge/Black River to the east. Decorah upper is a highly fossiliferous carbonate.

Below the Trenton the next unit of interest is the Knox Group. Figure 36 shows the stratigraphy between the two. Above the Knox is a carbonate layer called the Joachim and a sandstone called the St. Peter Sandstone. The name Knox group is applied to the thick succession of Upper Cambrian and Lower Ordovician carbonate rocks overlying St. Simon Sandstone in the southern part of Illinois. The Knox Group can be 6,500ft thick. The main formations in the Devonian, Silurian and Ordovician are shown in the Figure 36 (Nelson 1995).

Figure 35: Cross section of the Illinois Basin showing the Sebree Trough and the Galena and Lexington platforms (Hohman 1998).
**Figure 36: Stratigraphic column of the Ordovician (Nelson 1995).**
Figure 37: Formations and rock types during the same time across states (Hohman 1998).
To help connect the names of the formations across states from the Silurian to the Upper Ordovician Figure 37 shows comparable stratigraphic columns from Missouri to Ohio (Hohman1998).

Well Interpretation

Once the stratigraphy was identified and well logs digitized they were displayed on Hampson Russell software to be interpreted for formation tops. Logs have the approximate data given with them: resistivity, spontaneous potential, gamma, bulk density, and internal transit time (sonic velocity). Porosity, fluid composition and relative saturation are the two primary parameters determined from well log measurement. There are three general log types: electrical, nuclear, and acoustic/sonic. Gamma ray logs measure the amount of radioactive materials present in the rocks. Since there is a strong correlation between the gamma levels and rock types, lithologies can be inferred. Shaley rocks are highly radioactive as opposed to sandstones with a weak radioactivity. Clay-free sandstones and carbonates are the lowest gamma ray readings. The element source of the radioactivity can also be hypothesized. High gamma content at 60 means Potassium is the source in the shale. A high of 100 means uranium rich shale (Doveton 2013).

Resistivity levels can reveal lithologies because a high resistivity is generally indicative of a limestone and a low resistivity is shale. When interpreting a stacked seismic line a synthetic seismogram is created from the well log but two logs need to be present. These two are a sonic log because velocities need to be known and a density log or a comparable log type. From these two an approximate acoustical impedance log is calculated and when a source wavelet and frequency are chosen a synthetic seismic line can be compared to the real data and horizon locations found. Three of the well logs were accompanied by interpreted well tops by the provider. These were used as a reference to establish best places to place the authors picks.
Well 1 had well tops as followed in feet:

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casper</td>
<td>942</td>
</tr>
<tr>
<td>New Albany</td>
<td>1160</td>
</tr>
<tr>
<td>Devonian</td>
<td>1284</td>
</tr>
<tr>
<td>Bailey</td>
<td>1819</td>
</tr>
<tr>
<td>Niagaran</td>
<td>1918</td>
</tr>
<tr>
<td>Maquoketa</td>
<td>2230</td>
</tr>
<tr>
<td>Trenton</td>
<td>2350</td>
</tr>
<tr>
<td>Plattin</td>
<td>2525</td>
</tr>
<tr>
<td>Total Depth</td>
<td>2575</td>
</tr>
</tbody>
</table>

Well 2 had well tops as followed in feet:

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Genevieve</td>
<td>1309</td>
</tr>
<tr>
<td>New Albany</td>
<td>2474</td>
</tr>
<tr>
<td>Grand Tower</td>
<td>2685</td>
</tr>
<tr>
<td>Trenton</td>
<td>3792</td>
</tr>
<tr>
<td>Joachim</td>
<td>4392</td>
</tr>
<tr>
<td>St. Peter</td>
<td>4500</td>
</tr>
<tr>
<td>Knox</td>
<td>4748</td>
</tr>
<tr>
<td>Total Depth</td>
<td>4915</td>
</tr>
</tbody>
</table>

Well 3 had well tops as followed in feet:

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Genevieve</td>
<td>1194</td>
</tr>
<tr>
<td>St. Louis</td>
<td>1284</td>
</tr>
<tr>
<td>Salem</td>
<td>1603</td>
</tr>
<tr>
<td>New Albany</td>
<td>2311</td>
</tr>
</tbody>
</table>
Devonian 2435
Geneva 2526
Joachim 4181
St. Peter 4283
Knox 4332
Total Depth 4760

Figure 38: Well 1 with Gamma, Lateral_1, Neutron Porosity, caliper, spontaneous potential, and induction medium.

The above figure is a log digitized and was used as a starting point for the horizon picks of the formations since it lacked a sonic log and has less depth. The New Albany horizon was chosen to be the shallowest higher portion of gamma ray and spontaneous potential. This is also where it was placed by the drillers. The Niagaran formation is above the Maquoketa and it is not
clear what its lithology is but was displayed based on the driller logs. The Maquoketa is shale and the boundary was debated since at the time of these picks the exact top of the Maquoketa could not be determined but it was assumed it would have a dip in the top and the bottom in the gamma log with a peak in between. At the time this was confirmed by the driller’s log. The confidently picked formation was the Trenton since it has a distinct drop in gamma, porosity, and spontaneous potential. The bottom of the formation had the distinct peak of the Black River in the gamma log. This entire well was suspicious because the depths do not seem deep enough for the formations when the velocities of prominent reflectors from the seismic line were compared by looking at the time they occurred. It may not be the area it was assigned from the source. It did serve as a good exercise in the clues needed to identify formations in the next logs.

Figure 39: Well 1 with horizon picks.
Figure 40: Well 2 gamma, Neutron Porosity, P-wave velocity and computed accoustical impedance and reflectivity.

Well 2 has all the components needed to accomplish a majority of the formation picks and create a synthetic with little anticipation of error. The top formation picked was the New Albany and its location involved using the interpreted well log in Figure 33 and the average thickness. Since it is a shale deposit a high gamma signature was looked for. This left two options: around 2500 or below 3500. Since New Albany is a source rock, Figure 33 shows it having a high uranium at 100 and it can be then be connected the shale contains uranium. Also in Figure 33 there is a dip of gamma on the upper portion and then a peak before the top. At 2500 ft there is the higher gamma signature and a dip on top before a brief peak. Above that sharp peak is a potassium rich shale which corresponds to the Springville Shale. Therefore the last large peak on at 2500ft was chosen as the top of the New Albany and the bottom before the gamma goes to zero with the Lingle formation. This pick corresponds to the correct thickness of the New Albany at 130ft.
The Maquoketa also is a shale formation with a layer in the middle with more limestone in it. In Figure 34 it has a high gamma at about 60 which shows there being potassium as the source. It has limestone layers above and below making the boundaries where the levels drop. The thickness of the maquoketa matchs the picked boundaries at 3500 to 3750 feet since the avarage is at 140-200feet and it can reach 300 making the 250ft possible. The slight dip between in gamma could be caused by the limstone layer in the formation.

The Trenton is between Maquoketa and Black River. It is a true limestone layer making the gamma low and resistivity high. The Black River top is shown by a peak across all the logs caused by its bentolites present. This was also discussed with member of the Ohio Department of Natural resources. The Joachim and St. Peter formation tops mainly came from the well tops given with the log and were shown more to compare to well 3 which gives more of an indication of their locations.

The Knox formation is a dolomite with a higher velocity and higher porosity compared to the limestone of the Trenton and shale of the Maquoketa. This puts it on the bottom portion of the log where the accoustical impedence increases with the gamma. This corresponds to the driller’s top.
Figure 41: Well 2 horizon picks.
Figure 42: Well 3 logs with gamma, Neutron Porosity, caliper, spontaneous potential, p-wave velocity, and calculated acoustical imprudence and reflectivity.

Well 3 follows the same patterns as well 2 but has the addition of a spontaneous potential log which adds to the identification of the Joachim and St. Peter formation picks. St. Peter has the lower velocity and spontaneous potential since it is a sandstone and the units Joachim and Knox below are carbonates. The top of Joachim was found by the beginning of the erratic behavior of the log since it is a dolomite limestone layer which alternates.
Figure 43: Well 3 with horizon picks.

To check the picks the dip was approximated from differences of the depth of the tops of the Maquoketa in well 2 and well 3 and also the distance of the two wells. The top of the Maquoketa in well 2 was found to be 3500 ft and well 3 3280 ft. This leaves a 220 ft difference and it was determined the wells were 4.733 km apart. From these measurements the dip was found to be 46.4821466 ft/km which translates to 74.8 ft/mi. The dips given by “Depositional History of the Upper Ordovician” put it at 30 ft/mi to 70 ft/mi (Hohman 1998). Since the dip found is within an acceptable value the difference in depths between the logs seem reasonable.
Figure 44: Well 4 with gamma, density, p-wave velocity, reflectivity, lateral_1, and acoustical impedance.

When processing the data the well log above called Well 4 was used as a template for early interpretations. The depths seem to be similar to well 1 possibly making the location it came from the same. The New Albany, Maquoketa and Trenton are easily identified on it based on the picks from wells 2 and 3. This log contains both velocity and density which were used to make a synthetic before processing was complete. This was before a wavelet was extracted so a Ricker wavelet was used.

Wavelet Extraction and Synthetic

Well 4 was analyzed in Hampson-Russell to produce a synthetic. A normal phase Ricker wavelet and a frequency range with a dominate 25Hz was used to create the synthetic. The 25Hz was used since spectral analysis of the data showed it to be the dominant frequency. This well log and synthetic serves as an introduction to the general stratigraphic formations and the
possible reflector identification seen in the seismic data. The frequency content chosen and the wavelet are displayed in Figure 45.

Figure 45: Frequency content and Ricker wavelet used for synthetic in Well 4.
When the synthetic created with this log was compared to the stacked data the reflectors at 1750 and 1900ms were interpreted as being the Maquoketa and Trenton with the multiple bright reflections before starting at 2500 being the Knox. This is because in Figure 24 at time 450 and 550ms there are two strong reflectors which were thought to be the Maquoketa and Trenton. In later interpretations this would prove to be correct but the relation to the log was wrong since in well 2 and 3 picks put the top of the Maquoketa where the Knox is placed in Well 4.

To create better synthetics using well 2 and well 3, which have the best formation ties, three wavelets were extracted from the data at different time intervals. This number of wavelets was determined so there is one for each group of reflectors. They were extracted using Promax from the final stacked migrated data using the processor Derive Average Wavelet. When a spectral plot was made the software failed to save the wavelet. This means the processor first
needed to be ran with a spectral plot to check the result and then ran without to save the
wavelet as a dataset. The SEG-Y output processor then needed to be used to view the wavelet
and transferred to Hampson and Russell so they could be used to make synthetics. The three
wavelets were taken at these times:

- 100-500ms
- 400-1000ms
- 800-1800ms

They overlap times so none of the data was left out. The wavelets and frequencies content are
displayed in Figure 47-48. Each wavelet shows slight difference from the others with the time
400-1000 having the highest amplitudes of the side lobes and 800-1800 having the least.
Figure 47: Wavelets extracted from final stacked data at three time intervals for synthetics.
The frequency ranges varied slightly as well with the 100-500ms wavelet having the largest range. All three had peaks close to 25Hz which is why the preliminary Ricker wavelet was created with this dominant frequency. The 800-1800ms wavelet had a low peak frequency since there was attenuation deeper in the gather.
Figure 48: Frequency spectrum extracted from final stacked data from three time intervals.
The digitized logs from Wells 2 and 3 with sonic logs were used to make synthetics from the extracted wavelets and create acoustic logs. Each synthetic created in well 2 and 3 from each time interval shows slight differences in amplitudes and the spacing. Overall all of the times give the same amount of reflectors and the reflectors in one show up in the others at the same locations. The tops of New Albany, Joachim and St. Peter do not have reflectors in the synthetics. The Knox reflector matches up with the formation pick in well 3. Well 3 was used to choose horizons on the stacked data because it had more positive picks and matching of reflectors with those picks. The approximate times on the right of the well logs match with the placing of formation horizons chosen in preliminary processing from the well log given by the oil company.

Figure 49: Well 2 log with three synthetics and formation picks.
Figure 50: Well 3 log with three synthetics and formation picks.

**Tie to Seismic**

The synthetics and processed seismic line were viewed side by side. It can be seen in the screen shot below the succession and pattern of reflectors match with slight differences. The more shallow reflectors seem to have been compressed together in the real seismic data compared to the synthetic. The polarities of the synthetics had to be reversed to match the polarity of the real data.
Figure 51: Real data and synthetic side by side to identify horizons.

Only four of the horizons are distinctly seen in the seismic line. This is because the real data resolution is not equal to the synthetic. The bottom of New Albany has a positive polarity and is easily identified since it appears in the synthetic as having two peaks about the same separation as the true data. The top of the formation is not so clear cut since in the synthetic there is two negative polarity peaks but not in the real data.

The top of the Maquoketa formation is a negative polarity reflector and has a strong positive polarity reflection above. In the real data there appears to be a positive reflector in the middle of the Maquoketa not present in the synthetic. This reflector might correspond to the limestone layer in the formation. The bottom of the Maquoketa and the Top of the Trenton is imaged as the third reflector in the series and does not have much coherency in the overall stack. Last the Knox is matched up to be the strong reflectors starting close to 700ms with positive polarity.
Figure 52: Final stacked section with the bottom of New Albany, top of Maquoketa, Trenton and Knox labeled.
V. AVO

An AVO (amplitude versus offset) analysis was performed on the data since amplitude characteristics of reflections in stacked images can indicate locations of hydrocarbon traps. Since when an AVO volume is made it stacks the data, the processing flows before on Promax does not have stack or migration applied. Shortly before the AVO volume was made a Radon filter was done and power stack to increase the strength of reflectors and diminish multiples. Amplitude variations can be an important clue to the lithology and presence of hydrocarbons. An increase in amplitude with offset may indicate a gas sand reservoir and a decrease in amplitude with offset may indicate a carbonate reservoir. These anomalies are masked in the CMP stack since every trace is an average of the offsets. The processing was not done solely for the accuracy of AVO analysis so some processing operations such as trace to trace scaling with small windows, FK operations and deconvolution derived from trace summation must be avoided (Gadallah 1994). With limited time it was determined the interpretation of the seismic image was more important than the outcome of the AVO analysis leading to the processing not redone to benefit the AVO volume. In the volume displayed the attributes intercept and gradient are shown. These are computed using the pre-stack CMP data and during the AVO processing the data amplitudes are analyzed as a function of angle, and arrivals outside a predefined angle range are omitted. An algorithm computes the AVO attributes by fitting a curve through a distribution of data amplitudes as a function of incidence angle or square sine of the estimated incidence angle and outputs the attributes. The data generated by this analysis is referred to as a pseudo-stack because it consists of traces having one value per time sample.
per CMP (Ruger 2002).

\[ R(\theta) \approx P + G \cdot \sin^2 \theta \]

Figure 53: A linear AVO curve of reflection amplitude versus \(\sin^2 \theta\). P is the intercept and G is the gradient (Gadallah 1994).
Figure 54: Parameter window for an AVO Volume processor (CGG Veritas 2006).

To generate the volume Figure 54 was filled out with the velocity information coming from Well 2’s p-wave log (CGG Veritas 2006). The figure below is the AVO volume with the attributes gradient and intercept. The gradient is displayed as the trace with the curves to the right positive values and to the left negative. The intercept is shown in the color with blue as the negative value and red as the positive. The decrease in intensity in the upper portion may come from the effects of the guided waves since this effect appears in the stacked data in Figure 32 from Hampson and Russell.
There are four classes of anomalies seen in AVO analysis, each one describing a different relationship. Rutherford and Williams (1989) derived the following classification scheme for AVO anomalies, with further modifications by Ross and Kinman (1995) and Castagna (1997):

Class 1: High impedance with decreasing AVO.

Class 2: Near zero impedance contrast.

Class 2p: Near zero impedance contrast with polarity change.

Class 3: Low impedance with increasing AVO.

Class 4: Low impedance with decreasing AVO.
Figure 56 illustrates these four, the orange line is the impedance and the color key is the degree of increase and decrease of AVO. These classes are searched for in the AVO volume (Hapsari 2014). Based on the time and the formation picks in the interpreted seismic stack the blue color at 550ms corresponds to the Trenton reflector and would be a point of interest for oil and gas. Since in the well logs the Trenton has high impedance it can be assumed it is a class 1 anomaly. It can be seen in the magnified AVO volume with increased trace amplitude the intercept attribute reveals the anomaly while the gradient in the trace does not show any pattern. The New Albany and Maquoketa may show a class 3 or 4 anomaly since they have lower impedance. Some points below the Trenton show higher amplitude of intercept where there would be high impedance. Figure 57 shows a close up of the Trenton anomaly and a circle around the possible same anomaly below which are brighter in intercept than the surrounding.

Figure 56: Display of AVO class anomalies (Hapsari 2014).
VI. Final Interpretation

When the data was first displayed it had varied sources of noise which needed to be addressed. FK filtering with flow control decreased the effects of the guided waves, air blast, and stationary seismic source. Velocity analysis and rounds of residual statics improved coherency and made interpretations easier. Two well logs with attributes most useful and synthetics created from extracted wavelets made the base for the formation locations found on the seismic line. These formations include: the bottom of New Albany at 325 to 350ms, top of Maquoketa at 450ms, top of Trenton at 500 to 525ms, and the top of the Knox at 675 to 700ms.

Figure 57: Close up of AVO volume with increased trace amplitudes.
The line does not have any true structure since the syncline and anticline forms are centered in the middle making them caused by processing. The seismic image interpreted using the well ties and prior knowledge of stratigraphy is displayed in Figure 50. The AVO volume has an anomaly at the Trenton and lower amplitudes at the same locations as the stack done on Hampson Russell in Figure 32. Therefore four stratigraphic units were located and a type 1 anomaly found at the Trenton.

VII. Summary and Conclusion

The purpose of the research was to provide an image of the subsurface and possible points of interest for production of oil and gas by applying different processing efforts. With improved processing and well log picks an interpretation of the data was accomplished to give to the oil company, formations were identified and an anomaly was located on the AVO volume.

The area of the Illinois Basin has the possibility of having oil and gas reservoirs. During the processing portion of the research four stacks were made to be compared. The first one made was done by Wright State University and included killing all of the disturbed traces by the stationary seismic source. This diminished signal in the sources area but gave more distinct reflectors. The next two stacks were done by the author and kept the traces but attempted other means of lowering its effects. These include filtering and statics. The kills of near offset traces might have lowered the near surface amplitudes and could be considered another brute way of decreasing the guided waves in these stacks as well. The impact of this may not be seen on the stacked section on Promax but on the stack in Hampson and Russell. The intact traces affected by the outside seismic source helped increase the offset for later AVO analysis. The first stack done by the author involved one round of residual statics and presented strong reflectors. Some reflectors ran into each other and became indistinguishable from adjacent reflectors. The
second stack of the two had many rounds of residual statics and had separated reflectors compared to the first done by the author. This was used to extract wavelets to create synthetics from wells and to interpreting this improved stack. The last gather was done on Hampson Russell with added processors. It exhibited blurry shallow reflections and less reflectors imaged. Throughout all the stacks the one with the affected traces killed gave the best gather for formation interpretations. The data with the traces kept still contained reflectors to be interpreted and allowed for increased fold to aid proceeding steps making it more useful.

Well logs with desirable attributes were used to pick the tops of important formations using knowledge of log mechanics and stratigraphy. The deeper logs proved to be more useful and the presence of a p-wave velocity was essential to create a synthetic. Well 4 and Well 1 were used for preliminary interpretations since they lacked this either p-wave velocity or proper depths. The bottom of New Albany, top of Trenton, Maquoketa and Knox were accurately picked from synthetics created using wavelets extracted from data shown in Figure 25 and wells 2 and 3. An AVO volume was done to explore possible anomalies and what they mean. The Trenton had an anomaly imaged as a type 1 and others were seen. Decreased shallow reflectors affected the AVO volume and lowered the success of imaging anomalies at the New Albany and Maquoketa.

In this research the processing of seismic land data is explored to find what will be the more productive way to accomplish an interpretable stack. An interpretable stack was made which could be added to the oil company’s information of the subsurface and AVO analysis. Future research may include other possibilities for noise suppression, transferring data with trace kills to Hampson Russell for analysis, and increased attribute AVO analysis for reservoir characteristics. During processing software inconsistencies might have affected the outcome by corrupting procedures. Splitting procedures into two separate flows resulted at times with
different results on Promax. The software had to be repaired multiple times and reestablished on the system. Despite the inconsistencies, processing produced interpretable stacks and AVO results which can be built upon and be an aid to new discoveries. This research can be used to investigate future procedures and help interpretations of seismic data.
Bibliography


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Figure A1: First loop of residual statics stack section.
Figure A2: Second loop of residual statics stacked section.
Figure A3: Third loop of residual statics stacked section.
Figure A4: Forth loop of residual statics stacked section.