2011

Soft sediment relay zones: a high resolution seismic survey Livingston Parish, Louisiana

Erin T. Elliott
Louisiana State University and Agricultural and Mechanical College

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SOFT SEDIMENT RELAY ZONES:  
A HIGH RESOLUTION SEISMIC SURVEY  
LIVINGSTON PARISH, LOUISIANA

A Thesis  
Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Master of Science  
in  
The Department of Geology and Geophysics

by  
Erin T. Elliott  
Bachelor of Science in Geology, Millsaps College, 2008  
May, 2011
DEDICATION

First, I dedicate this thesis to Dr. Lorenzo and the field workers who spent their summer collecting the seismic data used in this thesis.

Second, I dedicate this thesis to Reginald Fessenden, Ludger Mintrop, and John Karcher, the first men to discover the benefits of using seismic data for geologic interpretation.

And last but certainly not least, to my amazing family and friends who have supported me throughout all my endeavors.
ACKNOWLEDGEMENTS

I thank my advisor, Dr. Juan Lorenzo for designing the seismic surveys, collecting the seismic data, and for his guidance throughout the data processing and writing of this thesis. Thank-you to my committee members, Dr. Jeff Nunn and Dr. Phil Bart, for their guidance and insight throughout the duration of this project. I sincerely thank the Applied Depositional Geosystems Corporate Affiliates who supported me with the Applied Depositional Geosystems Fellowship while at LSU. AAPG Grants in Aid also provided funding for my thesis.

Thank-you to Jason Griffith at the United States Geological Survey in Baton Rouge for your guidance in selecting the best well to use for correlating my seismic data.

Thank-you Dr. Dutrow, for all of your insight and suggestions for improving my figures.

I thank all of my family, friends, and friends and colleagues. To my family, thank you for your unending encouragement, support, and much-needed breaks and laughs throughout this entire project, I couldn’t have finished without you. Thank-you to all of my friends and colleagues for your help, support, and laughs throughout the years.
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The southern coast of the United States, bordering the Gulf of Mexico, is home to several down-to-the-south, listric, normal fault systems striking parallel to the coast. One of these, the Baton Rouge–Tepetate Fault System located in southern Louisiana, consists of a series of near-surface, reactivated growth faults and relay ramps– a broad area of ductile strain, with contemporaneous sedimentation. Evidence of recent fault and relay ramp movement is seen in surficial fault line scarps and offset roads. This thesis utilizes two near-surface (<500 m), high-resolution (10 - 300 Hz), continuous seismic reflection profiles (360 m and 480 m long, 3 m geophone spacing; 24-channel) previously collected across a growth fault and a portion of a possible relay ramp in Livingston Parish, Louisiana to study this soft sediment system. The seismic source is a down-hole Betsy seisgun and source-to-receiver offsets range from 4 to 73 meters. One seismic line, seismic line LSU 4 (480 m) crosses near the tip of the fault at a point where there is no noticeable vertical offset. Seismic line LSU 1 (360 m) crosses the fault where a surficial scarp shows an offset of 1.5 m. The two seismic profiles are processed and analyzed for broken, offset reflectors indicating fault movement. This analysis, combined with well log data and gravity surveys across the fault and in the relay ramp area has shown that: (1) the near surface consists of numerous small faults distributed over a distance of ~40 m (2) fault movement is ~40 m since the early Pleistocene (3) a previously interpreted gravity high coincides with the faulted region (4) the characteristics of the imaged region are consistent with those of a relay ramp.
CHAPTER 1. INTRODUCTION

Hard Linkage vs. Soft Linkage

Normal fault segment interaction is categorized as either hard linkage or soft linkage (Acocela et al., 2005). For the purposes of this thesis, linkage is defined as the interaction of two or more faults to create one long fault with a single offset. Hard linkage describes faults that are joined along strike by intersecting faults, distributing stress from one fault to another. Faults that are linked by ramps, a broad area of ductile strain, are referred to as soft linked. Transfer zones are regions where fault segments are interacting. Further more, the term transfer zone refers to the complex system of faults that develop between two larger faults to transfer the displacement from one large fault to another and is not indicative of the type of linkage (Bose and Mitra, 2010).

Hard linkage occurs in rocks that are undergoing a large amount of differential extension, resulting in transfer faults (Figure 1). A transfer fault is a nearly vertical transtensive fault that transfers differential extension between two contiguous crustal blocks. Transfer faults are found in areas such as continental rifts, the Basin and Range Province, and active plate boundaries (Acocela et al., 2005).

Soft linkage is expressed in the form of relay ramps or other related structures. A relay ramp (Figure 2) is a region of structural dip between two normal faults dipping in the same direction and overlapping in map view (Hus et al., 2005). Relay ramps form in areas with limited extension and accommodate only minor displacements. Generally, relay ramps are widespread and are found in areas such as the mid oceanic rifts, continental margins, and continental rifts (Acocela et al., 2005). This thesis will focus on the near surface evaluation of a soft sediment relay ramp.
Figure 1. Hard Linkage: schematic diagram of a transfer fault (dashed line) with arrows indicating direction of movement. The solid black lines represent the two preexisting faults that are connected by the transfer fault. In this case, the two preexisting faults dip in the same direction.

Figure 2. Soft linkage: schematic diagram of a relay ramp. The relay ramp is labeled and the thick black lines represent the faults that are approaching one another. The yellow polygons represent the sedimentary wedges that may accumulate in the rollover zone.
Relay Ramps

Relay Ramp Model

A relay ramp (Figure 2) is a broad area of ductile strain resulting in an area of structural dip between two parallel normal fault segments. Relay ramps form to accommodate an area of limited differential extension (Acocela et al., 2005; Hus et al., 2005) and may span an area as small as a single meter² to 1000 kilometers² (Acocela et al., 2005).

Morley (1990) proposes a classification scheme that classifies relay ramps into three broad categories or types: convergent, divergent, and synthetic (Table 1).

Table 1. Relay Ramp Classification Scheme

<table>
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<th>Conjugate</th>
<th>Synthetic</th>
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<tr>
<td></td>
<td>Convergent</td>
<td>Divergent</td>
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<tr>
<td>Approaching</td>
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<tr>
<td>Overlapping</td>
<td><img src="Image3" alt="Image" /></td>
<td><img src="Image4" alt="Image" /></td>
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Key: monocline, extensional fault, location of relay ramp

Modified from Morley (1990)

Relay Ramp Formation

The formation of a relay ramp (Figure 3) begins with the propagation of two normal faults toward one another to accommodate a broad area of differential extension (Figure 3a). As offset on the faults increases, a rollover forms (if permitted by fault geometry) and sediment gradually collects in the space created by the movement of the down-going block, forming a
sedimentary wedge. A sedimentary wedge will only form if there is sufficient erosion of the fault scarp and deposition of sediment (Figure 3b) (Densmore et al., 2003). The faults begin to interact and overlap, forming a small relay ramp with slightly dipping beds (Figure 3c). In this particular case, the faults curve toward each other (Figure 3d) and continue to propagate until one “captures” the other (Figure 3e). The small piece of the fault that is beyond the “captured zone” becomes part of the down going block.

Figure 3. Schematic diagram showing the formation of a relay ramp beginning with (a) faults approaching with no overlap or interaction to (e) the breach of the relay ramp where one fault has captured the other.
Relay Ramp Characteristics

Peacock and Sanderson (1994) describe the geometry and development of relay ramps in detail. They present a set of criteria that are useful in identifying relay ramps both in map view and in cross section (Table 2).

Table 2. Relay Ramp Characteristics

| 1. Bedding within the relay ramp reorients itself during extension to dip footwall down to the hanging wall. This is seen on a contour map of the relay ramp (Figure 4) (Peacock and Sanderson, 1994b). |

![Figure 4](image_url)

Figure 4. Schematic diagram of a contour map of a relay ramp. The bed dip arrow indicates the direction of dip and 9 is the highest and 0 is the lowest elevation. Modified from Peacock (1994).

| 2. The bedding within a relay ramp is dipping toward the hanging wall. Seismic Surveys across the whole ramp area will see the entire range of the dipping beds whereas a survey over a smaller would only show moderately dipping to horizontal beds (Figure 5). |

![Figure 5](image_url)

Figure 5. Diagrammatic cross section of a large-scale relay ramp in a normal fault system. The relay ramp forms between an antithetic fault and a normal fault and shows strata dipping toward the hanging wall. Modified from Peacock (1994). |
Problem

Relay ramps are currently only studied in areas that are made of hard igneous rock, such as the Red Sea (Khalil and McClay, 2002), Kilauea Volcano, Hawaii (Peacock and Parfitt, 2002), and the East African Rift System (Morley et al., 1990). In the Red Sea and the East African Rift System, relay ramps form from rift propagation in igneous rock.

Relay ramps also form in areas with soft sediments, such as the Gulf of Mexico Coast (Figure 6). Many studies look at the movement and propagation of faults of the Gulf of Mexico Coast (Cartwright et al., 1998; Hanor, 1982; Nunn, 1985). However, no study utilizing seismic data has looked at the near surface (< 500 m) characteristics of relay ramps and fault propagation the soft sediments of Louisiana. The study of the formation of faults and relay ramps at the near surface level in soft sediments provides a new look at the small-scale structures that form as a result of fault propagation. These shallow, small-scale structures are representative of both the fault formation at depth and the surface expression of the ongoing extension (Schlische, 2003). Consequently, and a study of these near surface characteristics will yield a greater understanding of fault linkage and growth in soft sediments.

Hypotheses

• Soft sediment relay ramps should display general features described in Peacock and Sanderson (1994).

• Near surface faulting in soft sediment relay ramps is expected to occur as several small offset faults over a wide distance due to the nature of faulting in soft sediments.

• Faults in soft sediment are expected to show multiple episodes of movement that may be recorded by patterns of sediment thickening and thinning, allowing the movement to be dated.
CHAPTER 2. GEOLOGIC HISTORY

Geologic History of the Gulf of Mexico Basin, North America

The Gulf of Mexico continental margin (Figure 6) is classified as a passive margin because it is seismically inactive and exhibits seaward thickening sediment deposits overlying a faulted basement (Allen and Allen, 2005). The most recent period of rifting in Gulf of Mexico Basin began in the Triassic Period (245 Ma), coincident with the break up of supercontinent Pangaea. This rifting episode occurred with brittle extension of the upper continental crust and ductile extension of the lower mantle lithosphere (Wicander and Monroe, 2004).

Figure 6. Google Earth Image of the Gulf of Mexico, Southern United States of America, and Mexico. Projection system is a Simple Cylindrical or Plate Carre projection that uses the WGS84 datum (Google Earth, 2008).
During the Early Triassic Period (248 Ma), Pangaea rifted into two principle continents: Gondwana and Laurasia. Near the end of the Triassic Period (227 Ma), North America and Africa were completely separated by the proto-Atlantic Ocean. North and South America broke apart in the Late Triassic Period through Early Jurassic Period (227-180 Ma). A mantle plume under the Gulf of Mexico basin thinned the continental crust and initiated rifting. This rift opened much like a pair of scissors and moved the Yucatan block to its current position (Bird, 2005). Seafloor spreading in the Gulf of Mexico commenced during the Late Jurassic Period (150 Ma) (Bird, 2005). The mantle plume moved away from the Gulf of Mexico in the Jurassic Period and Early Cretaceous Period and ended seafloor spreading. As the crust cooled, it subsided and contracted to form the present-day listric normal faults around the periphery of the Gulf of Mexico basin (Allen and Allen, 2005; Wicander and Monroe, 2004).

**Growth Faults of the Gulf Coast**

The concept of the listric normal fault was first recognized and introduced by Eduard Suess in 1904. The term listric comes from the Greek word *litron*, meaning shovel. Listric literally means spoon shaped or having a curved appearance (Bally et al., 1981). Listric normal faults are named for their curved like appearance in cross section (Shelton, 1984) and may form in a variety of ways based on the regional tectonics and the regional rock type. Faults that involve the basement generally form as a result of a rift system, prior to the development of a continental margin (Figure 7) (Wicander and Monroe, 2004). Soft sediment listric normal faults may form as a result of thermal subsidence, differential loading, salt withdrawal, or from gravitational slides (Bruce, 1973; Nelson, 1991).

A specific type of listric normal fault, known as a growth fault, possess a thickening stratigraphic sequence on the down-thrown block and increasing throw with depth, hence appearing to “grow”
on the down-thrown fault block (Figure 8) (Bally et al., 1981). Growth faults exhibit a “rollover” zone where the beds have collapsed into the space created by extension. Near the Louisiana Gulf Coast, growth faults are found around the periphery of the basin and many sole onto Jurassic age salt or shale (Hanor, 1982; Wallace, 1966).

Figure 7. Schematic Diagram of basement growth faults that formed as a result of the rifting of North America and Africa (Wicander, 2004).

Figure 8. Cross section of a growth fault exhibiting stratigraphic thickening on the downthrown side, a detachment surface known as a decollement, and a rollover. No scale is implied. (Modified from Nelson (1991).)
Figure 9. Growth fault systems around the periphery of the Gulf of Mexico Basin (Murray, 1960).
Louisiana Fault Systems

A large swath of very complicated east-west trending fault line scarps traverses most of southern Louisiana, USA (Figure 10 and Figure 11). The vast majority of these faults have been inactive since the Miocene, leaving the shallower sediments undisturbed (Hanor, 1982). In the case of the Tepetate and Baton Rouge Fault Systems, the scarps are the surficial expression of growth faults reactivated in the Pleistocene (Heinrich, 2005; Nunn, 1985). The reactivation of these growth faults is believed to stem from high sedimentation rates throughout the Louisiana Coastal Plain since the last continental glaciation (Heinrich, 2005). These reactivated growth faults are active today as evidenced by damage to buildings and roads throughout Baton Rouge (Hanor, 1982), fault line scarps on LiDAR images (Cazes, 2004) and satellite images (Gagliano et al., 2003).

Geologic History of Southern Louisiana

During the Late Wisconsin Glaciation (26 to 12 ka), the Louisiana Gulf Coast was approximately 160 kilometers south of the present day coastline. At that time, the Mississippi River carved the ancestral alluvial valley through the exposed Pleistocene Prairie Formation. Today, this area is known as the Mississippi River Valley (Louisiana Geological Survey, 2000). Because this study investigates near-surface fault propagation in the soft sediments of southern Louisiana, the sediments deposited in the Lower Mississippi River Valley are of interest.

Sedimentary units in this area include Prairie Formation, Holocene Alluvium, and valley trains (Figure 12). The Pleistocene Prairie Formation consists of layers of laminated clay that are many times more dense than the overlying water-saturated Holocene alluvium (Autin, 1989). The Holocene Alluvium comprises sandy meander belts, natural levees, and clays (Louisiana Geological Survey, 2000; Saucier, 1974). The Deweyville Complex is a very limited deposit
that consists of large meander belts within coarse-grained sediments overlain by silty and sandy clays. Deweyville deposits are found near the Ouachita and Arkansas Rivers and minor deposits are documented near the Amite and Calcasieu Rivers (Saucier, 1974). Valley Trains, braided stream terraces on a geologic map, are deposited from glacial outwash (Louisiana Geological Survey, 2000; Saucier, 1974). Sicily Island and Peoria loess are discontinuous deposits that overlie the Prairie Formation (Louisiana Geological Survey, 2000).

Figure 10. Fault systems throughout southern Louisiana. The Baton Rouge Fault Zone is highlighted in orange (Gagliano et al., 2003).
Figure 11. Interpretation of a regional seismic profile across Louisiana fault zones. The Baton Rouge Fault Zone is highlighted in orange. (Gagliano et al., 2003).
Figure 12. Generalized stratigraphic column for the Tertiary and Quaternary periods of southern Louisiana (Louisiana Geological Survey, 2000).
CHAPTER 3. OBJECTIVES AND STUDY AREA

Objectives

This thesis investigates the near-surface, soft sediment structure of a fault and portion of a relay ramp system in Livingston Parish, Louisiana, USA. The seismic data are integrated with a gravity survey (Cazes, 2004) and a water well log contributed by the United States Geological Survey located in Baton Rouge, Louisiana. This combination of data provides an excellent foundation for understanding soft sediment fault linkage and building a model for recent fault movement. The results from this local study may be useful when examining soft sediment fault linkage at different depths and ages. Specifically, this study may give insight to the propagation of near surface faults throughout the Gulf of Mexico Coast.

Scope

Two seismic lines (LSU 1-360 m and LSU 4-480 m) were acquired across a fault scarp in Livingston Parish, Louisiana. This fault scarp is associated with the Baton Rouge Fault Zone (Figure 9 and Figure 10). Dr. Juan Lorenzo collected seismic line LSU 1 in 1999 and LSU 4 in 2003. These seismic lines are reprocessed to yield a new look at the shallow (< 500 m) structures produced by a reactivated listric normal fault and relay ramp system in Livingston Parish, Louisiana. The LiDAR for this region indicate the presence of a fault line scarp and relay ramp through this area of study (Error! Reference source not found. to Figure 15) (Cazes, 2004).

Although a time-consuming operation, the collecting, processing, and interpreting of seismic data has many benefits not provided by other methods. Processed seismic data provides a reliable image of the subsurface structures and stratigraphy present throughout the faulted region. This image may provide information such as relative timing of fault movement and
amount of fault displacement. The seismic interpretations are constrained by a USGS well log and compared with gravity data along the same transect. A comparison of gravity data collected by Cazes (2004) to seismic profile LSU 1 in this study is included in the Discussion.

**Study Area**

The study area is located in Livingston Parish, Southern Louisiana. A regional LiDAR image (Figure 13 through Figure 15) shows the fault scarps, relay ramp and the study area. LiDAR, also known as Remote Light Detection And Ranging, is a remote sensing instrument used to collect information about the topography in a particular area. Data is collected by plane and is generally accurate to 0.75 meters (National Oceanic and Atmospheric Administration, 2010).

Figure 16 and Figure 17 show a Google Earth Image of the study area. The fault of interest is drawn in white and the yellow highlighted structure indicates the location of a landfill that contains shallow soil logs used by Cazes (2004). A blue line indicates the location of each gravity profile and the orange lines indicate the location of the seismic traverses. The traverse of seismic line LSU 1 is located along the same transect as gravity profile C. Seismic Line LSU 1 will be correlated to gravity profile C. A green circle approximates the location of USGS well log Li-241.

**Why Is This Study Important to Basic Geology?**

Most relay ramp studies focus on hard rock relay ramp systems or document laboratory experiments meant to imitate hard rock relay ramp systems (e.g. Acocela et al., 2005; Hus, 2006; Larsen, 1988; Peacock and Sanderson, 1991; Peacock and Sanderson, 1994b). This study is important to basic geology because it aims to provide a new look at the shallow (< 500 m) structures that form as a result of fault propagation and linkage in soft sediment.
Figure 13. LiDAR image with faults in solid and dashed black lines. Inset of Louisiana shows Baton Rouge (black star), the Study Area (blue circle) and the Mississippi River in blue. The box indicates the area of the LiDAR Image. On the LiDAR image, orange lines indicate the location of seismic traverses. Vertical black lines A, B, C, and D correspond to gravity profiles. Letter E refers to the outlined landfill area. Interstate 12 is noted for reference. Modified from Cazes (2004).
Figure 14. Schematic diagram of a synthetic relay ramp in map view. Faults (solid blue lines) overlap and form a relay ramp in between (shaded region). U and D refer to the upthrown and downthrown sides of the fault, respectively. Direction of fault dip is indicated by the small T symbol at the base of each fault. Notice that both of the faults are dipping in the same direction.

Figure 15. LiDAR image of possible relay ramp in study area (labeled Ramp) with the fault scarps indicated by white lines. The orange lines are the seismic transects (denoted as 1 and 4 on the map) and the blue lines indicate the location of the gravity profiles A, B, and C from Cazes (2004) (C is the only gravity profile used in this study). The landfill is outlined in yellow. For reference Interstate 12 has been noted. Modified from Cazes (2004).
Figure 16. Google Earth Image of the Study Area. White lines indicate interpreted fault scarps; green stars show the location of the USGS wells. Orange lines represent the location of seismic line traverses, and the blue lines represent three of the four gravity surveys. The fourth is not on the map. Base map image is from Google Earth. The red box is the area of Figure 17.
Figure 17. Seismic Line Traverses. Orange lines indicate the location of the geophone trajectory in seismic lines LSU 1 and LSU 4. The green line near LSU 1 indicates the location of the walkaway test. The walkaway test is along the same transect as LSU 1 and gravity line C, but has been slightly offset for clarity. The blue line indicates the transect of gravity line C. The white line represents the location of the interpreted fault line scarp. The area highlighted in yellow is the location of a landfill.
Why Is This Study Important to the Petroleum industry?

This study of relay ramps is important to the oil and gas industry in two ways. First, the dipping beds in a relay ramp provide a place for hydrocarbons to accumulate against a fault where there is a sufficient seal. Second, relay ramps can compromise the integrity of a reservoir seal by facilitating fluid migration across the faults (Rotevatn et al., 2009).

The faults and bedding orientation in relay ramps may form a trap where hydrocarbons can accumulate as long as there is an adequate seal across the fault and within the relay ramp (Figure 18). A trap is a geologic structure that has the ability to hold and accumulate hydrocarbons (Schlumberger, 2010).

In areas just outside of the ramp, where the bedding is not oriented, there is no fault present. Where the seal is not of sufficient thickness, hydrocarbons cannot be trapped and may migrate away from a well (Figure 19). Migration pathways depend on the relay ramp structure, the network of faults at depth, the quality of the strata that seals the trap, and the continuity of the seal (Rotevatn et al., 2009).

Figure 18. A fault and oriented bedding provide a structural trap for hydrocarbon accumulation. In this diagram, the oil (green) is trapped between the upper impermeable layer and the fault. The red dashed line indicates the location of the oil-water contact. Modified from Peacock (1994).
Figure 19. Schematic diagram of a relay ramp with cross sections. Cross section A-A’ shows a single fault and offset. Cross section B-B’ (Figure 18) shows the relay ramp with the two faults with two separate offsets, and hydrocarbons accumulation against the fault. Cross section C-C’ shows a single fault and a dashed line where the upper fault would project but does not exist. Therefore there is no place for hydrocarbons to accumulate. Modified from Peacock (1994).
CHAPTER 4. PREVIOUS WORK

Gravity Anomalies

Cazes (2004) presented a detailed analysis of three gravity surveys that cross the fault of interest to this study (Fault U). Gravity, Global Positioning System (GPS) location, and elevation measurements are taken every 30 meters along three north to south transects across the fault. A final graph plotting distance versus Bouguer anomaly and density distribution model are presented based on data that are corrected for tide, drift, meter height and the regional residual gravity.

Gravity line C (Figure 16) is located along the same transect as seismic line LSU 1. The gravity and density model for Site C (Figure 20) show a gravity high in the center of the profile with a density contrast of 0.1 mGal. The gravity high occurs across the fault, indicated by a steep 1.5 meter decline in elevation. Cazes interprets this gravity high as an asymmetric sedimentary wedge. There are two smaller anomalies north and south of the interpreted sediment wedge that Cazes attributes to individual buried channel sediments. However, these smaller anomalies are beyond the extent of seismic line LSU 1, and will not be addressed in this thesis. LSU Seismic Line 1 correlates to the middle third of gravity profile at Site C (Figure 20) and this correlation will be addressed in the Discussion.

Sediment Distribution Models

Densmore (2003) presented the results of two experiments that used a numerically generated, time-lapse landscape evolution model of drainage and deposition across a relay ramp system. The first experiment used a relay ramp that had fixed fault tips but allowed for fault displacement over time. The results of this experiment showed that the majority of sediment deposition in a relay ramp setting occurs next to the faults. His findings are comparable to field
studies of the interaction of en echelon fault segments. The second experiment used faults that propagate toward one another, remaining static once they reach the same geometry as in experiment one. A sediment distribution model is not presented for the second experiment because the experiment focuses on fault propagation and change in topography over time. The model was run for each experiment for 6,000 kilo years (ky). The findings of Densmore (2003) support the interpretation of Cazes (2004) and therefore provide valuable information to this thesis about the placement of sediment packages near Fault U.

![Diagram](image)

Figure 20. Gravity model at Site C (See map in Figure 16). The orange line indicates the approximate location of seismic line LSU 1 along the gravity profile. A large asymmetric body is interpreted as a sedimentary wedge and the two smaller bodies as buried channels. Modified from Cazes (2004).
Figure 21. Sediment distribution model (in map view) after a 6 ky run cycle. High sediment thickness is indicated by dark colors, showing the greatest thickness adjacent to the fault. Surface topography is contoured on a 75 m interval. The solid black lines are the faults; the arrows show the approximate direction of drainage, and the dashed black divides the two catchments (Densmore et al., 2003).

**Near-Surface Fault Characterization Using Ground Penetrating Radar**

Thomas and Nunn (2006) presented the findings of a study that used ground penetrating radar (GPR) to image the very shallow (<40 m) subsurface. GPR data and measurements of surficial offset were recorded throughout East Baton Rouge Parish along the Baton Rouge and Scotlandville faults. This study concluded that the Baton Rouge and Scotlandville faults are made of a complex zone of normal and antithetic faults. The complex zone extends to more than 20 meters in some places. These findings are significant to this thesis because they show that faulting in soft sediments occurs as a zone of small offset faults over a broad area.

**USGS Well Information**

The United States Geological Survey (USGS) evaluates water well logs and uses them to map the regional aquifer system. Griffith (2003) presents several cross-sections of the aquifer system throughout southeastern Louisiana. One cross section contains several well logs from the
same region as the study area (Figure 22). The well logs contain both a resistivity log and a spontaneous potential log. A resistivity log records the ability of the rock to resist electrical conduction on a logarithmic scale in ohm-meters (Schlumberger, 2010). A spontaneous potential log records the changes in relative natural electrical potential of a formation in millivolts (Schlumberger, 2010). Modified cross section P-P' (Figure 23) shows the closest well (Li-241) to seismic Line LSU 1.
Figure 22. USGS regional map showing the location of regional well log cross sections. White line indicates profile in Figure 23 and a green dot indicates the location of the well closest the study area. Modified from Griffith (2003).
Figure 23. Cross-section obtained by correlating well logs in Figure 22. This study uses the well log with the green dot above it. Areas in light blue indicate sands filled with fresh water and areas in white are clay (Modified from (Griffith, 2003)).
CHAPTER 5. METHODS

Seismic Data Collection

Two seismic lines were collected across a fault and portion of a relay ramp in Livingston Parish, Louisiana, USA (Figure 24 and Figure 25). Seismic Line LSU 1 was collected in 1999 and Seismic Line LSU 4 was collected in 2003. The surveys utilize a string of 48 vertical component spike-plant geophones as the receiver with a roll-along of 24 channels. This design is time efficient because 24 shots can be recorded before moving the geophones. The source was a down-hole Betsy Seisgun, loaded with 200 grains FFFF black powder for each shot. The survey used an off end source with a 4.5 meter spacing from the first geophone, and a 3 meter spacing between geophones (Figure 26). A Geometrics R-24 seismograph recorded the survey. Field notes were kept to record the time and position of each shot point. Factors that may have affected the quality of the data were also noted for reference. Acquisition parameters are in Table 3.

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<thead>
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<th>Table 3. Acquisition Parameters</th>
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<tr>
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<td><strong>Geophone Spacing</strong></td>
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<td><strong>Seismograph</strong></td>
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Figure 24. Trajectory of seismic line LSU 1. The trajectory of the source (orange) and geophones (blue) is plotted separately and then together for comparison. The letter F indicates the location of the surficial fault scarp.
Figure 25. Trajectory of seismic line LSU 4. The trajectory of the source (orange) and geophones (blue) is plotted separately and then together for comparison.
Figure 26. Schematic diagram of the seismic survey. The survey was designed with a 4.5-meter spacing between the source and receiver, a 3-meter spacing between each receiver, and a roll-along of 24 channels. The direction of rollover indicates the direction that the survey is moved after each shot and is indicated by the gray dashed line.
**Seismic Data Processing**

The data sets are processed using a processing package named Seismic Unix (Colorado School of Mines, 2010). Seismic Unix programs are written in the Perl and BASH (Bourne Again Shell) scripting languages, denoted by .pl or .sh at the end of the program name. All Perl and BASH scripts used in processing are located in Appendix B. The most recent version of Seismic Unix is available for free from the Center for Wave Phenomena at Colorado School of Mines (http://www.cwp.mines.edu/cwpcodes/). A helpful manual is available at ftp://ftp.cwp.mines.edu/pub/cwpcodes/sumanual_300dpi_a4.pdf. Table 4 is a quick reference list of the processing terminology used in this thesis.

The individual data files (a single file for each shotgathers) are collected and stored in either SEGY or SEG2 format, typical seismic data storage formats. Figure 27 outlines a simplified procedure for processing seismic data. The function of each processing program used in this thesis is located in Table 5 and the programs are located in the Appendix B. The exact processing procedure that this study uses and the flow of Seismic Unix programs is detailed below and in Figure 28 and Figure 29. A map of the file structure is included in Figure 30 and Figure 31. These programs are also in an electronic form at the Louisiana State University Geology and Geophysics Department.

Segy2su.pl converts the SEG2 files to SU (Seismic Unix) format, the standard format for data in the Seismic Unix program. Header geometries (Table 6) are entered into an Excel spreadsheet (Table 7 and Table 8) to upload as an ASCII file in to Seismic Unix. ASCII is an acronym for American Standard Code for Information Exchange. The Excel spreadsheet is imported to Seismic Unix and then run through a BASH script (a2bsushwcat.sh) to convert the entries to 8 bit binary format and place each header value with the correct trace.
### Table 4. Common Processing Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Trace</td>
<td>A recording by a single geophone of the seismic energy produced by the source.</td>
</tr>
<tr>
<td>Shotgather</td>
<td>A gather of seismic traces that record the energy from the same source over the same time period.</td>
</tr>
<tr>
<td>SEG2 and SEGY</td>
<td>Typical seismic data storage formats.</td>
</tr>
<tr>
<td>Trace Header</td>
<td>Contains all the information that identifies a specific seismic trace. This may include any or all of the values in Table 6.</td>
</tr>
<tr>
<td>Bandpass Filter</td>
<td>A filter that removes a specified range or band of frequencies from the seismic data. It is typically specified by four frequencies and denotes whether frequencies that are higher or lower than those values may pass (Figure 39).</td>
</tr>
<tr>
<td>Mute</td>
<td>Removes a particular arrival or area of the seismic data.</td>
</tr>
<tr>
<td>Automatic Gain Control (AGC)</td>
<td>Increases the amplitude of the traces. A typical AGC will attempt to make all of the amplitudes approximately equal, increasing the smallest amplitude by the greatest amount.</td>
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<tr>
<td>Frequency-Wavenumber Filtering (f-k)</td>
<td>Removes arrivals in the seismic data that have a specified slope.</td>
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<tr>
<td>Spiking Deconvolution</td>
<td>Used to collapse reflections over a specified time window</td>
</tr>
<tr>
<td>Common Depth Point Gather</td>
<td>A gather of seismic traces that image the same subsurface point or area.</td>
</tr>
<tr>
<td>Common Depth Point Stack</td>
<td>Seismic traces are stacked according to the subsurface point or area that they image.</td>
</tr>
</tbody>
</table>
Figure 27. Simplified flow for processing seismic data.
<table>
<thead>
<tr>
<th>Program</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segy2su.pl</td>
<td>Converts SEGY files to SU format</td>
</tr>
<tr>
<td>a2sushwcat.sh</td>
<td>Concatenates SU Files, Converts tab delimited text file to binary, associates header values with correct trace, creates new SU Files with correct header parameters.</td>
</tr>
<tr>
<td>rev3.sh</td>
<td>Reverse polarity of seismic traces that have the incorrect polarity.</td>
</tr>
<tr>
<td>Select_tr_Sukill.pl</td>
<td>Deletes Noisy traces that detract from data quality. This step requires two programs: Select_tr_Sukill.pl and Sukill.pl and a text file named kill that must remain in the same directory as the two programs. The file named kill records the picks from Select_tr_Sukill.pl (made by pushing “s” over the noisy trace) and sends the list to the program Sukill.pl to be deleted when Sukill.pl is run</td>
</tr>
<tr>
<td>PrestackFlow.pl</td>
<td>Performs the bandpass filter, refraction mute, f-k filtering and automatic gain control.</td>
</tr>
<tr>
<td>Brute Stack.pl</td>
<td>For a brute common depth point stack, the output file from PrestackFlow.pl is fed through the following program, BruteStack.pl, to obtain a constant velocity stack. In this case, the velocity is 1350 m/s.</td>
</tr>
<tr>
<td>IVA.pl</td>
<td>To conduct a velocity analysis, a consortium of programs, IVA.pl, is used. This program outputs the cdp of interest along with the previous velocity analysis of that cdp value for adjustment if needed. IVA.pl requires the following programs to work:</td>
</tr>
<tr>
<td></td>
<td>- iVrms2Vint.pl</td>
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<tr>
<td></td>
<td>- iVpicks2par.pl</td>
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<tr>
<td></td>
<td>- iSunmo.pl</td>
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<tr>
<td></td>
<td>- iSuvelan.pl</td>
</tr>
<tr>
<td></td>
<td>- iWrite_all_iva_out.pl</td>
</tr>
<tr>
<td>iVrms2Vint.pl</td>
<td>Converts $V_{rms}$ to $V_{interval}$</td>
</tr>
<tr>
<td>iVpicks2par.pl</td>
<td>Prepares velocity picks for input to Sunmo by writing all the values to one file.</td>
</tr>
<tr>
<td>iSunmo.pl</td>
<td>Applies a normal move out to the data.</td>
</tr>
<tr>
<td>iSuvelan.pl</td>
<td>Generates the velocity analysis.</td>
</tr>
<tr>
<td>iWrite_all_iva_out.pl</td>
<td>Writes the best velocity picks from IVA.pl to a file.</td>
</tr>
<tr>
<td>parfrompick.pl</td>
<td>Prepares velocity picks for input to Sunmo by writing all the values to one file.</td>
</tr>
<tr>
<td>NMOStack.pl</td>
<td>Stacks the data processed by the PrestackFlow.pl using the velocities obtained using IVA.pl.</td>
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Figure 28. Program processing flow to obtain brute stacks for LSU 1 and LSU 4. All programs ending in .sh are located in programs/sh and all programs ending in .pl are located in programs/pl (Figure 30 and Figure 31).
Figure 29. Program processing flow to produce Normal Move-out stacks of seismic lines LSU 1 and LSU 4. All programs ending in .sh are located in programs/sh and all programs ending in .pl are located in programs/pl (Figure 30 and Figure 31).
Figure 30. File Structure for processing seismic line LSU 1.
Figure 31. File Structure for processing seismic line LSU 4.
Table 6. Explanation of Header Values

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<td>tracl</td>
<td>Trace sequence number within line</td>
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<tr>
<td>tracr</td>
<td>Trace sequence number within reel</td>
</tr>
<tr>
<td>fldr</td>
<td>Field record number</td>
</tr>
<tr>
<td>tracf</td>
<td>Trace number within field record</td>
</tr>
<tr>
<td>trid</td>
<td>Trace identification code (1 = seismic data)</td>
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<tr>
<td>sx</td>
<td>UTM coordinate of the shot location in meters</td>
</tr>
<tr>
<td>sy</td>
<td>Coordinate of the shot location in meters</td>
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<tr>
<td>sdepth</td>
<td>Depth of the source from the surface of the earth in meters</td>
</tr>
<tr>
<td>sdel</td>
<td>Earth surface of shot location in meters above sea level</td>
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<tr>
<td>scalco</td>
<td>Scaling factor that scales sx, sy, gx, and gy</td>
</tr>
<tr>
<td>gx</td>
<td>Coordinate of the first geophone location in meters</td>
</tr>
<tr>
<td>gy</td>
<td>Coordinate of the first geophone location in meters</td>
</tr>
<tr>
<td>gelev</td>
<td>Earth surface of the geophone location in meters above sea level</td>
</tr>
<tr>
<td>scalel</td>
<td>Scaling factor that affects gelev, sdepth, and sdel among others not included in this study</td>
</tr>
<tr>
<td>offset</td>
<td>Distance of the source from a particular geophone</td>
</tr>
<tr>
<td>cdp</td>
<td>Common depth point value determined from offset and fold</td>
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<tr>
<td>scalco</td>
<td>A scaling factor applied to sx, sy, gx, gy that multiplies the entry by 10 to the nth power</td>
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<tr>
<td>ns</td>
<td>Number of samples</td>
</tr>
<tr>
<td>dt</td>
<td>Sampling interval (ns)</td>
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Table 7. Seismic Line 1 Header Geometry Spreadsheet Example (Shot 1001)

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Table 8. Seismic Line 4 Header Geometry Spreadsheet Example (Shot 1000)

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<td>41402</td>
<td>-102</td>
<td>7350</td>
</tr>
</tbody>
</table>

42
**Shot Gather Processing**

Data quality control begins with examining the seismic traces for inconsistencies in the wavelet strength and character. In this particular data set, the shot gathers exhibit both a polarity reversal of specific traces and traces that are too noisy to be useful in further processing.

The polarity of the last twelve traces of each shot gather is opposite the first twelve traces (Figure 33). The change in polarity is most likely a result of an equipment malfunction in the field. Polarity reversals are a concern because they may introduce bogus anomalies, noise, or a null trace to the final stack (Figure 32a). However, if the traces have a consistent polarity, the result is a trace with larger amplitude to represent the arrival (Figure 32b). The program rev3.sh reverses the polarity of the last 12 traces in each shot gather resulting in a shot gather that exhibits uniform polarity for all 24 traces (Figure 34). A shotgather with uniform polarity exhibits different arrivals such as the ground roll, refractions, and reflections (Figure 35).

![Figure 32. Schematic Diagram of stacked traces. (a) If the polarity of the seismic traces is not consistent the sum will be a null trace. (b) If the polarity of the traces is consistent, the sum will be a strong event.](image)
While collecting data in the field, it is common for some of the geophones to work improperly and produce unreliable recordings. In each shot gather of both data sets at least one or two geophones are not working correctly. These traces appear to be different from the surrounding geophones in the same shotgather. Each seismic trace is analyzed individually and great care is taken to ensure that only the traces holding little or no relevant information are killed (Figure 36 and Figure 37). This is very important because these are two very small data sets (2400 and 3300 traces) and every possible trace is needed to produce a quality image of the subsurface. Analysis of each trace is done by hand on an individual basis. Noisy traces are killed when they appear to hold no relevant information (i.e. no reliable arrivals are seen).

Traces containing both noise and good arrivals are kept when they clearly contain information closely resembling nearby traces in the same shotgather. The noise in these traces is visible in the shot gathers but the small amount of noise does not have an impact on the quality of the final stack. The two scripts for killing noisy traces are Select_tr_Sukill.pl and Sukill.pl. The output from these programs is a text file, “kill”, that resides in the same directory.

This study focuses on interpreting the reflections in the seismic profiles. Therefore, arrivals, such as the ground roll, refractions, and air blast, are not needed and may even interfere with the strength and continuity of the reflections in the final stack.

The sample rate is 1000 samples per second meaning that the highest frequency the data can contain is 2000 Hz. A bandpass filter of 0, 3, 1000, 2000 Hz is sufficient to allow all frequencies in the data to pass and to distinguish different arrivals (Figure 35). Applying a fast fourier transform (fft) to the data shows the range of frequencies the data contains (Figure 38). The ground roll has dominant frequencies between 20 Hz and 60 Hz, where the fft exhibits the greatest amount of power.
Typically an f-k filter is sufficient to remove the ground roll. However, in the soft sediments of the very near surface a bandpass filter (command: sufilter) is better suited for removing the ground roll because of the dispersion and frequency content. The bandpass filter of most benefit (determined by the effect on the ground roll) is defined by 80, 120, 200, 250 Hz (Figure 39). The low cut off of 80 - 120 Hz eliminates the ground roll that was approximately 20 to 60 Hz. The high cut off of 200 - 250 is eliminates some of the air blast (Figure 40).

Some of the bandpass filters attempted are tabulated in Table 9.

An f-k filter is applied to seismic data to remove noise or arrivals that occur along a specified slope (command: sudipfilt). An f-k filter works much like the previously mentioned bandpass filter except that rather than using frequencies the numbers specified are in seconds per meter, creating a slope. The f-k filter uses two sets of 4 numbers each to delineate the slope and what data are allowed to pass. The best f-k filter (identified by most closely matching the slope of the airblast arrival or the slope of the back scatter) utilizes a combination of two filters: 0, 6, 30, 50 \( \text{s/m} \) and 10, 20, 48, 70 \( \text{s/m} \) (Figure 41). The first filter of 0, 6, 30, 50 \( \text{s/m} \) is designed to eliminate the slope of the airblast. The second filter of 10, 20, 48, 70 \( \text{s/m} \) is designed to eliminate the slope of the backscatter. This combination of f-k filters has a minimal effect on suppressing backscatter and airblast, but does slightly improve the strength of the reflectors throughout the shot gather. Because the bandpass filter thoroughly eliminates the ground roll the f-k filter was not used for that purpose.

A composite profile of pseudo-walkaway tests aids in outlining the extent of the refractions (green line, Figure 17). A pseudo-walkaway test involves placing a static array of geophones at a consistent spacing (in this case 3 meters) in a single file line with the source. The source is moved away at a regular interval after each shot. Reflected and refracted arrivals
separate with distance from the source; therefore these arrivals can be identified more easily as
distance from the source increases. This particular pseudo-walkaway test begins approximately
30 meters north of seismic line LSU 1 (Figure 16). The pseudo-walkaway test is approximately
145 meters long versus the standard distance of 72 meters for each shot gather. Because this
study is interested in the reflections, it is necessary to remove the refractions. A surgical mute
(command: sumute) that is tailored to the intersection of the refractions with the reflections
eliminates the refractions (Figure 43).

The program PrestackFlow.pl runs the shot gathers through the required processing flow.
Prestack processing parameters are limited to a surgical mute, bandpass filter (80, 120, 200, 250
Hz), and f-k filtering (0, 6, 30, 50 and 10, 20, 48, 70 Hz). The filtered shot gathers are then
divided into cdp gathers.

Common Depth Point Gather Processing

A common depth point (CDP) gather encompasses a small number of traces from several
shot gathers. For CDP gather processing, all shot gathers for the entire seismic profile are put
into a single file. CDP values are created as needed in the programs BruteStack.pl (creates a
single velocity stack), PreVel.pl (creates CDP values for velocity analysis, and NMOStack.pl
(create a normal moveout stack). Using the command suchw (Appendix A) in these programs
allows for the creation of 12, 24, 36, or 48 fold cdp gathers on an as needed basis (Figure 44 to
Figure 53). Figure 44 and Figure 45 show the locations of the different CDP gathers for each
fold examined in seismic lines LSU 1 and LSU 4. The trajectories are shown separately and then
as a composite for comparison. These trajectories are important because they show the actual
location of the subsurface point or area that is sampled in the final profile instead of only the
surface geophone location.
Figure 33. Original Shot gather 1010.su (AGC, bandpass filter: 0, 3, 1000, 2000 Hz) from the field (variable amplitude plot left and wiggle plot right). In this shot gather the polarity of the traces is reversed in traces 13 through 24.
Figure 34. Shot gather 1010.su (AGC, bandpass filter: 0, 3, 1000, 2000 Hz) with modified polarity (variable amplitude plot left and wiggle plot right). This shot gather has been modified from the shot gather in Figure 42 so that the polarity is consistent in all 24 traces.
Figure 35. Shot gather 1010.su (AGC, bandpass: 0, 3, 1000, 2000) with the arrivals of a refraction, a reflection, and ground roll noted on both a variable amplitude plot (left) and a wiggle plot (right).
Figure 36. Wiggle Plot shot gather 1010.su (AGC, bandpass: 0, 3, 1000, 2000 Hz): (a) original with noisy traces, (b) shot gather with noisy traces removed.
Figure 37. Variable amplitude plot of shot gather 1010.su (AGC; bandpass: 0, 3, 1000, 2000 Hz): (a) original with noisy traces, (b) shot gather with noisy traces removed.
Figure 38. Fast fourier transform (fft) of Shot Gather 1010.su: (Left) fft of 24 traces reveals that the most energy is between 20 and 60 Hz.(b) fft of Trace 12.
Table 9. Bandpass Filter Parameters

<table>
<thead>
<tr>
<th>Filter (Hz)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 3, 1000, 2000</td>
<td>The sample rate for the data was 1000 samples/second. Therefore the highest frequency that could be sampled was 2000 Hz. This filter is used to look at all frequencies within the data (Figure 33). It also allows interpretation of arrivals (Figure 35).</td>
</tr>
<tr>
<td>80, 120, 600, 750</td>
<td>The dominant frequency of the ground roll was determined from a fft plot (Figure 38). The majority of the energy was between 20 to 60 Hz, interpreted as the ground roll. This filter eliminates the ground roll by using a low cut off of 80, 120 Hz. The filter nearly eliminates ground roll, revealing the high frequency air blast.</td>
</tr>
<tr>
<td>80, 120, 200, 250</td>
<td>Best filter. The best filter used the low cutoff to remove the ground roll (80, 120 Hz) and the high cut off (200, 250 Hz) to remove some of the airblast. The low cut off of filter nearly eliminates ground roll while the high cut off helps to suppress some of the air blast.</td>
</tr>
</tbody>
</table>

Figure 39. Graph of bandpass filter. Area inside of the trapezoid indicates the frequencies that are allowed to pass.
Figure 40. Variable amplitude plots of shot gather 1010.su containing AGC and different bandpass filters: (a) Uses a bandpass filter that allows all frequencies (0, 3, 1000, 2000 Hz) through. The extent of the ground roll is outlined in gray and labeled Ground Roll. (b) Utilizes a bandpass filter of 80, 120, 200, 250 Hz, removing ground roll present in (a).
Figure 41. Variable amplitude image of (a) original shot gather and (b) after f-k Filtering. Filtering the data has increased the visibility of the reflections by eliminating some of the airblast and backscatter.
Figure 42. Profile of the pseudo-walkaway test (processing: AGC, bandpass: 80, 120, 200, 250 (to remove ground roll)). This 145-meter profile is used to delineate the extent of the refractions. Notice that this profile has 48 traces versus the standard 24. This profile begins approximately 30 meters north of line LSU 1 (Figure 16, green line).
Figure 43. Mute of Refractions: (a) Original processed shot gather (AGC, bandpass of 80, 120, 200, 250 Hz) and (b) processed shot gather with refractions muted above the white line. The noise at the top of profile b is due to filtering after the mute is applied.
Several constant velocity (1350 m/s) brute stacks are created to view the stacked data prior to performing a velocity analysis. BruteStack.pl is the program that creates the brute stacks. Brute stacks help determine the best final configuration for stacking and give an idea of the best fold for the final stack. The 12-fold brute stack does not provide a representative stack because of the low fold and the inconsistency of the reflections across the profile (Figure 54). The 24-fold brute stack provides an adequate stack and provides some detail near the area that corresponds to the surficial fault scarp (Figure 55). Reflections near the fault scarp are more coherent than in any other stack. Individual reflections and sediment packages characteristics, such as channels or sediment pinch-outs, are discernable. The 36-fold stack produces an image of the subsurface with continuous reflectors, but appears to lose the unique characteristics of the reflectors (Figure 56). The 48-fold stack does not provide the detail needed to interpret the profile because, although it produces continuous reflections, it seems to average the smaller features seen in the other lower fold profiles. However, the large fold and reflector strength make this an excellent choice for the velocity analysis (Figure 57).

To further improve the quality of the stack, the cdp gathers are reexamined. The cdp gathers still contain small traces of the ground roll (Figure 58). This is problematic because if left unchanged, it may affect the quality of the final stack. CDP gathers appear to have clear, reliable reflections at large offsets (< 40 meters). One remedy is to use the last 12 of the traces that contain the large offsets (Figure 59) in the final stack. A 24-fold brute stack using only the last 12 traces that have large offsets of < 40 meters from the cdp gathers (Figure 60 and Figure 61) shows that the low fold is a disadvantage because of diminished reflector strength. Using a full 24-fold stack still yields more reliable stack because of the higher fold.
In the brute stack (Figure 62), there is a region of dampened reflectors throughout the area near the surficial fault scarp. Close examination of the shot gathers reveals that shot gathers away from the dampened region have strong, continuous reflections while those within this region do not (Figure 63 and Figure 64). This will be further addressed in the Discussion.

**Velocity Analysis**

The velocity analysis utilizes six equally spaced CDP gathers and contains the first and last full fold cdp gathers (Figure 65 and Figure 67). A 48-fold cdp gather (Figure 52) is chosen for the velocity analysis because of the continuity of reflections and the large fold. IVA.pl performs the velocity analysis and writes the time and rms (root mean squared) velocity picks to a file for each CDP gather. The rms velocity is a weighted average of all the layers that the seismic energy passes through while the interval velocity is a representative velocity of a particular layer. By definition the interval velocity will always be higher than the rms velocity unless approaching zero offset. From the rms velocity, we can calculate the interval velocity using Dix Formula (Equation 1) (Dix, 1955).

\[
V_{\text{int}} = \left[ \frac{(V_{\text{rms}}_n)^2 t_n - (V_{\text{rms}}_{n-1})^2 t_{n-1}}{t_n - t_{n-1}} \right]^{1/2}
\]

Equation 1. Dix Formula where \(V_{\text{int}}\) is the interval velocity, \(V_{\text{rms}}\) is the root mean squared velocity of the \(n\) and \(n-1\) layers, and \(t\) is the travel time in the \(n\) and \(n-1\) layers (Dix, 1955).

After picking all of the rms velocities for each seismic line, graphs are made that compare the rms velocity and interval velocity of each cdp gather (Figure 65 to Figure 68). These graphs also allow for the comparison of the velocities of different CDP gathers. Rapid changes in
velocity are expected because this is a near-surface survey. The unlithified sediments of the near surface change laterally very quickly as evidenced in several Gulf Coast Studies (Autin, 1989; Cazes, 2004; Saucier, 1974, 1994). In this area, the interval velocity or layer cake model cannot be used because of the lateral changes in velocity. RMS velocities are used instead. Graphing the rms velocity of all cdp gathers on one plot creates the velocity model used to produce the normal moveout stack of seismic lines LSU 1 and LSU 4 (Figure 69 and Figure 70). This velocity model is superimposed over the seismic interpretation to give insight to the changes in velocity across profile LSU 1 and LSU 4 in the Discussion. The velocity model is also used to convert time to depth providing an approximate depth and length of interpreted features.

**Normal Moveout Stack**

All of the time-velocity picks from the velocity analysis are located in different files for each cdp gather, however the program that creates the normal moveout stack (NMOstack.pl) requires that all the picks be located in the same input file. The program parfrompick.pl puts all of the picks into one file (partemp.p). The cdp picks are associated with 48-fold cdp gathers, but the stack we want to produce is 24-fold. The values in partemp.p are manually transferred to their proper location along a 24-fold cdp line to create the final cdp values for stacking.

**Spiking Deconvolution**

Spiking deconvolution collapses the reflections over a specified time window (command: supef). This is useful when there are multiple arrivals for the same layer (ringing). A spiking deconvolution with a 0.0125 millisecond window is applied to LSU 1 and LSU 4 resulting in a
clearer image of the subsurface (Figure 71 and Figure 72). In processing, the actual value used was 0.000125 milliseconds to account for the scaling in the header geometries.

An automatic gain control (AGC) is applied to the final stacks to increase the amplitude of the reflections. The command sugain agc=1 applies the AGC. Since the strength of the reflections vary across the profile, a gain called pbal (command: sugain pbal=1) is also applied to even out the amplitudes. The final stacks with interpretations are displayed in Chapter 3.
Figure 44. Plot of LSU 1 Common Depth Point (CDP) locations for 12, 24, 36, and 48 fold lines and a composite of all folds. The cdp gathers used for Figure 46 to Figure 53 are highlighted. Easting and Northing are in UTM (Universal Transverse Mercator) coordinates.
Figure 45. Plot of LSU 4 Common Depth Point (CDP) locations for 12, 24, 36, and 48 fold lines. Easting and Northing are in UTM coordinates.
Figure 46. Variable amplitude image of a 12-fold common depth point gather (cdp=76) (AGC, bandpass=80, 120, 200, 250 Hz).

Figure 47. Wiggle plot of a 12-fold common depth point gather (cdp=76) (AGC, bandpass=80, 120, 200, 250 Hz). Blue circle highlights the noise from mute and filter.
Figure 48. Variable amplitude image of a 24-fold common depth point gather (cdp=67) (AGC, bandpass=80, 120, 200, 250 Hz).

Figure 49. Wiggle plot of a 24-fold common depth point gather (cdp=67) (AGC, bandpass=80, 120, 200, 250 Hz).
Figure 50. Variable amplitude image of a 36-fold common depth point gather (cdp=45) (AGC, bandpass=80, 120, 200, 250 Hz).

Figure 51. Wiggle plot of a 36-fold common depth point gather (cdp=45) (AGC, bandpass=80, 120, 200, 250 Hz).
Figure 52. Variable amplitude image of a 48-fold common depth point gather (cdp=35) (AGC, bandpass=80, 120, 200, 250 Hz).

Figure 53. Wiggle Plot of a 48-fold common depth point gather (cdp=35) (AGC, bandpass=80, 120, 200, 250 Hz).
Figure 54. 12-Fold brute stack. The low fold does not provide continuous reflections throughout the profile.

Figure 55. 24-Fold brute stack. Reflections are more continuous than in the 12-fold stack and broken reflectors are revealed throughout the center region.
Figure 56. 36-Fold brute stack. Although this stack contains high quality reflections, the character of the disturbed region is lost because of the higher fold.

Figure 57. 48-Fold brute stack. Reflections are high quality but due to the size of the CDP gathers detail has been lost around the disturbed region.
Figure 58. 24-Fold CDP gather (cdp=14) with remnants of ground roll highlighted.

Figure 59. Last 12 Traces of 24-fold CDP gather (cdp=14) appear to have continuous, identical reflections.
Figure 60. Original 24-Fold CDP Stack.

Figure 61. 24-Fold CDP Stack only using the last 12 traces of each CDP gather. This stack is technically only 12-fold and shows diminished amplitude strength within the faulted area.
Figure 62. 24-fold CDP brute stack. The shaded region indicates the portion of the stack where the reflections are diminished.
Figure 63. Shot gather 1010.su shows several coherent reflections.

Figure 64. Shot gather 1050.su does not have reliable reflections past 0.1 seconds.
Figure 65. Plot of cdp gathers used for velocity analysis of seismic line LSU 1.
Figure 66. RMS and Interval velocities used for line LSU 1.
Figure 67. Plot of cdp gathers used for velocity analysis of seismic line LSU 4.
Figure 68. RMS and Interval velocities for line LSU 4.
Figure 69. RMS velocity model for seismic line LSU 1. Lines indicate regions of uniform velocity.
Figure 70. RMS velocity model for seismic line LSU 4. Lines indicate regions of uniform velocity.
Figure 71. Normal Moveout Stack of seismic line LSU 1 with (a) no spiking deconvolution and (b) spiking deconvolution. The spiking deconvolution has greatly reduced the amount of ringing in the data.
Figure 72. Normal Moveout Stack of seismic line LSU 4 with (a) no spiking deconvolution and (b) spiking deconvolution. The spiking deconvolution results in coherent reflections.
CHAPTER 6. RESULTS

**LSU Seismic Line 1**

Seismic Line LSU 1 (Figure 73) is approximately 360 meters long and crosses the surficial fault scarp where there is a vertical offset of approximately 1.5 meters. The relative elevation profile is from Cazes (2004). The velocity model is used to create a depth scale posted on the right of each seismic profile (Figure 73 to Figure 75). The vertical resolution of the data is approximately 10 meters, although fault offsets can be distinguished at a lesser interval. The most noticeable feature in profile LSU 1 is the area in the center of the profile (between 135 meters and 270 meters) that exhibits a severe disruption of reflectors (Figure 74). This region contains numerous offset reflectors and is interpreted as a region of nearly vertical faulting (Figure 75). The longest interpreted fault spans approximately 250 meters (Figure 75). All of the interpreted faults have small offsets of less than 18 meters (+/- 4 m). The interpreted fault that reaches the surface appears to coincide with the center of the surficial fault scarp (Figure 75).

The inconsistent amplitudes of the reflections in the seismic data make it nearly impossible to carry a single reflector throughout the interpreted fault zones. Instead of looking at a single reflector, two asymmetric wedge-shaped sediment units are interpreted throughout the shallow section of the interpreted faulted region (Figure 75 and Figure 76). These structures show small amounts of offset across the interpreted faults and thickening on the downthrown block of individual fault segments.

**Seismic Line LSU 4**

Seismic line LSU 4 is located approximately 500 meters west of seismic line LSU 1, crossing closer to the tip of the fault (Figure 16 and Figure 17). LSU 4 shows no distinct change
in the elevation profile (Figure 77). The relative elevation is recorded at each shot point and graphed to create the relative elevation profile (Figure 77 to Figure 79). The velocity model is used to create a depth scale posted on the right of each seismic profile.

The most noticeable feature in LSU 4 is a zone of discontinuous weak amplitude reflectors throughout the northern portion of the profile (Figure 78). The reflectors appear to show a small amount of offset in this region (Figure 78, purple highlight) as well as large variations in amplitude across the profile from north to south. On the northern end of the profile, faults have been interpreted at the apparent end of the discontinuous reflections (Figure 79 and Figure 80).
Figure 73. Uninterpreted seismic profile LSU 1. This seismic profile is the result of a surgical mute, bandpass filter (80, 120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The relative elevation survey is modified from Cazes (2004). The fold of the stack is graphed at the bottom of the profile. Red lines labeled F indicate the region of the surficial fault scarp.
Figure 74. Seismic profile LSU 1 showing interpretation of disrupted zone (purple highlight). This seismic profile is the result of a surgical mute, bandpass filter (80, 120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The relative elevation survey is modified from Cazes (2004). The fold of the stack is graphed at the bottom of the profile. Red lines labeled F indicate the region of the surficial fault scarp.
Figure 75. Seismic Profile LSU 1 with interpreted faults (black lines) and possible sediment wedges (yellow). This seismic profile is the result of a surgical mute, bandpass filter (80, 120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The relative elevation survey is modified from Cazes (2004). The fold of the stack is graphed at the bottom of the profile. Red lines labeled F indicate the region of the surficial fault scarp.
Figure 76. Close up image of the interpreted faulted area in seismic profile LSU 1. Wedge shaped packages are indicated by yellow polygons and black lines indicate the faults.
Figure 77. Uninterpreted Normal Move Out Stack of Seismic Line LSU 4. This seismic profile is the result of a surgical mute, bandpass filter (80, 120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The relative elevation survey is modified from Cazes (2004). The fold of the stack is graphed at the bottom of the profile.
Figure 78. Seismic Line LSU 4 interpretation of disrupted zone (purple highlight). This seismic profile is the result of a surgical mute, bandpass filter (80, 120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The profile along the top of the stack is a relative elevation survey and the profile at the bottom of the stack indicates the fold of the data.
Figure 79. Seismic Line LSU 4 interpreted faults (black lines) and packages (yellow). This seismic profile is the result of a surgical mute, bandpass filter (80, 120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The profile along the top of the stack is a relative elevation survey and the profile at the bottom of the stack indicates the fold of the data.
Figure 80. Close up image of the faulted area in seismic profile LSU 4 with interpreted faults (black lines) and packages (yellow).
CHAPTER 7. DISCUSSION

A reactivated growth fault and relay ramp system in Livingston Parish, Louisiana is imaged using two high-resolution seismic surveys. The seismic surveys are 360 m and 480 m long and encompass a small portion of a relay ramp and the area near a surficial fault scarp. The strength of the reflectors on the seismic profiles varies both horizontally and vertically. Vertical variations in reflector strength correspond to lithology changes indicated on well logs from a nearby well. Griffith (2003) presents cross sections that utilize several interpreted water well logs from across Louisiana. Horizontal changes in reflector strength correspond to the density of faults in a particular region and rapid changes in near-surface un lithified sediments (Griffith, 2003).

**LSU Seismic Line 1**

**Interpreted Vertical Faulting**

An area of interpreted near vertical faulting (black lines) and offset wedges (yellow) in the center of profile LSU 1(Figure 75 and Figure 76). Interpretation of region of vertical faulting is supported by the fact that corresponding beds are closely juxtaposed across each fault, and that there appears to be a limited amount of extension. There are several options to consider when explaining the interpreted faulting in LSU 1:

1. Rollover zone
   - Forms on listric normal faults when the hanging wall subsides into accommodation space created by lateral movement of the fault (Xiao and Suppe, 1992).
   - Growth faults in this area are reactivated (Hanor, 1982) which has produced near surface vertical faulting. According to Xiao and Suppe (1992), a rollover will only
form when an accommodation space is created for the down going block to collapse into (Figure 81). If accommodation space is not created, the down going block will not collapse in a rollover (Figure 82).

Figure 81. Model of a listric normal fault. Beds collapse into the space created by lateral extension (Xiao and Suppe, 1992)

Figure 82. Schematic diagram of a relay ramp and normal fault without accommodation space for a rollover (Peacock and Sanderson, 1994a).
2. Gas Chimney

- Occurs when a seismic wave travels through gas-filled fractures in the subsurface, creating an area of deteriorated seismic reflectors (Arntsen et al., 2005).

- The amplitudes of reflections throughout the interpreted faulted zone appear greatly reduced from those throughout the rest of the profile. One possible explanation for this is that gas is diffused through the fault zone. Such phenomena are not uncommon throughout Southern Louisiana. The Baton Rouge Tepetate Fault System is associated with a large number of oil and gas fields (Miller and Heinrich, 2003), most notably, Livingston Field (Johnston and Johnson, 1987).

Figure 83. Synthetic seismic image of a gas chimney. Modified from Arntsen (2005).
3. Segmented Vertical expression of a reactivated fault

- Created when a fault is reactivated. The displacement occurs first in mechanically strong materials (possibly sandstone) and then in mechanically weak units (possibly shale). This results in a fault expression made of several small faults and displacements (Figure 84) (Frankowicz and McClay, 2010; Peacock, 2002)
- This option appears to be the most likely scenario based on (1) the observed faulting is segmented with variable near vertical dip (2) previous literature indicates that this is a reactivated growth fault.

![Schematic diagram of segmented fault structures](image)

The most reasonable explanation is that this faulted region is a segmented vertical expression of a reactivated growth fault that may contain gas. Previous literature states that
growth faults in this area have been reactivated (Cazes, 2004; Hanor, 1982; Nunn, 1985). The interpretation of profile LSU 1 shows faults with small offsets (< 18 meters) in the soft sediments of the near surface. Sediments in this region comprise mostly soft sand and clay as indicated on nearby interpreted well logs (Griffith, 2003), therefore this is a reasonable interpretation.

**Explanation of Fault Features**

**Fault Scarp**

The interpreted fault does not have a sharp surficial expression in the relative elevation profile located above the seismic profiles and schematic diagrams. In soft un lithified sediments, the fault scarp easily erodes, leaving behind a wide sloping region seen in the elevation profiles and shown in Figure 85 (McCulloh, 2001).

![Figure 85. Schematic diagram of a typical surficial fault line scarp in soft sediment. The area between the fault-line scarp, the projected fault scarp, and the surface indicates the amount of sediment that is eroded. Modified from McCulloh (2001).](image)
Fault Structure

The large swath of faults can be separated into two distinct fault zones (Figure 88 and Figure 89). The largest fault zone (green shading) is interpreted as a down-to-the-south normal fault zone made of several small offset faults. The smaller zone (blue shading) is interpreted as a down-to-the-north compensator or antithetic fault because it has a northern footwall and the displacement is opposite to the large down-the-south normal fault. The presence of a normal fault with an opposite-dipping antithetic fault is a common occurrence in extensional systems (Bose and Mitra, 2010).

Velocity Correlation

A velocity model is created using the RMS velocities from the velocity analysis (Figure 66). Time is converted to depth using this velocity model and posted on the right axis. From the depth scale, the thicknesses of the different interpreted packages and offsets of interpreted faults are inferred. Due to the fact that velocity generally increases with depth, in a seismic profile layers or sediment packages at depth will seem smaller than similar packages near the surface (Figure 86).

Superimposing the velocity model onto the interpretation from Figure 93 yields some interesting insights (Figure 90 and Figure 91). The most noticeable correlation is the occurrence of a low velocity zone, between 135 and 300 meters or between CDP values 40 and 90 that directly corresponds to the interpreted zones of faulting.

Gravity Correlation

The final gravity profile of Site C by Cazes (2004) (Figure 16) shows a gravity high near the fault scarp that she interprets as an asymmetric sediment wedge.
Figure 86. Schematic diagram of differences in apparent bed thickness with depth. The blue and orange blocks indicate areas of different velocities. The green beds are the exact same thickness, but the shallower green bed appears to be thicker than the deeper green bed because of the slower velocity between 0 and 0.4 seconds.
Figure 87. Schematic diagram of profile LSU 1. Black lines indicate faults and possible sediment wedges are indicated by yellow polygons. The profile along the top of the diagram is the relative elevation survey from Cazes (2004) and the profile at the bottom of the diagram is the fold of the data. The red line labeled F indicates the location of the surficial fault scarp.
Figure 88. Seismic Profile LSU 1 with interpreted faults and asymmetric wedges. Faults have been grouped into two fault regions: a down to the south normal fault that reaches the surface (green) and an antithetic fault (blue). This stack is the result of a surgical mute, bandpass filter (80,120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The profile along the top of the interpretation is the relative elevation survey from Cazes (2004) and the profile at the bottom of the interpretation indicates the fold of the data. The red line labeled F indicates the location of the surficial fault scarp.
Figure 89. Schematic diagram of profile LSU 1. Black lines indicate faults and possible sediment wedges are indicated by yellow polygons. Faults have been grouped into two regions: a down to the south normal fault that reaches the surface (green) and an antithetic fault (blue). The profile along the top of the interpretation is the relative elevation survey from Cazes (2004) and the profile at the bottom of the interpretation indicates the fold of the data. The red line labeled F indicates the location of the surficial fault scarp.
Figure 90. Seismic Line LSU 1 faults and asymmetric wedges with velocity model superimposed to give insight to the cause of variation in velocity. Lines indicate locations of constant velocity. This seismic profile is the result of a surgical mute, bandpass filter (80, 120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The profile along the top of the stack is the relative elevation survey from Cazes (2004) and the profile at the bottom of the stack indicates the fold of the data. The red line labeled F indicates the surficial fault scarp. The low velocity zone occurs between 135 and 300 meters.
Figure 91. Schematic diagram Line LSU 1 faults and asymmetric wedges with velocity model superimposed to give insight to the cause of variation in velocity. Lines indicate locations of constant velocity. The profile along the top of the interpretation is the relative elevation survey from Cazes (2004) and the profile at the bottom of the interpretation indicates the fold of the data. The red line labeled F indicates the location of the surficial fault scarp. The low velocity zone occurs between 135 and 300 meters.
To further understand the source of the gravity high, the gravity data is plotted on the same scale as the seismic interpretation (Figure 92 and Figure 93). The first and most noticeable observation is that the gravity high corresponds to the faulted region. This is significant because Cazes (2004) interpreted that the gravity high corresponded to the edge of a fault and an asymmetric wedge, like those seen in seismic profile LSU 1.

According to Densmore (2003), it is expected that relay ramp systems will exhibit sediment deposition across the faults. The interpreted wedges pinch out on the downthrown side of the fault and are thickest within the faulted zone indicating that the deposition of these wedges is contemporaneous with faulting.

**Model of Fault Movement**

Seismic line LSU 1 exhibits vertical variations in amplitude with depth. These amplitude variations are attributed to changes in lithology. To confirm this, a nearby well (~3.5 miles northwest) is converted to the depth scale of the seismic profile for comparison of the seismic amplitudes to lithology changes seen on the interpreted well log well (Figure 94). Seismic profile LSU 1 encompasses the near surface (< 500 meters), which is expected to change rapidly. Therefore it is not expected that the well will correlate very well the amplitude changes. With few exceptions, it appears that the character of the seismic does not correspond to changes in well lithology. However, the relative ages of the sand packages in the well are known and can be used to date fault movement using the seismic profile.

Using the locations of the interpreted sedimentary wedges and the ages provided by the water well log, a model for fault movement is created. Due to complexity, the entire faulted region is removed so that only the total offsets for each sedimentary wedge can be examined (Figure 102). At present, the fault cuts both the upper and lower sediment wedges.
Figure 92. Seismic Line LSU 1 faults and asymmetric wedges with gravity data from Cazes (2004). This seismic profile is the result of a surgical mute, bandpass filter (80, 120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The profile along the top of the stack is the relative elevation survey from Cazes (2004) and the profile at the bottom of the stack indicates the fold of the data. The surficial fault scarp is indicated by the red line labeled F.
Figure 93. Schematic diagram of Line LSU 1 faults and asymmetric wedges with superimposed gravity model (gray) from Cazes (2004). The profile along the top of the interpretation is the relative elevation survey from Cazes (2004) and the profile at the bottom of the interpretation indicates the fold of the data. The surficial fault scarp is indicated by the red line labeled F.
The upper wedge has an offset of 12 meters and the lower wedge has an offset of 40 meters. This upper wedge package was deposited prior to the 400-foot sand that is approximately Middle Pleistocene in age. The lower wedge was deposited between the 400 and 600-foot sands indicating an age of Early Pleistocene. During the early Pleistocene the fault was active and moved approximately 12 meters. The fault was active again during the Middle Pleistocene and moved 25 meters. Figure 95 shows the ages and displacement on the fault.

**LSU Seismic Line 4**

**Interpreted Faulting and Packages**

Although the interpreted faults in profile LSU 4 appear to be less complex than in profile LSU 1, it is quite likely that there are numerous small faults throughout the profile that are below resolution and therefore not visible in the seismic profile. Taking this into consideration, the interpretation is quite simplified. The interpretation of profile LSU 4 shows a small area of near vertical faulting (black lines) in the northern portion of the profile and interpreted offset packages (yellow) (Figure 96). The majority of the reflections in seismic profile LSU 4 appear to have an inconsistent reflection strength that can be attributed to rapid changes in lithology as in seismic Line LSU 1.

There are numerous small channels throughout the profile. This is expected due to the fact that fault tips comprise numerous small offset faults and concave fluvial channels (Densmore et al., 2007). Fault tips are typically sediment starved, producing small infilled channels as opposed to the more efficient sediment wedges located in regions where the fault is offset. The presence of channels at the tip of the fault indicates that there has been a drastic change in fault expression in just 500 meters from seismic line LSU 1. This is further explained
Figure 94. Seismic profile LSU 1 with interpreted faults (black lines) and sediment wedges (yellow polygons). The schematic inset shows that well Li-241 (indicated by a green circle) is 3.5 miles from the fault of interest (indicated by a black line) and seismic lines 1 and 4 (approximate trajectories indicated by orange lines). Well log Li-241, to the right of the seismic profile shows regions of clay in white and freshwater filled sand in blue. The sands are labeled (400, 600, 1000, 1200, and 1500) indicating that they are the 400-foot sand, 600-foot sand, etc.
Figure 95. Reconstruction of fault movement from the early Pleistocene to present day.
by Densmore (2007), who maintains that the tips of faults are transient and change more rapidly than at the fault center where there is generally more offset.

Overlying the velocity model for LSU 4 on the seismic interpretation gives insight to the cause of variations in velocity (Figure 97 and Figure 98). A low velocity zone is expected near faults and sediment wedges. The velocities in Figure 100 appear lowest across the faulted region where there are thickened sediment wedges on the down thrown sides of faults. These observations support the fault and sediment package interpretation.

**Relay Ramp Structures**

Peacock (1994) presents a list of criteria that may be used to distinguish a true relay ramp in both map view and in cross section. These are enumerated in Table 2.

In a cross section of a relay ramp, the beds within the ramp dip in the direction of the hanging wall (Table 2). In the case of seismic lines LSU 1 and LSU 4, which image only a small portion of the relay ramp, the reflectors are expected to be horizontal on the down thrown side of the fault to slightly south dipping. Profile LSU 1 (Figure 75 and Figure 76) and LSU 4 (Figure 79 and Figure 80) exhibit interpreted beds that are horizontal to south dipping, consistent with a relay ramp in cross section.

To establish that a relay ramp exists in map view, there are two important criteria that must be met: overlapping fault segments and the presence of an elevation gradient within the inferred relay ramp. First, overlapping fault segments must be present. Without overlapping fault segments, by definition a relay ramp cannot exist. LiDAR is used to image topography across the relay ramp. In Figure 100 and Figure 101, the faults (indicated by white lines in Figure 107) are seen as sharp contrasts in topography. The LiDAR shows that these faults
Figure 96. Schematic diagram of line LSU 4 interpretation. Black lines represent faults and sediment packages are represented by yellow polygons. The profile along the top of the interpretation is a relative elevation survey and the profile at the bottom of the interpretation indicates the fold of the data.
Figure 97. Seismic Line LSU 4 with interpretation with velocity model superimposed to give insight to the cause of variation in velocity. Lines indicate locations of constant velocity. This seismic profile is the result of a surgical mute, bandpass filter (80, 120, 200, 250 Hz), f-k filter, AGC, and spiking deconvolution. The profile along the top of the stack is the relative elevation survey from Cazes (2004) and the profile at the bottom of the stack indicates the fold of the data. The surficial fault scarp is indicated by the red line labeled F.
Figure 98. Schematic diagram of line LSU 4 interpretation with velocity model superimposed to give insight to the cause of variation in velocity. Lines indicate locations of constant velocity. The profile along the top of the interpretation is a relative elevation survey and the profile at the bottom of the interpretation indicates the fold of the data.
Figure 99. Seismic line LSU 4 fault reconstruction.
overlap, establishing the first criteria. Second, there must be an elevation change or gradient within the inferred relay ramp. According to Peacock (1994) this is most easily seen in a contour map across the relay ramp resembling. Black Contours have been added to the LiDAR image in Contours broadly show that elevation changes throughout the relay ramp from the level of the upper footwall to the level of the lower hanging wall. Closer examination of the contours reveals that beds are dipping slightly in the direction of the hanging wall, as expected (Figure 108). These LiDAR observations establish that there appears to be a relay ramp in map view.

Figure 100. LiDAR image of possible relay ramp. Pink shading indicates area of high elevation and blue shading indicates areas of low elevation. The orange lines are the seismic transects and the blue lines are the gravity profiles. The area of the relay ramp is labeled ramp The landfill is outlined in yellow. For reference Interstate 12 has been noted. The outline of the landfill has been left out for clarity. Modified from Cazes (2004).
Figure 101. LiDAR image of possible relay ramp with faults scarps indicated by white lines. Pink shading indicates areas of high elevation and blue shading indicates areas of low elevation. The orange lines represent the location of the seismic transects and the blue lines are location of the gravity profiles. The possible relay ramp is labeled Ramp. For reference Interstate 12 has been noted. The outline of the landfill area seen in has been left out for clarity. Modified from Cazes (2004).

Figure 102. LiDAR image of possible relay ramp with faults scarps indicated by white lines. Black contours highlight changes in topography. Pink shaded areas indicate high elevation and blue shaded areas indicates low elevation. The orange lines represent the location of the seismic transects and the blue lines are location of the gravity profiles. The possible relay ramp is labeled Ramp. For reference Interstate 12 has been noted. Modified from Cazes (2004).
CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Two seismic lines (LSU 1 and LSU 4) traverse a fault and a portion of a relay ramp system in Livingston Parish, Louisiana. Seismic line LSU 1 crossed the fault where there was an offset of approximately 1.5 meters and line LSU 4 crossed the tip of the fault where there was no discernable offset. These seismic lines were processed using Colorado School of Mines Seismic Unix processing package and then analyzed for structures indicating relay ramp development and fault movement.

Analysis of the final seismic profiles, previously interpreted gravity profile (Cazes, 2004), and available LiDAR images indicate that the character of the region imaged is consistent with the features of a relay ramp (Peacock and Sanderson, 1994). The LiDAR image shows a region of structural dip between two faults, confirming the existence of the relay ramp in map view. Seismic lines LSU 1 and LSU 4 image a very small portion of the proposed relay ramp. Although the lines do not image the entire ramp, they provide valuable information consistent with the structure of a relay ramp: the imaged area has beds that are horizontal to south-dipping.

Faulting in the near surface soft sediments occurs as a series of small faults over a broad area (Thomas and Nunn, 2006). The faults imaged by seismic lines LSU 1 and LSU 4 comprise several down-to-the-south, near vertical, normal faults and down-to-the-north antithetic faults that occur over a distance of approximately 40 meters. This is consistent with the findings of Cazes (2004) who interpreted a gravity high along the same transect as seismic line LSU 1. This high is most likely associated with the interpreted faulting in the seismic profile. The faults contain thickening and thinning sedimentary wedges that have been used to date fault movement, a technique that can be applied to other faults in similar settings.
A fault movement reconstruction of seismic lines LSU 1 and LSU 4 indicates that the fault was active two times during the Pleistocene. In the early Pleistocene, the fault moved approximately 25 meters. During the middle Pleistocene, the fault moved another 12 meters. Consequently, the total measured fault movement since the beginning of the Pleistocene is approximately 40 meters.

While previous studies (e.g., Cartwright et al., 1998; Hanor, 1982; Nunn, 1985) focused on the movement and propagation of faults along the onshore Gulf of Mexico, the near surface characteristics of relay ramps and fault propagation in the soft sediments of southern Louisiana had not been investigated. Through the evaluation of near-surface high-resolution seismic data, this study has contributed to understanding near-surface faulting in soft sediments that can be extrapolated throughout the Gulf Coast.

**Recommendations for future study**

1. A new seismic study utilizing a set of long seismic surveys, one at the tip of the fault and one where there is offset within the proposed relay ramp, extending across the upper fault, relay ramp, and lower fault to properly image the entire relay ramp system.
2. A new seismic study of a single fault in southern Louisiana that is not affected by relay ramp development to compare to this study.
3. Dating of nearby sediments to get exact ages on fault movement to better pinpoint periods of reactivation.
4. Future evaluation of seismic data to establish the possible benefits of depth-converting conversion.
REFERENCES CITED


Autin, W., 1989, Geomorphic and stratigraphic evolution of the Middle Amite River Valley, Southeastern Louisiana, Louisiana State University, Baton Rouge, Louisiana, 177 p.


APPENDIX A. EXPLANATION OF SEISMIC UNIX COMMANDS

All explanations and commands can be found in the Seismic Unix Manual (ftp://ftp.cwp.mines.edu/pub/cwpcodes/sumanual_300dpi_a4.pdf).

Reading and Writing

• SEGYREAD- Importing SEG-Y data into Seismic Unix
• SEGYWRITE-Used to write to a SEGY Tape or Diskfile
• SEGYHDRS - make SEG-Y ascii and binary headers for segywrite
• BHEDTOPAR, SETBHED - Editing the binary header file

Formatting Data

• A2B – ASCII to Binary conversion
• B2A – Binary to ASCII Conversion

Manipulating Trace Headers

• SUADDHEAD – Add SU Headers to Binary Data
• SUSTRIP – Strip SU headers from SU data
• SUPASTE – Paste SU Headers onto Binary Data

Setting, Editing, and Viewing Trace Header Fields

• SUADDHEAD – add Headers
• SUSTRIP – Strip SU Headers
• SUPASTE – Paste SU Headers
• SUKEYWORD – See SU Keywords
• SURANGE -- Get the Range of Header Values
• SUGETHW-Get the Values of Header Words in SU Data
• SUSHW – Set the Header Words

Importing Header Geometry

• SUCHW – Compute or change Header Words
• SUXEDIT – Edit Header Words

Editing SU Data

• SUWIND – window traces by keyword
• SUSORT – sort on any header key words
• SUKILL and SUMUTE - zeroing out data
• CAT-Concatenating Data
General Operations

• SUGAIN – Apply different types of gain to data
• SUOP – Unary Arithmetic Operations on data

1D Filtering Operations

• SUFILTER – applies a zero-phase, sine-squared tapered filter
• SUPEF – Wiener predictive error filtering
• SURESAMP – Resample Data in Time

Seismic Processing Utilities

• SUSTACK – Stacking Data
• SUVELAN – Velocity Analysis
• SUNMO -- Normal Moveout Correction
APPENDIX B. SEISMIC UNIX PROGRAMS USED IN THIS STUDY

(In order of use)

- **Segy2su.PL**
- **Converts SEGY to SU format for use with Seismic Unix.**

```perl
#! /usr/bin/perl

# PROGRAM NAME
# Segy2su
# Author: Dr. Juan Lorenzo
# This file does the following:
# It runs perl scripts that convert
# a SUnix segy binary file to an SU file for
# a PC

# library path (location of the library where the paths to all the seismic data etc is stored)
use lib './libAll';

# import system variables
use System_Variables qw($HOME $DATA_SEISMIC $DATA_GEOMAPS $DATA_GEOMAPS_TEXT $DATA_SEISMIC_SEGY $DATA_SEISMIC_SU $DATA_SEISMIC_SEGY_RAW $DATA_SEISMIC_SU_RAW $DATA_TYPE $GIF $PL_SEISMIC $PS $PS_SEISMIC $TEMP_DATA_GEOMAPS $TEMP_DATA_SEISMIC $V $date $junk $landscape $line $no_tail $no_head $portrait $symbols_point $verbose $projection $cal_coil $cal_LL401 $default_sample_rate $instrument $station);

$file_name[1] = $date;                  # name of file to be converted
$inbound[1]   = $DATA_SEISMIC_SEGY.'/'.$file_name[1];
$outbound[1]  = $DATA_SEISMIC_SU_RAW.'/'.$file_name[1];

# CONVERT SEGY FILES TO SU FILES

@segy2su = " segyread \  \ # Segy2su actually converts the
    tape=@inbound[1].sgy \  \ # inbound file to .su format
    endian=0 \  \ 
    > @outbound[1].su \  \ 
    ");

@flow[1] = "@segy2su & \  \ # this program was written to run as
    ");
```

124
# RUN FLOW(s)
    
    system IsNot[1];
    
    system 'echo', IsNot;

    # This final command runs the flow
    # and outputs the sequence to the
    # computer screen.

• a2bsushwcate.sh
• Input Header Geometries
  o Note: Values were first tabulated in an Excel Spreadsheet and then inspected for
        the carriage return character (^M) before running the following program.

#!/ /bin/sh --verbose
#Author: Erin Elliott
#Version: 1
#Purpose: Concatenate SU Files
#
# Convert tab delimited text file to binary
#
# Insert header parameters
#
# Create new SU Files with correct header parameters

# DEFINE WORKING DIRECTORIES
HOME='/'data1/EE_Processing_2011/lsu_line1'  # Directory with all files
DATA=$HOME'/seismic/data/revsu_w_headergeom'  # Directory with the data
HEADERS=$HOME'/geometry'  # Directory with the header files to be imported.

# DEFINE FILE NAMES AND PARAMETERS

# Data files
# Note: If populating multiple files,
#       set suinfile=catoutput and uncomment
#       uncating step at the end.

catoutput=$DATA/'lsu1cat'  # Output file
suinfile=$catoutput  # Input file
ascii=$HEADERS/'lsu1hgfinal'  # Name of ascii header file to input
binary=$ascii'.b'  # Name to use for created binary ascii file
suoutfile=$suinfile'h'  # Output file
infct='rh'  # The last two lines are functions used to
oufct='rh.2'  # categorize data files in this study, these are
              # only for the author’s reference and may be
              # removed.

#Parameters
catfirst='1001'  # First file to use
catlast='11000'  # Last file to use
col='11'
key='flr,sx,sy,sdepth,sdel,scalco,gx,gy,
    gelev,scalel,offset'
trf=$catfirst
trl=$catlast

# Remove previous files
rm -rf $suoutfile.su &
rm -rf $catoutput.su &

# Concatenating files
# The following code concatenates all specified shots (catfirst and catlast above) together
first=$catfirst
last=$catlast
for ((file_num=$first; file_num<=$last; file_num=$file_num+1))
  do
    echo 'Concatenating' $file_num.$infct'.su to' $catoutput'.su'
    cat $DATA/$file_num.$infct.su >> $catoutput.su
  done

# Zero out headers
# The following removes all unwanted header parameters. If other parameters are not
# needed, then specify the key and add a 0 to both the a and b columns.

echo 'Removing unwanted header parameters...' &
sushw < $suinfile.su
    key=grnors,grnlof,grnofr,cdp
    a=0,0,0,0 \
    b=0,0,0,0 \
    > $suinfile.z.su
&

# Remove Carriage Return Symbols
# Carriage symbols cannot be converted to binary code, therefore they must be removed
# from the ascii file using VI or another editor.

echo "Warning: Tidy up ascii files by removing carriage symbols or this will not work..."

#Converting file from ascii to binary

echo 'Converting binary files...' &
a2b <$ascii.txt n1=$col >$binary && #Actual code that converts the file, $ col
#specifies the number of columns.

# Set permissions

chmod 755 $binary &&

# Replace Header Parameters
# The following piece of code reads in the concatenated file and replaces the header
# parameters with those from the binary ascii file.

echo 'Populating header parameters...' &

$sushw < $suinfile.z.su \\
   infile=$binary \\
   key=$key \\
   > $suoutfile.su

&&

#Split files back into shot gathers:

echo 'Creating individual shot gather files...' &&

for ((num=$trf; num<=$trl; num=$num+1))
do
echo 'Creating file '$num'.rkh.su.' &
$suwind < $suoutfile.su \\
   key=fldr \\
   count=24 \\
   min=$num \\
   > $DATA/$num.$o utfct.su
done

echo 'Operation Complete' &

• rev3.sh
• Reverse polarity of traces that have incorrect phase.
  o Note: This program is only needed if the polarity of the traces has been reversed
    within a single shot gather. If this is not the case, this step may be skipped.

  o
#!/bin/sh
# set -x
# rev3.sh
# Authors: Dr. Juan Lorenzo and Erin Elliott
# Oct 7, 2009
set up working directories
Directory with input data

SU_DIR='"/data1/EE_Processing_2011/lsu_line1/seismic/data/su'  
OUT_DIR=$SU_DIR'/revsu'  
# Output directory

file names
first=1001  
last=1100  
# When using numbers as the file name, first is the first file to read in and last is the last file. All files in between will be read.

for ((file_num=$first; file_num<=$last; file_num=$file_num+1))
do
  # Taking traces 1 to 12 and writing them to a file
  echo 'Reversing trace polarity for file' $file_num.su

  suwind <$SU_DIR/$file_num.su
  key=tracf
  min=1 max=12
  > $SU_DIR/$file_num.temp1_to12.su

  # Taking traces 13 to 24, reversing the polarity and then writing them to another file.
  suwind <$SU_DIR/$file_num.su
  key=tracf
  min=13 max=24

  suop op=neg
  > $SU_DIR/$file_num.temp_13to24.su

  # Putting together files 1 and 2
  cat $SU_DIR/$file_num.temp1_to12.su
  $SU_DIR/$file_num.temp_13to24.su
  >$SU_DIR/$file_num.rev.su

  # remove temp files
  rm $SU_DIR/$file_num.temp1_to12.su
  rm $SU_DIR/$file_num.temp_13to24.su

# plotting concatenated data
sugain <SU_DIR/$file_num.rev.su  \
  age=1 wage=0.1  \
  | sufilter f=65,90,400,760  \
  | suxwigb title=$file_num.rev.su clip=1. &
done

- Select_tr_Sukill.pl and Sukill.pl
- Deletes Noisy traces that detract from data quality.
  - This step requires two programs: Select_tr_Sukill.pl and Sukill.pl and a text file
    named kill that must remain in the same directory as the two programs. The file
    named kill records the picks from Select_tr_Sukill.pl (made by pushing “s” over
    the noisy trace) and sends the list to the program Sukill.pl to be deleted when
    Sukill.pl is run
  
    - Select_tr_Sukill.pl

#!/usr/bin/perl -w

# SCRIPT NAME
# Select_tr_Sukill.pl
# Purpose: choose traces to kill
# Juan M. Lorenzo and Erin Elliott
# September 17, 2009

# Use shell transparently to locate home directory before compilation
my $library_location;
BEGIN {
  use Shell qw(echo);
  $home_directory = `echo $HOME`;  
  chomp $home_directory;
  $library_location = $home_directory.'/EE_Processing_2011/lsu_line1/libAll';
} # Location of local libraries

# LOAD GENERAL PERL LIBRARY
use lib $library_location;

# library path
#use lib /libAll;  # Library to use

# use library
use System_Variables2; # System variables is a package that contains the paths to all
                        # files and data in the system.
# import system variables
my ($DATA_SEISMIC_SU) = System_Variables2::DATA_SEISMIC_SU();
print("$DATA_SEISMIC_SU\n");

# sample rate = 125 us
# d1 = sample rate in ms = .000125

# sufile names
$sufile_in[1] = 'lsu1cat.h_kill';  # Input file
$inbound[1] = $DATA_SEISMIC_SU.'/'.$sufile_in[1].'.su';  # Path to input file

# GAIN DATA
@sugain[1] = (" sugain
  pbal=1
adiens
");  # Applies a pbal gain when selected

# GAIN DATA
@sugain[2] = (" sugain
  wagc=0.1
  agc=1
adiens
");  # Applies an automatic gain control when selected

# FILTER DATA
@sufilter[1] = (" sufilter
  f=65,90,400,760
adiens
");  # Applies a bandpass filter to data

# WINDOW DATA by time
@suwind[2] = (" suwind
  tmin=0
  tmax=1
adiens
");  # Windows the data to a maximum # time of 1 second.

# DISPLAY DATA
#key=offset
@suxwigb[1] = (" suxwigb
  title='Inbound[1]'
  label1='No. samples'
  label2='No. traces'
  wbox=600 hbox=800 xbox=0 ybox=0
  mpicks='kill'
  va=1
  xcur=3
adiens
");  # Displays the data to the screen in a # wiggle plot.
clip=2.5
"");

# DEFINE FLOW(S)
@flow[1] = (
    @suwind[2] < @inbound[1] | @sugain[2] |
    @suxwibg[1] &
"");

# RUN FLOW(S)
system @flow[1];
system 'echo', @flow[1];

Sukill.pl

#! /usr/bin/perl
# SCRIPT NAME
# Sukill.pl
# Purpose: kill traces
# Juan M. Lorenzo

# Mar 22 2009
# Modified
# Sept 29, 2009

# Use shell transparently to locate home directory before compilation

my $library_location;

BEGIN {
    use Shell qw(echo);
    $home_directory = `echo \$HOME`; chomp $home_directory;
    $library_location = $home_directory;
}

# LOAD GENERAL PERL LIBRARY
use lib $library_location.'/EE_Processing_2011_thesis/lsu_line1/libAll'; # Location of library

# CLASSES
use manage_files_by;
# use library
use System_Variables2; # Library to use

# import system variables
my ($DATA_SEISMIC_SU) = System_Variables2::DATA_SEISMIC_SU();
my ($PL_SEISMIC) = System_Variables2::PL_SEISMIC();

# sufile names
$sufile_in[1] = 'lsu1cat.h_kill'; # Input file
$sufile_out[1] = $sufile_in[1].'_kill'; # Output file
$su_inbound[1] = $DATA_SEISMIC_SU.'/'.$sufile_in[1].'.su';
$su_outbound[1] = $DATA_SEISMIC_SU.'/'.$sufile_out[1].'.su';

# sukill name
$sukill_in[1] = 'kill'; # input file from Select_tr_Sukill.pl output ‘kill’
$sukill_inbound[1] = $PL_SEISMIC.'/'.$sukill_in[1]; # Location of kill file
$sukill_outbound[1] = $PL_SEISMIC.'/'.$sukill_out[1]; # Location of output

# read file names
$file_in[1] = 'kill'; # File to read in
@read_file[1] = $PL_SEISMIC.'/'.$file_in[1]; # Location of file to read

# GAIN DATA
@sugain[1] = (" sugain
  pbal=1
"); # Applies a pbal gain

# GAIN DATA
@sugain[2] = (" sugain
  wage=0.1
  agc=1
"); # Applies an automatic gain control

# FILTER DATA
@sufilter[1] = (" sufiltter
  f=65,90,400,760
"); # Applies a bandpass filter

# WINDOW DATA
@suwind[2] = (" suwind
"); # Windows the data to a maximum
\[t_{\text{min}} = 0 \quad \text{\# time of 1 second}\]
\[t_{\text{max}} = 1\]

```
)

# READ KILL DATA

\[
(#\text{ref\_T\_kill},#\text{ref\_X\_kill},#\text{num\_tr\_kill}) = \text{manage\_files\_by::read\_2cols(}@\text{read\_file}[1]);
\]

# reads kill file

# report traces killed
# round off traces to whole number

\[
\text{print("\n\n\ntNumber of traces = } #\text{num\_tr\_kill}\n")};
\]

# Prints to the screen the
# number of traces killed.

\[
\text{for (}#i=1; #i<=#\text{num\_tr\_kill}; #i++) { # Rounds the trace
\]
\[
\text{\$#\text{ref\_X\_kill}\$[i] = int(\$#\text{ref\_X\_kill}\$[i] + 0.5); # number to the}
\]

# nearest integer

\[
\text{\text{print("\ntKilled trace } #\$#\text{ref\_X\_kill}\$[i]\n")};
\]

# KILL DATA

# Kill first trace

\[
<@\text{sukill}[1] = (" # When called, kills the first
\]

\[
<@\text{su\_inbound}[1] \quad #\text{su\_inbound}[1] \quad #\text{trace recorded in the kill}
\]

\[
\text{min} = \$\text{ref\_X\_kill}[1] \quad #\text{smallest} \quad #\text{file.}
\]

\[
\text{count} = 1
\]

```

# Kill remaining traces

\[
\text{for (}\#i=2; \#i<=\#num\_tr\_kill; \#i++) { # When called, kills the
\]

\[
\text{\@sukill}[\#i] = (" | \# remaining traces recorded
\]

\[
\text{\sukill} \quad #\text{su\_inbound}[1] \quad #\text{remaining traces recorded}
\]

\[
\text{\min} = \$\text{ref\_X\_kill}[\#i] \quad #\text{smallest}
\]

\[
\text{\count} = 1
\]

```

# Kill all traces
# initiate text array

\[
\@\text{sukill\_All}[1] = \@\text{sukill}[1];
\]

\[
\text{for (}#i=2; #i<=#\text{num\_tr\_kill}; #i++) { \# Flow calls the programs to
\]

\[
```

133
```plaintext
@sukill_All[1] = @sukill_All[1].@sukill[i]; # kill all traces.

# DISPLAY DATA

#key=offset
@suxwigb[1] = (" suxwigb
    title='SH component'
    label1='TWTT(s)' 
    label2='No. traces'
    wbox=400 hbox=600 xlabel=0 ylabel=0
    va=1
    xcur=3
    clip=4.0
    ");

# DISPLAY DATA

#key=offset
@suxwigb[2] = (" suxwigb
    title='SH traces killed'
    label1='TWTT (s)'
    label2='No. traces'
    wbox=400 hbox=600 xlabel=450 ylabel=0
    va=1
    xcur=3
    clip=4.0
    ");

# DISPLAY DATA

@suximage[1] = (" suximage
    title='SH traces killed'
    label1='Time (s)'
    label2='No. traces'
    n2tic=1 d2num=20
    wbox=400 hbox=600 xlabel=900 ylabel=0
    ");

# DEFINE FLOW(S)

@flow[1] = ("
    @sugain[2]
    "); # Defines flow to display original
```
< @su_inbound[1] |
@suxwieg[1]
&
"");

# DEFINE LOOPED FLOW

@flow[2] = (" @sukill_All[1] |
@sugain[2] |
@suxwieg[2]
&
"));

# DEFINE LOOPED FLOW

@flow[3] = (" @sukill_All[1] |
@sugain[2] |
@suximage[1]
&
"));

# DEFINE FLOW

@flow[4] = (" @sukill_All[1]
>$su_outbound[1]
&
"));

# RUN FLOW(S)

system @flow[1];
#system 'echo', @flow[1];

system @flow[2];
#system 'echo', @flow[2];

system @flow[3];
#system 'echo', @flow[3];

system @flow[4];
#system 'echo', @flow[4];
• **PrestackFlow.pl**
• There was a single program that performed the bandpass filter, refraction mute, f-k filtering and automatic gain control. The usage for each is outlined below and the program follows.

  - **Bandpass filter**
  @sufilter[1] = (" sufilter \f=80,120,250,600
                 ");

  - **Refraction Mute**
  @sumute[1] = (" sumute \tfile=tmute2
                  \xfile=xmute2
                  \nmute=7
                  \key=tracf
                  \below=0
                  \ntaper=4000 ");
  - where xfile and tfile contain the values that tailor the mute to the refractions.

  - **f-k Filtering**
  @airdipfilter[1] = (" sudipfilt \dt=1 \dx=.01
                      \amps=1,0,0,1
                      \bias=0
                      \slopes=0,6,30,50
                      ");

  - **Automatic Gain Control**
  @sugain[2] = (" sugain \wagc=.1
                 \agec=1
                 ");

  - **PrestackFlow.pl**

    ```perl
    #!/usr/bin/perl
    #-w
    # SCRIPT NAME
    # Prestack/ Velocity Analysis Processing Flow
    ```

  ```bash
  #!/usr/bin/perl
  ```
# Purpose: Process Data
# Author: Erin Elliott
#

# Use shell transparently to locate home directory before compilation

my $library_location;

BEGIN {
    use Shell qw(echo);
    $home_directory = `echo $HOME`;
    chomp $home_directory;
    $library_location = '/data1/EE_Processing_2011/lsu_line1';
}

# LOAD GENERAL PERL LIBRARY

# use lib $library_location;
# library path
use lib '/data1/EE_Processing_2011/lsu_line1/libAll';
# use library
use System_Variables2;
use Input_me;
# use library
use manage_files_by;
# import system variables

my ($DATA_SEISMIC_SU) = System_Variables2::DATA_SEISMIC_SU();
my ($INPUT_FILE) = Input_me::INPUT_FILE();

# Define files and parameters:
# Note: Change file in Input_me.pm, not here.

# sufile names
$sufile_in[1] = $INPUT_FILE;
$sufile_out[1] = $sufile_in[1].'_p';  # Input
$inbound[1] = $DATA_SEISMIC_SU.'/'.s$ufile_in[1]'.su';  # path to input file
$outbound[1] = $DATA_SEISMIC_SU.'/'.s$ufile_out[1]'.su';  # path to output file

print("n INPUT: $inbound[1]n");
print("n OUTPUT: $outbound[1]n");

### Please do not alter below here unless you know what you are changing!###
# Begin Mute Data
# Muted data points come from tmute and xmute individual files located in /pl.

# Refraction Mute
@sumute[1] = (" sumute
   tfile=tmute2
   xfile=xmute2
   nmute=7
   key=tracf
   below=0
   ntaper=4000 ");

@sumute[2] = (" sumute
   tfile=tmute2
   xfile=xmute2
   nmute=2
   key=tracf
   below=0
   ntaper=4000 ");

#Airblast f-k Fiter
@airdipfilter[1] = (" sudipfilt
   dt=1 dx=.01
   amps=1,0,0,1
   bias=0
   slopes=0,6,30,50
   ");

#End Muting Data

# Begin Window Data (window data by time)
@suwind[1] = (" suwind
   tmin=0
   tmax=0.6
   ");

# End Window Data

# Begin Gain Data

# GAIN DATA
$text_sugain[1]="pbal ";
@sugain[1] = (" sugain
   pbal=1
   ");

# GAIN DATA (AGC)

$wagc = 0.1;
$text_sugain[2] = 'wagc='.$wagc;
@sugain[2] = (" sugain
   wage=$wagc
   age=1
   ");

# Gain Data (tpow)
@sugain[3] = (" sugain
   tpow=2
   ");

# End Gain Data
#

#Begin Band Pass filter

$bp_filter = '80,120,200,250';
$text_sufilter[1] = 'bpf '.$bp_filter;
@sufilter[1] = (" sufilter
   f=$bp_filter
   ");
@sufilter[2] = (" sufilter
   f=0,3,1000,1200
   ");

#Begin Spiking Decon

$min_lag = 0.000125;
$max_lag = .0023;
$text_supef[1] = 'Lag '.$min_lag.' '.$max_lag;
@supef[1] = (" supef
   maxlag=$max_lag
   ");

#End Spiking Decon
#

#Begin F-K Analysis
# F-K SPECTRAL ANALYSIS
@suspecfk[1] = (" suspecfk
dt=1 dx=1"");

# LINEAR MOVEOUT

@sSureduce[1] = (" sureduce
rv=1.5"");

# LINEAR MOVEOUT

@sSureduce[2] = (" sureduce
rv=-1.5"");

# APPLY DIP FILTER

@sudipfilter[1] = (" sudipfilt
dt=1 dx=.01
amps=1,0,0,1
bias=0
slopes=10,20,48,70"");

# APPLY DIP FILTER

@sudipfilter[2] = (" sudipfilt
dt=1 dx=.01
amps=1,0,0,1
bias=0
slopes=10,100,175,250"");

#End F-K Analysis

# Begin Display Data

# Not processed Data

$xlabel = 'Trace number';
$ylabel = 'Time(s)';
$X0 = 0;
$widthbox = 300;

@suximage[1] = (" suximage
  title='Gain'
  label1='$tlabel'
  label2='$xlabel'
  windowtitle='No Processing:$sufile_in[1]' \
  xbox=$X0
  wbox=$widthbox
  clip=5
  ");

# Processed Data

$xlabel = 'Trace number';
$tlabel = 'Time(s)';
$X0 = 400;
$widthbox = 300;
$windowtitle = 'Processed Data:$sufile_in[1]';

@suximage[2] = (" suximage
  title='Mute,S.D.,Filter,Gain'
  label1='$tlabel'
  label2='$xlabel'
  windowtitle='Processed Data:$sufile_in[1]' \
  xbox=$X0
  wbox=$widthbox
  clip=5
  ");

# END Display Data

# DEFINE FLOW(S)
# Uncomment Flow[3] to save file

@flow[1]= ("  @suwind[1]    \ # Flow that outputs a gained and
  < @inbound[1]     | \ # filtered version of the data to the
  @sufilter[2]      | \ # screen.
  @sugain[2]        | \n  @suximage[1]     \ & ");
@flow[2] = (" 
  @suwind[1]  \<  @inbound[1]   \<  @sumute[1] | \<  @sufilter[1] | \<  @sugain[2] | \<  @airdipfilter[1] | \<  @sudipfilter[1] | \<  @suximage[2] & ");

@flow[3] = (" 
  @suwind[1]  \<  @inbound[1]   \<  @sumute[1] | \<  @sufilter[1] | \<  @sugain[2] | \<  @airdipfilter[1] | \<  @sudipfilter[1] | > @outbound[1] & ");

# Always check to see if you are running the correct flow! 
# RUN FLOW(S)

system @flow[1];
system 'echo', @flow[1];
system @flow[2];
system 'echo', @flow[2];
system @flow[3];
system 'echo', @flow[3];

- Brute Stack.pl
  o For a brute common depth point stack, the output file from PrestackFlow.pl was fed through the following program, BruteStack.pl, to obtain a constant velocity stack. In this case, the velocity was 1350m/s.

#!/usr/bin/perl
# w

# SCRIPT NAME
# BruteStack.pl
# Run After running Prestack Flow
# Purpose: Stack Data
# Erin Elliott

# Use shell transparently to locate home directory before compilation

my $library_location;
BEGIN {
    use Shell qw(echo);
    $home_directory = `echo $HOME`;
    chomp $home_directory;
    $library_location = '/data1/EE_Processing_2011/lsu_line1';
}

# LOAD GENERAL PERL LIBRARY
# use lib $library_location;
# library path
use lib '/data1/EE_Processing_2011/lsu_line1/libAll';       # Path of library to be used.

# use library
use System_Variables2;                                    # Files from library to be used.
use Input_me;
# use library
use manage_files_by;

# import system variables

my ($DATA_SEISMIC_SU) = System_Variables2::DATA_SEISMIC_SU();
my ($INPUT_FILE) = Input_me::INPUT_FILE();

#Define files and parameters:

# Note: Change file in Input_me.pm, not here.

# sUfile names
$sufile_in[1]   = $INPUT_FILE.'p';     # Input file, in this case, is read from
                                          # a file in the library.
$sufile_out[1]  = $sufile_in[1].'bs';  # Output file
$inbound[1]     = $DATA_SEISMIC_SU.'/'.$sufile_in[1].'.su';  # Location of
                                          # inbound file.
$outbound[1]    = $DATA_SEISMIC_SU.'/'.$sufile_out[1].'.su'; # Location of
                                          # outbound file.
$tempfile[1]    = $DATA_SEISMIC_SU.'/'.$sufile_in[1].'_s.su'; # Temporary
                                          # output file.

print("\nINPUT: $inbound[1]\n");
print("\nOUTPUT: $outbound[1]\n");
## Begin Creating CDP Values
# Each portion of this section creates different common depth point (cdp) values based on 
# the fold (12, 24, 36) desired. This is done by calling the fold desired in the flow.

```
@fold[12] = (" suchw
    key1=cdp
    key2=sy
    key3=gy
    a=0
    b=1
    c=1
    d=300
 
);
```

```
@fold[24] = (" suchw
    key1=cdp
    key2=sy
    key3=gy
    a=0
    b=1
    c=1
    d=600
 
.FromSeconds
```

```
@fold[36] = (" suchw
    key1=cdp
    key2=sy
    key3=gy
    a=0
    b=1
    c=1
    d=900
 
.Consumer
```

## End Creating CDP Values

## Begin Sorting by CDP Values

```
@sort[1] = (" # Sorts the cdp values by cdp number and then
```
susort \ \  # offset.
cdp \ \
offset \ \

");

#End Sorting by CDP Values
#

# Begin Window Data by trac1 to remove cdp empty cells (no data)

@suwind[1] = ("suwind \ \ # Windows the data based the location
dowl \ \ # within the line. This effectively removes
dowl \ \ # all traces without cdp values, these were
dowl \ \ # traces within shot gathers that need to be
dowl \ \ # deleted, and done here for ease in
dowl # processing.

#End Window Data
#

#Begin Normal Moveout
#vel='1500';

@NMO[1] = ("sunmo \ \ # Applies a single stacking velocity to the
dowl \ \ # entire stack. Velocity is large because
dowl \ \ # every header value has been scaled by 100
dowl # and therefore the velocity must be as well.

#End Normal Moveout
#

#Begin Stacking Data

@stack[1] = (" sustack \ \ # Stacks the data based on a specified key
dowl \ \ # value, in this case it is cdp

dowl 
");

#End Stacking Data
#

#Begin Spiking Decon
$min_lag = 0.000125;
$max_lag = .0023;
$text_sup[1] = 'Lag '.$min_lag.' '.$max_lag;
@sup[1] = (" sup[1] \ \ # Applies a spiking deconvolution
dowl \ \ # to collapse reflections in the final
dowl \ \ # profile.

dowl ");

#End Spiking Decon
#

#End Gain Data
# GAIN DATA
$text_sugain[1] = 'pbal';
@sugain[1] = (' sugain
  pbal=1
'));

# GAIN DATA
$wagc = 0.1;
$text_sugain[2] = 'wagc='.$wagc;
@sugain[2] = (' sugain
  wagc=$wagc
  agc=1
'));

# End Gain Data
#_______________________________________________________________________
#Begin Band Pass filter
#
$bp_filter = '80,120,200,250';
$text_sufilter[1] = 'bpf '.$bp_filter;
@sufilter[1] = (' sufilter
  f=$bp_filter
'));

#End Band Pass filter
#_______________________________________________________________________
#Display Data
# Stacked Data
$xlabel = 'Trace';
$tlabel = 'Time(s)';
$X0 = 10;
$widthbox= 1600;

@suximage[1] = (' suximage
  title='Brute Stack 1350 m/s'
  label1='$tlabel'
  label2='$xlabel'
  windowtitle='$sufile_out[1]'
  xbox=$X0
  wbox=$widthbox
  clip=5
'));

# @suxwigb[1] = suxwigb key=cdp clip=2
# Outputs the final brute stack to the screen in a wiggle plot.

#
# DEFINE FLOW(S)
# Uncomment Flow[3] to save file

@flow[1] = ("
@fold[24] \n< @inbound[1] | \n@sort[1] \n> cdptemp.su \n""); # Flow that creates cdp values (12, 24, 36)
# sorts them based on cdp value, and then # writes the new data to a temporary file.

@flow[2] = ("
@suwind[1] \n< cdptemp.su \n> cdptempwind.su \n""); # This flow windows the data.

@flow[3] = ("
@NMO[1] \n< cdptempwind.su | \n@stack[1] | \n@sufilter[1] | \n@sugain[1] | \n@suximage[1] \n& "); # This flow performs the normal moveout,
# stacking and output to the screen in a # variable amplitude plot.

@flow[4] = ("
@NMO[1] \n< cdptempwind.su | \n@stack[1] \n> @outbound[1] \n& "); # This flow performs the normal moveout,
# stacks the data, and then outputs it to a # file.

# End Define Flows
#

# Run Flows
system @flow[1];
system 'echo', @flow[1];
system @flow[2];
system 'echo', @flow[2];
system @flow[3];
system 'echo', @flow[2];
system @flow[4];
To conduct a velocity analysis, a consortium of programs, called IVA.pl, was used. This program outputs the cdp of interest along with the previous velocity analysis of that cdp value for adjustment if needed. IVA.pl requires the following programs to work:

- iVrms2Vint.pl
- iVpicks2par.pl
- iSunmo.pl
- iSuvelan.pl
- iWrite_All_iva_out.pl

IVA.PL

# SCRIPT NAME
# IVA.pl
# Purpose: Moveout data
# Juan M. Lorenzo
# April 2 2009
# Modified Feb 16 2010 by Erin

# Use shell transparently to locate home directory before compilation

my $library_location;

BEGIN {
    use Shell qw(echo);
    $home_directory = `echo \$HOME`;
    chomp $home_directory;
    $library_location = '/data1/EE_Processing_2011/lsu_line1';
}

# LOAD GENERAL PERL LIBRARY

# use lib $library_location;

# library path
    use lib '/data1/EE_Processing_2011/lsu_line1/libAll'; # Location of libraries.

# use library
    use System_Variables2; # Libraries to use.
    use Input_me;

# use library
    use manage_files_by;
# import system variables
my ($DATA_SEISMIC_SU) = System_Variables2::DATA_SEISMIC_SU();
# my ($PL_SEISMIC) = System_Variables2::PL_SEISMIC();

# DEFINE FLOW(S)
# The following flow runs each of the programs in succession as long as the user
# answers that the picks made are not sufficient by typing n for no when prompted
# at the end of the flow. If the user is satisfied with the outcome, then typing y for
# yes saves the output to a file.

@flow[1] = ("response='n';
                while [\$response = 'n'];
                do
                    perl iVrms2Vint.pl;
                    perl iVpicks2par.pl;
                    perl iSunmo.pl;
                    perl iSuvelan.pl;
                    echo 'junk';
                    echo 'Picks OK? y/n' > /dev/tty;
                    read response;
                done;
                perl iWrite_All_iva_out.pl;
"");

# RUN FLOW(S)

    system @flow[1];
    #system 'echo', @flow[1];

- iVrms2Vint.pl

    #!/usr/bin/perl
    # SCRIPT NAME
    # iVrms2Vint.pl
    # Purpose: Convert Vrms to Vinterval
    # Juan M. Lorenzo
    # April 7 2009

    # Use shell transparently to locate home directory before compilation
    my $library_location;
    BEGIN {
        use Shell qw(echo);
        $home_directory = `echo \$HOME`;
        chomp $home_directory;
$library_location = '/data1/EE_Processing_2011/lsu_line1';
}

# LOAD GENERAL PERL LIBRARY
use lib '/data1/EE_Processing_2011/lsu_line1/libAll'; # location of libraries

# CLASSES
use manage_files_by;
use seismics;

# library path
use lib '/data1/EE_Processing_2011/lsu_line1/libAll'; # Location of libraries.

# use library
use System_Variables2; # Libraries to use.
use Input_me;

# import system variables
my ($PL_SEISMIC) = System_Variables2::PL_SEISMIC();
# my ($date) = System_Variables2::date();
my ($INPUT_FILE) = Input_me::INPUT_FILE();

# su file names
@sufile_in[1] = $INPUT_FILE; # Input file from library.
@vpicks_stdin[1] = 'ivpicks_old';
@vint_std[1] = 'ivint_old';

# suffixes
@sorted_suffix[1] = 'sorted'; # Used to denote files as
@plot_prefix[1] = '.plot'; # and plotted.
# Name of sorted files
@sortfile_in[1] = @vpicks_stdout[1];
@sortfile_out[1] = @vpicks_stdout[1].'_'.@sorted_suffix[1];

# Input file
@inbound[1] = $PL_SEISMIC.'/'.@sortfile_in[1].'_'.@sufile[1];

# Output file
@outbound[1] = $PL_SEISMIC.'/'.@sortfile_out[1].'_'.@sufile[1];

# Names of Velocity files
@Vrmsfile_in[1] = @vpicks_stdout[1].'_'.@sorted_suffix[1];
@Vrms_read_file[1] = $PL_SEISMIC.'/'.@Vrmsfile_in[1].'_'.@sufile[1];

# a2b file names
# Names of files converted from ascii format to binary.
$num_samples_file[1] = '.num_samples_Vrms_Vint';
$num_sample_cols[1] = 2;

# Write out file names to a file
@writefile_out[1] = @vint_stdout[1];
@Vint_outbound[1] = $PL_SEISMIC.'/'.@writefile_out[1].'_'.@sufile[1];

@writefile_out[2] = @plot_prefix[1].'_'.@vint_stdout[1];
@Vint_plot_outbound[1] = $PL_SEISMIC.'/'.@writefile_out[2].'_'.@sufile[1];

# SORT TEXT FILE
@sort[1] = (" sort \\
          -n \\
          ");
# TEXT to BINARY CONVERSION
# Converts ascii files to binary files.

    @a2b[1] = ("a2b
          outpar=$num_samples_file[1] \n
          n1=$num_sample_cols[1] \n
          ");

# DEFINE FLOW(S)
# Defines the order that the previous commands are to be executed.

    @flow[1] = (" \n          @sort[1] \n
          < @inbound[1] \n
          > @outbound[1] \n
          ");

# RUN FLOW(S)
# Runs the flows in the order previously created by DEFINE FLOW(S) above.

    system @flow[1];
    #system 'echo', @flow[1];

################################################################## NON-STRUCTURED
##################################################################

# READ FILE
# read Vrms file

    ($ref_T,$ref_Vrms,$num_points_Vrms) =
    manage_files_by::read_2cols(@(Vrms_read_file[1]));

    #print("ntime=$ref_T[1]\nVrms=$ref_Vrms[1]\nn=$num_points_Vrms \n");

# CONVERT VRMS to VINT FILE

    ($ref_Vint,$ref_Tnew,$num_points_Vint) =
    seismics::Vrms2Vint($ref_T,$ref_Vrms,$num_points_Vrms);
# CREATE PLOTTING VALUES
# normally, first time is >0
# This section plots all of the picked points on the graphs for analysis.

if($$ref_Tnew[1] > 0.) {
    $Time_plot[1] = 0;
    $Vint_plot[1] =$ref_Vint[1];
    for ($i=1; $i<$num_points_Vint; $i++) {
        $j = 2 * $i;
        $Time_plot[$j] = $$ref_Tnew[$i];
        $Time_plot[$j+1] = $$ref_Tnew[$i];
        $Vint_plot[$j] = $$ref_Vint[$i];
        $Vint_plot[$j+1] = $$ref_Vint[$i+1];
    }
    $num_points_Vint_plot = $j+1;
}

if($$ref_Tnew[1] == 0.) {
    $Time_plot[1] = 0;
    $Vint_plot[1] =$ref_Vint[1];
    for ($i=2; $i<=$num_points_Vint; $i++) {
        $j = 2 * $i;
        $Time_plot[$j] = $$ref_Tnew[$i];
        $Time_plot[$j+1] = $$ref_Tnew[$i];
        $Vint_plot[$j] = $$ref_Vint[$i];
        $Vint_plot[$j+1] = $$ref_Vint[$i];
    }
    $num_points_Vint_plot = $j+1;
}

# WRITE OUTPUT FILE
# write Vint file for plotting.

$format='%10.3f  %10.3f';
manage_files_by::write_2cols(@(Time_plot,@Vint_plot,$num_points_V
int_plot,@Vint_plot_outbound[1],$format);

# Parameters to graph files using XGRAPH.

$wbox = 300;
$hbox = 450;
$xbox = 970;
$ybox = 0;
@geometry[1] = '-geometry '.$wbox.'x'.$hbox.'+'.$xbox.'+'.$ybox;

@xgraph[1] = (" xgraph
n=$num_points_Vrms,$num_points_Vint_plot
x1beg=0 x2beg=20 x1end=50000 x2end=450000
label1=’Time (sec)’
label2=’Velocity (m/sec)’
windowtitle=@sufile_in[1]’ $date
title=@Vrmsfile_in[1]’ Vrms(Green) Vint(Red) $cdp’
grid1=solid grid2=solid
mark=0,8 marksize=12,8
@geometry[1]
linewidth=2,2 linecolor=3,2
style=seismic
");

###################################
#
# DEFINE FLOW(S)
# Defines the order that the previously created commands and generic commands
# are to be run.
#
@flow[2] = (" cat @Vrms_read_file[1] @Vint_plot_outbound[1] | \n@a2b[1] | \n@xgraph[1] \n& \n")

# RUN FLOW(S)
# Runs commands in the order specified by DEFINE FLOW(S)
system @flow[2];
system 'echo', @flow[2];

# WRITE OUTPUT FILE
# Writes Vint file

$format="%10.3f %10.3f;
    manage_files_by::write_2cols($ref_T,$ref_Vint,$num_points_Vint,[],$Vin
t_outbound[1],$format);

o iVpicks2par.pl

#!/usr/bin/perl
# SCRIPT NAME
# iVpicks2par_vpicks.pl
# Purpose: Prepare velocity picks for input to Sunmo
# Interactive mode
# Juan M. Lorenzo
# April 7 2009
# Adapted from Forel and Pennington's iva.sh script
# Modified by Erin on Feb 16 2010

# Use shell transparently to locate home directory before compilation
my $library_location;
BEGIN {
    use Shell qw(echo);

    $home_directory = `echo \$HOME`;
    chomp $home_directory;
    $library_location = '/data1/EE_Processing_2011/lsu_line1';
}

# LOAD GENERAL PERL LIBRARY
use lib '/data1/EE_Processing_2011/lsu_line1/libAll';

# library path
# Path to preferred library directory:

    use lib '/data1/EE_Processing_2011/lsu_line1/libAll';

# use library
# Different variable and path packages within library directory to load:
    use System_Variables2;
    use Input_me;
# import system variables
my ($PL_SEISMIC) = System_Variables2::PL_SEISMIC();
my ($INPUT_FILE) = Input_me::INPUT_FILE();

# Preferred file names to use:
@sufile_in[1] = 'trash';
@sortfile_in[1] = 'ivpicks_old_'.@sufile_in[1];
@sortfile_out[1] = 'ivpicks_sorted_'.@sufile_in[1];
@inbound[1] = $PL_SEISMIC.'/'.@sortfile_in[1];

# Parameter file names that contain the picks from the interactive velocity analysis.
@parfile_out[1] = 'ivpicks_sorted_par_'.@sufile_in[1];
@outbound[1] = '$PL_SEISMIC/'.@parfile_out[1];

# SORT TEXT FILE
@sort[1] = ('sort -n', '');

# CONVERT TEXT FILE TO PAR FILE
# Converts the files containing the picks into one parameter (par) file for use in stacking.
@mkparfile[1] = ('mkparfile string1=tnmo string2=vnmo ');

# Prepare picks for sunmo
# DEFINE FLOW(S)
# Defines the order of programs and commands are to be run.
@flow[1] = ('@sort[1] < @inbound[1] | @mkparfile[1] > @outbound[1] & ');

# RUN FLOW(S)
# Runs the flows previously defined in DEFINE FLOW(S).
system @flow[1];
#system 'echo', @flow[1];
# SCRIPT NAME

# Sunmo.pl
# Purpose: Moveout data
# Juan M. Lorenzo
# April 2 2009
# Modified by Erin on Feb 16 2010

# Use shell transparently to locate home directory before compilation
my $library_location;
BEGIN {
    use Shell qw(echo);
    $home_directory = `echo ~/.HOME`; 
    chomp $home_directory;
    $library_location = '/data1/EE_Processing_2011/lsu_line1';
}

# LOAD GENERAL PERL LIBRARY
# Library Directory
use lib '/data1/EE_Processing_2011/lsu_line1/libAll';

# Path to Library Directory
use lib '/data1/EE_Processing_2011/lsu_line1/libAll';

# Libraries within Library Directory to use.
use System_Variables2;
use Input_me;

# System Variables to import from Libraries
my ($DATA_SEISMIC_SU) = System_Variables2::DATA_SEISMIC_SU();
my ($PL_SEISMIC) = System_Variables2::PL_SEISMIC();
my ($INPUT_FILE) = Input_me::INPUT_FILE();

# SU File Names
@sufile_in[1] = $INPUT_FILE;
@parfile_in[1] = 'ivpicks_sorted_par'.@sufile_in[1];
@inbound[1] = $DATA_SEISMIC_SU.'/'.@sufile_in[1].'.su';

# Parameter file names
@vel_in[1] = $PL_SEISMIC.'/'.@parfile_in[1];

# GAIN DATA
# Applies a pbal gain to the data set
@sugain[1] = (" sugain
    pbal=1
"");

# Applies an automatic gain control to the data set
@sugain[2] = (" sugain
    wagc=0.1
    agc=1
"");

# FILTER DATA
# Applies a bandpass filter to the data
@sufilter[1] = (" sufilter
    f='30,32,600,750'
"");

# MOVE OUT DATA
# Applies a normal move out to the data. Velocity is specified by an input file.
@sunmo[1] = (" sunmo
    par=@vel_in[1]
"");

# DISPLAY DATA
# Displays the data on the screen as a variable amplitude image
@suximage[1] = (" suximage
    title=@sortedfile_in[1]
    label1='Time (s)'
    label2='No. traces'
    perc=99
    n2tic=1 d2num=20
    wbox=300 hbox=450 xbox=670 ybox=0
"");

# DEFINE FLOW(S)
# Defines the order to run the previously created commands.
@flow[1] = (" @sunmo[1]
    < @inbound[1] |
    @sugain[2] |
    @sufilter[1] |
    @suximage[1]
    &
"");
# RUN FLOW(S)
# Runs the flows created in DEFINE FLOW(S).
#     system @flow[1];
#     system 'echo', @flow[1];

- **iSuvelan.pl**

```perl
#!/usr/bin/perl

# SCRIPT NAME
# Suvelan.pl
# Purpose: Generate Velocity Analysis
# Juan M. Lorenzo
# April 1 2009
# Modified by Erin Feb 16 2010

# Use shell transparently to locate home directory before compilation
my $library_location;
BEGIN {
  use Shell qw(echo);
  $home_directory = ` echo
                   \$HOME`;
  chomp $home_directory;
  $library_location = '/data1/EE_Processing_2011/lsu_line1';
}

# LOAD GENERAL PERL LIBRARY
# Path to general library
use lib '/data1/EE_Processing_2011/lsu_line1/libAll';

# CLASSES
use manage_files_by;

# library path
use lib '/data1/EE_Processing_2011/lsu_line1/libAll';

# use library
use System_Variables2;
use Input_me;

# import system variables
my ($DATA_SEISMIC_SU) = System_Variables2::DATA_SEISMIC_SU();
my ($PL_SEISMIC) = System_Variables2::PL_SEISMIC();
my ($INPUT_FILE) = Input_me::INPUT_FILE();
```
# sufile names
@sufile_in[1] = $INPUT_FILE;
@inbound[1] = $DATA_SEISMIC_SU.'/'.$sufile_in[1].'.su';

# text file in
@textfile_in[1] = 'ivpicks_old_'.$sufile_in[1];
@Tvel_inbound[1] = $PL_SEISMIC.'/'.$@textfile_in[1];

# text file out
@textfile_out[1] = 'ivpicks_'.$sufile_in[1];
@Tvel_outbound[1] = $PL_SEISMIC.'/'.$@textfile_out[1];

# duplicate fileout
@duplicatefile_in[1] = 'ivpicks_'.$sufile_in[1];
@Tvel_duplicate_inbound[1] = $PL_SEISMIC().'/'.@duplicatefile_in[1];
@duplicatefile_out[1] = 'ivpicks_old_'.$sufile_in[1];
@Tvel_duplicate_outbound[1] = $PL_SEISMIC().'/'.@duplicatefile_out[1];

# COLLECT FILE INFORMATION
($ref_T_nmo,$ref_Vnmo,$num_tvel_pairs) = manage_files_by::read_2cols('@Tvel_inbound[1]');
print("nReading: @Tvel_inbound[1]
\nTime=$$ref_T_nmo[1],Vel=$$ref_Vnmo[1],npairs=$num_tvel_pairs \n");

# GAIN DATA
@sugain[1] = (" sugain
  pbal=1"
);

# GAIN DATA
@sugain[2] = (" sugain
  wagc=0.1
  agec=1"
);

# FILTER DATA
@sufilter[1] = (" sufilter
  f='0,3,700,900'
"
);

# DUPLICATE FILE
@cp[1] = (" cp
    ");

# VELAN DATA
$number_of_vels[1] = 30;
$vel_increment[1] = 20000;
$first_velocity[1] = 50000;
@suvelan[1] = (" suvelan
    nv=$number_of_vels[1]
    dv=$vel_increment[1]
    fv=$first_velocity[1]
    ");

# DISPLAY DATA
$time_inc = 0.2;
$time_tick_inc = 2;

@suximage[1] = (" suximage
    title=@textfile_in[1]
    legend=1
    cmap=hsv2
    units=Semblance
    npair=$num_tvel_pairs
    curve=@Tvel_inbound[1]
    perc=99
    f2=$first_velocity[1]
    d2=$vel_increment[1]
    label1='TWTT(s)'
    label2='Velocity (m/s)'
    n2tic=1000 d2num=100000 f2num=0
    n1tic=$time_tick_inc d1num=$time_inc
    wbox=300 hbox=450 xbox=10 ybox=10
    grid1=solid grid2=solid
    verbose=0
    mpicks=@Tvel_outbound[1]
    curvecolor=2
    ");

# DISPLAY DATA

@suximage[2] = (" suximage
    title=@sufile_in[1]
    style=seismic
    label1='TWTT(s)'
    label2='Distance (m)'
    wbox=300 hbox=450 xbox=350 ybox=10
    ");
";

# DEFINE FLOW(S)

# DEFINE FLOW(S)

# RUN FLOW(S)
system @flow[1];
# system 'echo', @flow[1];
system @flow[2];
# system 'echo', @flow[2];

o iWrite_All_iva_out.pl

#!/usr/bin/perl
# Write_All_iva_out.pl
# Purpose: Write out best vpicked files from IVA
# Juan M. Lorenzo
# April 9 2009
# Modified by Erin Feb 16 2010

# Use shell transparently to locate home directory before compilation

my $library_location;

BEGIN {
    use Shell qw(echo);
    $home_directory = `echo $HOME`;
    chomp $home_directory;
    $library_location = '/data1/EE_Processing_2011/lsu_line1';
}
# LOAD GENERAL PERL LIBRARY
use lib '/data1/EE_Processing_2011/lsu_line1/libAll';

# library path
use lib '/data1/EE_Processing_2011/lsu_line1/libAll';

# use library
use System_Variables2;
use Input_me;

# use library
use manage_files_by;

# import system variables
my ( $DATA_SEISMIC_SU ) = System_Variables2::DATA_SEISMIC_SU();
my ( $PL_SEISMIC ) = System_Variables2::PL_SEISMIC();
my ( $INPUT_FILE ) = Input_me::INPUT_FILE();

# sufile names
@sufile_in[1] = $INPUT_FILE;

# file suffixes
@vpicks_stdin[1] = 'ivpicks_old';

# CP text file names
@cpfile_in[1] = @vpicks_stdin[1];
@cpfile_out[1] = 'All_ivpicks_iva';
@storefile_outbound[1] = $PL_SEISMIC.'/' . @cpfile_out[1] . '_' . @sufile_in[1];
@catfile_inbound[1] = $PL_SEISMIC.'/' . @cpfile_in[1] . '_' . @sufile_in[1];

# DEFINE FLOW(S)
@flow[1] = (""
  \ cp @catfile_inbound[1] @storefile_outbound[1]; \"
);  

# RUN FLOW(S)
system @flow[1];
system 'echo', @flow[1];

• After performing the velocity analysis, the results were compiled into a single file using
  o parfrompick.pl
# parfrompick.pl
# Create Parameter files for NMO and Stacking

# 04/21/2010
# Erin Elliott

# Create Parameter file from cdp and pick files

# Creating cdp=1,2,3,4,... portion.

open (FILE1, '>partemp.p');
print FILE1 "cdp=";
close (FILE1);

# Printing CDP=#
for ($num=0; $num<=400; $num=$num+1)
{
    if (-e "ivpicks_sorted_par_$num.lsu1.rkhcv.36f"){
        open (FILE, '>>partemp.p');
        print FILE "$num,";
        close (FILE);
    }
    else {next;}
}

# Adding n/.

open (FILE, '>>partemp.p');
print FILE "n";
close (FILE);

# Creating list of tnmo and vnmo values

for ($num=0; $num<=400; $num=$num+1)
{
    if (-e "ivpicks_sorted_par_$num.lsu1.rkhcv.36f"){
        open (FILE1, '<ivpicks_sorted_par_$num.lsu1.rkhcv.36f');
        open (FILE2, '>>partemp.p');
        while (<FILE1>)
            {print FILE2 $_;}
        close (FILE1);
        close (FILE2);
    }
    else {next;}
}
#Print File to Screen
open (FILE, '<partemp.p');
    while (<FILE>)
        (Wallace, 1966);
close (FILE);

# Operation Complete
print "\n Operation Complete \n";

• This file was then read into the program NMOStack.pl (below) that performs the normal move out function, interpolates the velocity between the picked common depth point values, and stacks the data for the final section.

#!/usr/bin/perl

# NMOStack.pl
# To Stack - After running Prestack Flow and IVA.pl
# Purpose: Stack Data with appropriate velocities
# Erin Elliott
#

# Use shell transparently to locate home directory before compilation
my $library_location;
BEGIN {
    use Shell qw(echo);
    $home_directory = `echo \$HOME`;    chomp $home_directory;
    $library_location = '/data1/EE_Processing_2011/lsu_line1';
}

# LOAD GENERAL PERL LIBRARY
# use lib $library_location;

# library path
    use lib '/data1/EE_Processing_2011/lsu_line1/libAll';

# use library
    use System_Variables2;
    use Input_me;

# use library
    use manage_files_by;
# import system variables
my ($DATA_SEISMIC_SU) = System_Variables2::DATA_SEISMIC_SU();
my ($INPUT_FILE) = Input_me::INPUT_FILE();

#Define files and parameters:
#Note: Change file in Input_me.pm, not here.
# sufile names
$sufile_in[1] = $INPUT_FILE.'p';
$sufile_out[1] = $sufile_in[1].'_nmo';
$inbound[1] = $DATA_SEISMIC_SU.'/'.su_in[1].'.su';
$outbound[1] = $DATA_SEISMIC_SU.'/'.su_out[1].'.su';
$tempfile[1] = $DATA_SEISMIC_SU.'/'.su_in[1].'o.su';

print("n INPUT: $inbound[1]\n");
print("n OUTPUT: $outbound[1]\n");
### Please do not alter unless you know what you are doing!!!! #####
#_____________________________________________________________________
#Begin Creating CDP Values
@fold[12] = (" suchw \n
  key1=cdp \n  key2=sy \n  key3=gy \n  a=0 \n  b=1 \n  c=1 \n  d=300 \n  ");

@fold[24] = (" suchw \n
  key1=cdp \n  key2=sy \n  key3=gy \n  a=0 \n  b=1 \n  c=1 \n  d=600 \n  ");

@fold[36] = (" suchw \n
  key1=cdp \n  key2=sy \n  key3=gy \n  \n  \n  \n  ");
a=0  \ \\
b=1  \ \\
c=1  \ \\
d=900  \ \\
"");

#End Creating CDP Values
#______________________________________________________________________

#Begin Sorting by CDP Values

    @sort[1] = (" susort  \ \
                  cdp  \ \
                  offset  \ \\
              ");

#End Sorting by CDP Values
#________________________________________________________________________

# Begin Window Data by trac1 to remove cdp empty cells (no data)

    @suwind[1] = (" suwind  \ \
                  key=fldr  \ \
                  reject=1005,1006  \ \\
              ");

    @suwind[2] = (" suwind  \ \
                  key=cdp  \ 
                  min=1  \ \\
              ");

# End Window Data
#_______________________________________________________________________

#Begin Normal Moveout

#vel='1500';

    @NMO[1] = (" su
          sunmo  \ \\

167
par=partemp.p"
"
);

#End Normal Moveout
#

#Begin Stacking Data
#
@stack[1] = (" sustack \n   key=cdp \n   ");

#End Stacking Data
#
# Begin Gain Data
#
# GAIN DATA

$wagc = 0.1;

$text_sugain[2] = 'wagc='.$wagc;

@sugain[1] = (" sugain \n    wage=$wagc \n    age=1 \n    ");

#End Gain Data
#
#Begin Band Pass filter
#
$bp_filter = '80,120,200,250';

$text_sufilter[1] = 'bpf'.$bp_filter;

@sufilter[1] = (" sufilter \n    f=$bp_filter \n    ");

#End Band Pass filter
#
#Display Data
# Stacked Data

$xlabel = 'Trace number';
$tlabel = 'Time(s)';
$X0    = 0;
$widthbox= 600;

@suximage[1] = (" suximage
    title='NMO Stack'
    label1='$tlabel'
    label2='$xlabel'
    windowtitle='NMO Stack'
    xbox=$X0
    wbox=$widthbox
    clip=5
    ");

# @suxwigb[1] = suxwigb key=cdp clip=2
#____________________________________________________________
# DEFINE FLOW(S)
# Uncomment Flow[3] to save file

@flow[1]= ("
    @fold[12]
    < @inbound[1] | 
    @suwind[1] | 
    @suwind[2] | 
    @sort[1] 
    > cdptemp.su
    ");

@flow[2]= ("
    @NMO[1]
    < cdptemp.su | 
    @stack[1] | 
    @sufilter[1] | 
    @sugain[1] | 
    @suximage[1] 
    & ");

# End Define Flows
#_____________________________________________________________________________

# Run Flows
system @flow[1];
system 'echo', @flow[1];
system @flow[2];
system 'echo', @flow[2];

# system @flow[3];
#system 'echo', @flow[2];
Vita

Erin Elliott graduated from McComb High School in 2004. She received her Bachelor of Science degree in geology with honors from Millsaps College in May 2008. Erin began her Master of Science degree in geology at Louisiana State University in August 2008. While at LSU, Erin was awarded the Applied Depositional Geosystems Fellowship, participated in the American Association of Petroleum Geologists student chapter, was graduate student liaison to the faculty, and held a geophysics internship with Newfield Exploration in Houston, Texas. Her professional interests include seismic interpretation and processing.