Quantifying Seismic Reflections Within A Mini-Basin, Gulf of Mexico

Scott Rubio

Thesis Committee:
Advisor: Dr. Chris Liner, UH
Member: Dr. Janok Bhattacharya, UH
Member: Dr. Charles Winker, Shell
Abstract

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Committee: Dr. Chris Liner (Advisor, UH), Dr. Janok Bhattacharya (Member, UH),
Dr. Charles Winker (Outside Member, Shell)

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Seismic data is a preferred method in viewing subsurface geologic features and it makes geologic interpretations of structure and stratigraphy possible. Seismic attributes reveal characteristics of the data not easily seen in amplitude data. Seismic attributes are integrated in this study to analyze a 3D seismic survey in the Gulf of Mexico. Using only seismic amplitude data, Perov (2009) interpreted growth-faulted delta sequences, fluvial channels, mass transport complexes, and other stratigraphic features.

My study area lies within the Gulf of Mexico salt dome/mini-basin province, one of the local tectono-stratigraphic regimes. Structure and stratigraphy in this area are controlled by salt tectonics which aid in developing small mini-basins. The goal of my study is to re-examine Perov’s interpretation using seismic attributes. I hypothesize that geologic interpretation can be improved by the use of seismic attributes, including coherence, curvature, and spectral inversion.

APPROVED as PROPOSED       APROVED as MODIFIED       DISAPPROVE

Modifications

Committee Chairman

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## Introduction
The salt dome / mini basin province described by Galloway (1975) is found off shore Southeastern Louisiana in the Northern quadrant of the Gulf of Mexico. The sediments in this area are Pliocene / Pleistocene in age and primarily deltaic in origin embedded within various salt structures (Winker, 1982; Winker and Edwards, 1983). Petroleum Geo-Services provided a 3D seismic dataset that lies in the salt dome / mini basin province that covers an area of 8000 km² (288 OCS blocks) located about 150 kilometers south of the Louisiana coast. (Figures 1 & 2) The seismic data was acquired via ship with two sources and three streamers with a maximum offset of 6000 meters. The data was then processed using a 3D Kirchhoff bending-ray pre-stack time migration. There were 240 channels per streamer that have a 25 meter group interval and a CMP bin dimension of 12.5 meters x 40 meters. The data was also acquired using a 48 nominal fold, 10.5 second record length, and a 2 millisecond time sample rate. The extent of the time-depth that will be used in this study will begin at 0.00 ms and end at -2000.00 ms. The dominant frequency of the data was measured to be 35 Hz. Therefore, this data has been calculated to have a vertical resolution of 8.75 meters and a horizontal resolution of 131 meters at 1 second depth.

This area has previously been studied by several students at the University of Houston. Doctoral Candidate, Felipe Lozano characterized the upper 200 milliseconds of the data cube in his dissertation. Master Candidate’s Grigoriy Perov and Patricia Lee have worked the western most mini-basin in this data cube, where they observed and detailed the sequence stratigraphy, structural features, and origin of sediment.

The purpose of this study is to test Perov and Lee’s interpretations of the mini-basin by applying seismic attributes like coherency, curvature and ThinMan in hopes of providing a seismic image that will reveal more precise estimates of growth fault interpretation and fluvial
channel extent. The aim is to gain a better geologic interpretation of mini-basin characteristic and development.

Objectives

The focus of this study is to show that certain growth faults observed in Perov and Lee’s deltaic sequence are not present and that the fluvial channels used to depict shelf margins are not precisely mapped. This study will seismically image the sequence stratigraphy and resolve their relationships by incorporating seismic attribute images in hopes to clarify Perov and Lee’s seismic amplitude images. In order to accomplish this goal, my first objective will be to determine the true location and parameters of these growth faults. Secondly, I will detail the extent of the fluvial channels observed in Perov and Lee’s deltaic complexes. Both of these objectives will be accomplished by applying a suite of seismic attributes. The resulting seismic images will provide a platform for a more accurate interpretation.

Perov and Lee’s interpretations find intra-parasequence growth faults. Because these types of faults are known to occur when a high sediment supply is present, it argues for a fluvial dominated delta morphology described by Bhattacharya and Davies (2004). In figures 8A & 8B of Perov’s thesis we see an example of a series of observed growth faults (Figure 5). Because these faults are picked on a seismic amplitude reflection image it is clear that there are some discrepancies with these interpretations. My objectives which integrate an application of detailed seismic attribute analysis, will dispute that Perov and Lee’s fluvial dominated delta conclusions are incorrect. The morphology of this basin will be correctly identified by applying geophysical processing techniques that provide a more distinct image of the seismic reflections. Moreover,
fluvial channels give a good indication of the shelf margin edge and its characteristics (Bhattacharya, 2006). By mapping the extent and determining the type of fluvial channels I could argue that the fluvial dominated delta interpretation made by Perov and Lee is inaccurate.

Models

Seismic attributes are defined by Chopra and Marfurt (2005) as any measure of seismic data that helps us better visualize or quantify features of interpretation interest. Analysis of seismic attributes has been used since the 1930’s and there are now more than 50 distinct seismic attributes calculated from seismic data (Chopra and Marfurt, 2005). It is now important to apply these helpful processes to the interpretation of geologic structure and stratigraphy.

Chopra (2002) details the coherence seismic attribute which measures and represents in three dimensions the trace-to-trace similarities. Depending on a trace’s neighboring likeness in the x or z planes with others, a value of one or zero is inserted into the newly created image giving the interpreter a different outlook on the seismic data. Therefore, this algorithm is excellent for identifying faults, fractures, channels, and stratigraphic features in any orientation because of the lateral changes that occur with their presence (Chopra, 2002; Marfurt et al., 1998). The hope is that this attribute will indicate sharp delineations that when applied to my seismic section easily pinpoints growth faults and fluvial channels.

The coherence algorithm is similar to the curvature attribute that will also help display strong discontinuities in the data. Curvature is a three dimensional attribute as well that highlights areas of zero, positive, and negative curvature (Sigismondi and Soldo, 2003). Areas where most positive and most negative curvatures appear are useful in delineating faults,
fractures, flexures, and folds (Al-Dossary and Marfurt, 2006). This concept is exceptionally valuable in the case of growth faults which exhibit a listric pattern and fluvial channels that tend to meander.

A published study by Puryear and Castagna (2008) incorporated an advanced broadband software called Fusion ThinMan that was able to create a spectral inversion of the seismic data. They formulated a method that was able to image seismic well below the tuning thickness and improve imaging of subtle stratigraphic features. It was a two step process that first inverted the seismic amplitudes into a reflectivity series, and then transformed this reflectivity series into relative impedance layers. This seismic attribute will be invaluable in identifying stratigraphic features that would be invisible when analyzing seismic data in amplitude alone.

While incorporating these seismic attributes into my research it will be important to remember the parameters of my seismic data. Spatial aliasing is one element that will need to be controlled and is the result of trace spacing relative to frequency, velocity, and slope of an event (Liner, 2004). Seismic data must remain unaliased during processing and by knowing the acquisition details we can prevent this. Once the limits of the data are known, I can continue to incorporate the above models with acute accuracy.

**Regional Geology**

The extensive salt deposits along the continental shelf of the modern day Gulf of Mexico occurred during the Middle Jurassic (Ewing, 1958). These deposits were a result of sporadic advances of the sea onto the continent. As sea levels rose, these deposits found their way onto the continental margin, where sediments soon began accumulating as a result of several nearby fluvial systems (Galloway et al., 2000; Suter and Berryhill, 1985). Since Late Jurassic time, the
basin has been a stable geologic province characterized by the persistent subsidence of its central part, probably due at first to thermal cooling and later to sediment loading as the basin filled with thick prograding clastic wedges along its northwestern and northern margins, particularly during the Cenozoic. (Galloway et al., 2000) The result was a typical basin setting where the salt subsidence created accommodation in the form of mini basins. These smaller chiefly circular basins were created in great numbers replacing the common large ocean basin, where deltaic deposits within these mini-basins commonly display listric growth faults. Furthermore, successive deltaic sequences comprise clinoforms and are separated by the flooding surfaces that can be clearly seen in the seismic. Deltaic deposits capped by flooding surfaces represent high impedance reflection boundaries and are imaged as continuous reflectors on seismic profiles. These principles were thoroughly described and scrutinized in Perov and Bhattacharya (2010) and will be invaluable to understanding the complex geology occurring within the mini-basin.

Methodology

Previous interpretations have been made concerning the depositional environment of the western most mini-basin in Petroleum Geo-Services dataset. A strict review of the seismic sections has shown examples of growth faulted deltaic sequences and fluvial channels at different intervals. However, there are still discrepancies in the interpretations and more extensive geophysical processing that needs to occur. The work by Perov and Lee will be a starting point where I will analyze their interpreted faults, horizons, channels, and stratigraphic boundaries. Their interpretations will constantly be utilized in comparing results and distinguishing features.
The aforementioned 3D seismic dataset will be loaded into Schlumberger’s Petrel Software where it will be cropped and manipulated to best display the areas of interest. With this software it will be possible to incorporate the seismic attributes mentioned in the models section in order to begin generating results (Figure 4). With different seismic volumes illustrating the different seismic attributes the seismic dataset can be thoroughly investigated. These seismic volumes will allow interpretations to be made about growth faults and fluvial channels. They will also permit stratigraphic and structural inferences that will aid in determining if Perov and Lee were correct in their fluvial dominated delta explanation.

Well log information will then be incorporated to calculate a proper time-depth conversion. These statistics can also further the production of fault throws, layer thicknesses, and horizon depths. If well logs are incapable of providing the necessary data then published velocity curves and interval velocities by Fliedner (2002); Wellner et al. (2004) will be used as a backup. This additional data will be useful for providing better estimates of the scale of growth-faulting and fluvial channels.

Summary

This study is aimed at quantifying seismic reflections within a Gulf of Mexico mini-basin. Previous geologic studies in this mini-basin have noted growth faults and fluvial channels with uncertain confidence. Using seismic attribute analysis, structures and stratigraphic features will be enhanced. These results will determine if a more accurate geologic interpretation can be made by processing the seismic volume and incorporating seismic attribute volumes. This should depict the value of geophysical data processing as well as showing the beneficial methods and steps needed in order to better geologic interpretations.
Timeline

Fall 2009

- Literature review
- Research depositional models
- Learn to use and operate software programs
  - Complete tutorials
  - Practice interpretation and manipulation of seismic data

Spring 2010

- Load 3D seismic cube
- Crop mini basin section
- Begin quantitatively analyzing seismic
- Compile citations
- Complete proposal and present

Fall 2010

- Complete quantitatively analyzing seismic
- Generate results
- Compare with other models and interpretations
- Thesis submission
- Defend Thesis
References


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Figure 1. Topographic map of the Northern Gulf of Mexico. Red box indicates area of research. Note the beginning of the salt dome / mini basin province in the lower portion of the red box.

*Image from ESRI Data & Maps (2000).*

Figure 2. FlexR Phase III is the 3D seismic cube provided by PGS for this project. Yellow box indicates the region where the mini-basin of interest lies. Image from www.pgs.com
Figure 3. Time slice of the PGS provided data cube. Note the abundance of noisy salt reflections embedded with circular mini basins. Yellow box highlights the mini-basin studied in my research. Taken from Perov, 2009
Figure 4. A snapshot of the seismic data with the coherence attribute applied. This attribute will be used to analyze faults, channels, and other structural features. Generated in Petrel
Figure 5. These are two figures, 8A & 8B, from Perov’s thesis that I intend to detail and interpret more clearly.