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Reflector Dip Trends in Seismic SH-Wave Imaging of a Modern Lower Mississippi River Point Bar

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REFLECTOR DIP TRENDS IN SEISMIC SH-WAVE IMAGING OF A MODERN LOWER MISSISSIPPI RIVER POINT BAR

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

Adam Gostic
B.S., Sam Houston State University, 2015
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Abstract

Various studies of ancient point bars have noted that a relationship can be observed between the dip angle and grain size of point bar lateral accretion deposits, with the most mud-rich deposits tending to exhibit the greatest dip. No analysis and only cursory explanations for this relationship have been provided. Additionally, buried mid-channel bars are absent from typical models of point bar architecture.

We successfully image the architecture of late-stage point bar deposits with a near surface 2D seismic SH-wave reflection survey and generate an SH-wave velocity model of the subsurface in the study area in order to interpret the history of its development. The presence of inclined reflectors with uniform dip directions toward the paleochannel confirms a typical model of point bar architecture, but the observation of coherent reflectors dipping away from the paleochannel complicates the ideal model by suggesting the burial of a mid-channel bar by the migrating point bar.

Spatial trends in reflector dip magnitude calculated via the analysis of dip-affected reflectors. Dips trend toward an increase both upwards and laterally in the paleochannel direction. The SH-wave velocity model and well-logs from previous studies demonstrate a lateral fining trend in the paleochannel direction but fail to support upwards fining. The failure to confirm upwards fining in the presence of a ubiquitous upwards increase in reflector dip suggests that sediment cohesion is an incomplete explanation for the relationship between dip angle and grain size in point bar lateral accretion deposits. As a whole, this study provides an example of the ability of seismic SH-wave reflection methods to image and characterize the shallow subsurface.
Chapter 1. Introduction

1.1. Research Problem

The relationship between stratigraphic dip and mud content in point bars is poorly understood. Observations of modern and ancient point bars identify a characteristic architectural element composed of inclined, heterolithic, laterally accreting sediment packages that dip in the direction of the channel and strike parallel to channel orientation (de Mowbray, 1983; Fustic, 2007; Jackson II, 1981; Strobl et al., 1997; Thomas et al., 1987). The dip angle of laterally accreting point bar strata tends to increase with increasing mud content (Allen, 1970; Edwards et al., 1983; Jackson II, 1978, 1981; Mossop and Flach, 1983; Thomas et al., 1987; Van der Meulen, 1982; Visser, 1986), and these mud-bearing inclined, heterolithic units always show greater dip than the underlying coarser grained, cross-bedded sandstones typical of lower point bar facies. (Fustic et al., 2012; Jackson II, 1981; Mossop and Flach, 1983; Thomas et al., 1987). The cause of the correlation between the relative mud content and dip angle of point bar strata has gone largely undiscussed.

1.2. Research Objectives

The first objective of this study is to image the inclined architecture of the modern False River point bar in east Pointe Coupee Parish, Louisiana with 2D seismic SH-wave reflection methods. I expect to find seismic evidence for laterally accreting point bar sediment packages in the form of inclined seismic reflectors which dip in the paleochannel direction. I also expect that for a seismic survey positioned just downstream of a cutoff meanders paleoapex, it is probable I will observe seismic evidence for a buried mid-channel bar in the form of opposite-dipping seismic reflectors inclined towards the point bar interior given the prevalence of such bars positioned within meanders of the active Lower Mississippi River channel.

The second objective is to investigate the trends in both seismic reflector dip and relative mud content of the False River point bar to determine if a correlation is observed. Reflector dips are expected to show trends of increasing inclination in the directions that fining is predicted by current models of point bar architecture [Section 1.4]. Evidence of these fining trends is expected to be observed in geophysical logs of the study area. Verification of a correlation between relative mud content and reflector dip could provide a method by which interpretations
of the spatial distribution of fine grained sediment in point bar reservoirs could be aided by the analysis of seismic data.

1.3. Point Bar Facies

Distinct facies are associated with vertical position in relation to point bar deposits [Figure 1.1]. The base of the point bar is expected to overlap older, coarse grained stream bed and channel lag deposits over which the point bar migrated. Lower point bar units are typically trough cross stratified sandstones with limited fine-grained material (Labrecque et al., 2011a; McGowen and Garner, 1970; Mossop and Flach, 1983; Strobl et al., 1997; Thomas et al., 1987). Above this trough stratification, epsilon cross-stratified and interbedded shales and sandstones are typically present (Labrecque et al., 2011a; Mossop and Flach, 1983; Strobl et al., 1997; Thomas et al., 1987). Termed Inclined Heterolithic Stratification (IHS), the dips of these beds are depositional and oriented roughly perpendicular to the direction of channel flow (Fustic, 2007; James and Dalrymple, 2010; Mossop and Flach, 1983; Strobl et al., 1997; Thomas et al., 1987). They represent the sloping surface of the point bar on the inner accretionary bank (Jackson II, 1978), and the interbedding is indicative of variations in discharge (Labrecque et al., 2011b; McGowen and Garner, 1970; Mossop and Flach, 1983; Thomas et al., 1987) or seasonal sediment flux (Durkin et al., 2015). The uppermost section of a typical point bar deposit typical consists of laminated fine-grained material.

Figure 1.1. (Left) Generalized point bar stratigraphy. (Right) Idealized electrical conductivity log response to generalized point bar stratigraphy.
sediments (Labrecque et al., 2011a; McGowen and Garner, 1970; Mossop and Flach, 1983; Thomas et al., 1987) deposited in the backwater environment during flood stage as the channel’s banks are overwhelmed and the floodplain is inundated.

1.4. Point Bar Fining Trends

Various fining trends within point bar deposits have been described in previous research and can be categorized into three groups: fining upsection, fining downstream, and fining towards the channel [Figure 1.2].

Upwards point bar fining is the combined result of fining in directions both parallel (Allen, 1970; Thomas et al., 1987) and orthogonal (Thomas et al., 1987) to the bedding planes of inclined sediment packages. Fining parallel to bedding occurs in the up-dip direction within individual inclined sediment packages. Up-dip fining is the result of coeval reduction in flow velocity with increasing distance up the point bar slope and away from the channel thalweg. This reduction in flow velocity occurs because of bed friction as channel depth decreases towards its banks (Chiu, 1988, 2002). Fining orthogonal to the inclined bedding planes in the younging direction in a point bar is the result of time-dependent reductions in flow velocity associated with flooding (Mossop and Flach, 1983). As river floods begin to wane after reaching their peak discharge values, river stage drops along with flow velocity, resulting in a gradual fining of the deposited sediment in the younging direction.

The general point bar facies model of IHS overlying cross-bedded sandstones of the lower point bar and capped by overbank mud deposits represents a gross upward fining trend (Strobl et al., 1997). This gross upward fining trend is an expression of the upward fining trends described above as predicted by Walther’s Law. Descriptions of upwards fining trends in the literature of point bar studies are common. Three facies assemblages characterize the Willow Creek outcrops of the Horseshoe Canyon Formation in Alberta, Canada, and all three assemblages include a description of fining upwards beds that dip in the paleochannel direction (Durkin et al., 2015). Sandstone beds are often sharp-based with a gradual fining parallel to bedding in the up-dip direction. Mudstone breccias formed from the mass wasting of bank material are present near the base of the point bar, and fine-grained facies are more common near the top. In point bar deposits of the McMurray Formation, the upward fining trend is expressed as an upsection decrease in mean grain size and an upsection increase in the abundance of mudstone interbedding (Mossop and Flach, 1983). The point bars of the Baraboo River in Wisconsin & Illinois
States, USA display a general tendency for mud-bed thickness to increase upward within a point bar sequence (Jackson II, 1981). Within a point bar system of the Usri River in India, a fining-upwards tendency is attributed to the process of fluvial grain sorting (Purkait, 2006).

Downstream fining around a single point bar is associated with flow separation near the meander bend apex in addition to increases in sediment sorting and cumulative grain abrasion with increasing transport distance (Allen, 1970; James and Dalrymple, 2010; Leeder and Bridges, 1975; Paola et al., 1992). In the mesotidally influenced point bars of the Willapa River of southwest Washington State, USA, mean grain sizes decrease both downstream and upsection (Smith, 1985). In the muddy, mixed-load Athabasca point bars in northeast Alberta, a downstream increase in both thickness and frequency of mud beds is observed (Calverly, 1984). A fining upward trend in overall mud content of these Athabasca point bars is also described, but not an upward increase of frequency or thickness of mud beds. As with the Willow Creek outcrops of the Horseshoe Canyon Formation, the

![Diagram](image)

Figure 1.2. Illustration of various fining trends in point bar deposits (Thomas et al., 1987): 1) Gross upsection fining. 2) Updip fining parallel to bedding planes. 3) Upwards fining perpendicular to bedding planes. 4) Downstream fining around a meander bend. 5) Fining in the direction towards the channel.
sand members of the inclined alternating sand-mud units in the Athabasca point bars are typically sharp based and grade upwards (Calverly, 1984; Mossop and Flach, 1983).

A fining trend towards the paleochannel occurs in outcropping point bars of the McMurray Formation both at the Muskeg River Mine north of Fort McMurray, Alberta, Canada and at Crooked Rapids to the west of Fort McMurray along the Athabasca River. As the meander developed, the thickness of the Inclined Heterolithic Stratigraphy (IHS) facies increased relative to the thickness of the underlying cross-bedded sandstone facies in both outcrops (Fustic, 2007; Mossop and Flach, 1983; Strobl et al., 1997). The pattern towards the channel of an increasing ratio of inclined heterolithic beds compared to coarse, cross-bedded sandstones continues until the IHS beds extend to the base of the point bar deposit. As the proportion of interbedded sand and mud to clean, coarse sand increases, the average grain size in a vertical section through the bar decreases.

All three fining trends (upsection, downstream, and towards the channel) are observed in a single outcropping point bar of the lower McMurray Formation (Labrecque et al., 2011a). The prevalence of siltstone beds increases upsection at every location in the bar, and the younger deposits (towards the channel) are increasingly siltstone dominated. In the downstream direction, siltstone beds increase in individual thickness and comprise a greater portion of the vertical sections. Fining trends typical of the aforementioned point bars are expected to be expressed in modern point bars of the Lower Mississippi River. Point bars such as those within the McMurray and Horseshoe Formations in Alberta, Canada, are expected to represent ideal ancient analogues to modern Lower Mississippi River point bars because of their similar scale, owing to their deposition by channels in the lower reaches of rivers with continental-scale drainage basins.

Despite the understanding of the mechanics of point bar deposition, the distribution, abundance, and extent of impermeable mud drapes is difficult to predict. Not all point bar deposits adhere to the fining upward trend predicted by the prevailing depositional models. The Eocene Simsboro sandstones and the modern and ancient point bars of the Amite and Colorado Rivers are notable examples (McGowen and Garner, 1970). Nevertheless, it is not unreasonable to expect the relative mud content in a point bar to increase vertically upwards, and laterally both downstream and towards the channel.
1.5. Inclined Point Bar Strata Dip

Some authors have described a relationship between the dip angle and grain size for inclined point bar strata in ancient outcrops. The total range of recorded dip values for laterally accreting point bar surfaces is 2°-29°, with a typical range of around 5°-15° (Arche, 1983; Calverly, 1984; Durkin et al., 2015; Fustic et al., 2012; Labrecque et al., 2011a; Mossop and Flach, 1983; Visser, 1986). The highest recorded dip angle for ancient fluvial IHS is 29° from a mudstone dominated set of the Cretaceous Judith River Formation in southeast Alberta (Visser, 1986). In outcropping point bars of the McMurray Formation in Alberta, Canada, the coarser grain size, thicker bedding, and larger scale sedimentary structures of the most gently dipping IHS units indicate deposition under higher flow conditions when compared to that of more steeply dipping IHS units (Mossop and Flach, 1983). As the grain size decreases and the mud content increases, the dip of these units tends to increase. A similar relationship is also described in sedimentary analyses of outcropping point bars of the Monllobat Formation in Spain (Van der Meulen, 1982), the Clear Fork Group in Texas (Edwards et al., 1983), and the Judith River Formation in Alberta, Canada (Visser, 1986). An example of this relationship is expressed in the Steepbank River Outcrop of the McMurray Formation [Figure 1.3]

Figure 1.3. Outcropping point bar of the McMurray Formation along the Steepbank River in Alberta, Canada (Fustic et al., 2012). Paleochannel direction is to the north, towards the right side of the image. Note the tendency within the IHS facies for both dip angle and the relative amount of mud-rich (light-colored) strata to increase upwards and towards the paleochannel.
1.6. Mechanisms for a Dip-Grain Size Relationship in Point Bars

Sediment cohesion is a likely explanation for the tendency for the dip angle of inclined point bar strata to increase as grain size decreases. The angle of sediment repose is expected to control the dip of inclined heterolithic stratigraphy (IHS) because IHS dip is depositional in nature and represents the slope of the point bar bank surface (James and Dalrymple, 2010; Mossop and Flach, 1983; Thomas et al., 1987). Angle of repose increases as particle size decreases [Figure 1.4] because an increase in the surface area:volume ratio increases cohesion between particles. (Carstensen and Chan, 1976; Zhou et al., 2002). Additionally, very fine sediments contain clay minerals that exhibit additional cohesion as a result of electrostatic forces which bind them together, increasing their frictional strength and natural angle of repose (Loseth, 1999). The increase in cohesive forces between grains as sediment size decreases is the only mechanism that has been suggested previously by researchers to explain the observed correlation between dip angle and mud content of inclined point bar strata in which dip tends to increase in the fining directions (Visser, 1986). Sediment cohesion should be considered a causal mechanism because cohesive strength is dependent on grain size, and the changes in cohesive strength produce changes in dip angle.

Figure 1.4. Relationship between grain size and angle of repose for mono-sized spherical grains (Zhou et al., 2002). Angle of repose increases with decreasing grain size even as friction coefficients vary.
Meander radius of curvature may also be responsible for a correlation between grain size and dip angle for inclined point bar sediments. Radius of curvature is a measure of how tight a meander bend is. As meander bends develop, erosion along the outer bank and deposition along the inner bank tends to result in a progressive decrease in radius of curvature [Figure 1.5]. This progressive decrease in curvature causes lateral fining of point bars in the direction of the paleochannel (Van de Lageweg et al., 2016) as well as increasing of transverse bed slope (Kleinhans et al., 2012).

Changes in meander radius of curvature affect the frequency of deposition of drapes of fine-grained sediment within laterally accreting point bar sediment packages. These sediment drapes are often the result of minor increases in stage, which temporarily inundate the unvegetated upper point bar slope that is subaerially exposed at normal river stage. This flow across the upper point bar is of sufficiently low velocity to allow for the deposition of the suspended load, and as radius of curvature decreases, this inundation occurs more frequently.

\[ R = \text{Radius of Curvature} \]

![Figure 1.5. Diagrammatic depiction of the tendency for meander bend radius of curvature to progressively decrease as meanders develop. No scale.](image)
This results in a lateral fining of point bar sediment packages towards the channel expressed as an increase in the frequency of mud drape deposition. As the meander bend sharpens, water flowing around the meander must be diverted a greater distance from its original course, making it progressively easier to spill over the exposed surface of the point bar (Van de Lageweg et al., 2016).

Meander radius of curvature also affects the dip angle of lateral accretion deposits in point bars. Point bar lateral accretion slopes correspond to transverse bed slopes of the inner banks of river meanders (Van de Lageweg et al., 2016), and an empirical relationship is established between meander radius of curvature and transverse bed slope (Figure 1.6), which is confirmed both experimentally (Van de Lageweg et al., 2016; Van Dijk et al., 2012) and in the field (Kleinhans et al., 2012). This relationship exists because decreases in meander radius of curvature increase the intensity of secondary, helicoidal currents (Figure 1.7) relative to downstream flow (Struiksma, 1985). The increase in secondary current relative intensity is responsible for increasing transverse bed slope in river meanders (Figure 1.8) as bedload sediment can be transported further up the inner river bank (Baar et al., 2018).

![Figure 1.6. Relationship between meander bend radius of curvature (R/h) and transverse bed slope (dz/dy) in bends of the upper Columbia River (Kleinhans et al., 2012). Sharper bends, with lower radii of curvature, are characterized by greater transverse bed slope.](image)
Figure 1.7. Illustration of the development of secondary, helical currents within bends of meandering river channels (Easterbrook, 1993). These currents develop because of fluid superelevation (Hickin, 2003; Rozovskii, 1957) that occurs as a result of centrifugal forcing of water towards the outer, concave bank (Ashworth et al., 2015). This secondary flow transports bed materials towards the inner bank in a direction transverse to the primary, downstream flow direction.

Figure 1.8. Comparison of transverse bed slope (dz/dy) to relative sediment mobility (Θ/Θc) and secondary flow intensity (un/us) (Baar et al., 2018). Transverse bed slopes correlate positively with secondary flow intensity.
Meander abandonment may also be a link between lateral changes in grain size and dip specific to the late-stage point bar deposits. Waning flow velocity relating to gradual meander abandonment will cause an increase in the depth to which mud drapes are observed in point bar sediments (Mossop and Flach, 1983; Visser, 1986). A progressive increase in the depth to which muddy sediments can be deposited on the point bar surface represents lateral fining in the direction of the channel. Gradual abandonment can also affect changes in point bar slope. There is a vertical component to the accretion of point bar sediments (Nanson, 1980) that could be amplified relative to lateral migration rates as outer bank erosion slows as a result of waning flow (Hooke, 1986) related to abandonment, resulting in increased dip of late-stage inclined point bar deposits.

1.7. Mid Channel Bars

Mid-channel bars are common in actively meandering river channels, especially within overwidened channels of a meander loop and often just downstream of the meander apex (Hooke, 1986). Mid-channel bars migrate and grow from accretion both laterally and in the downstream direction (Bridge and Lunt, 2009). A characteristic feature of these mid-channel bars is an inner slope which dips towards the inner, accretionary bank. A four-stage model [Figure 1.9] describes the evolution of a typical mid-channel bar within an active meander loop. The incipient mid-channel bar forms in association with a sudden downstream shallowing, often just downstream of the meander apex. Downstream shallowing within a river meander is common just past the meander apex and occurs because of rapid sedimentation in the zone of flow separation that results from the helical nature of current flow around a meander loop (Leeder and Bridges, 1975). The bar grows and begins to become vegetated as the channel widens to accommodate it, resulting in relatively equal flow on each side of the mid-channel bar. Over time the mid-channel bar becomes more densely vegetated and deposition in the gap between the mid-channel bar and the inner (the bar-bank gap) results in the attachment of the mid-channel bar to the inner bank starting at its upstream end. After the bar-bank gap becomes filled in entirely, the mid-channel bar is eventually incorporated within the deposits of the developing meander as the point bar migrates over and past it. Mid-channel bars can be observed in satellite imagery of the modern lower Mississippi River channel in Louisiana [Figure 1.10] and are expected to be present within point bars deposited by stretches of the Mississippi River channel that have been cut off as a result of avulsive processes.
Stage 1 - incipient mid-channel bar.
Stage 2 - mid-channel bar, sparsely vegetated, equal flow either side.
Stage 3 - densely vegetated bar, unequal flow.
Stage 4 - bar becoming attached to bank.

Figure 1.9. Four stage model of typical mid-channel bar evolution in meanders (Hooke, 1986).
Figure 1.10. Examples of mid-channel (circled in black) bars present within meander loops of the modern lower Mississippi River in Louisiana. (Top) Mid-channel bar at an early stage of development near Ashland, LA. (Bottom) Mid-channel bar in a later stage of development near Angola, LA. Note the development of heavy vegetation and attachment of the bar to the inner bank at its upstream end.
1.8. Economic Significance

Northern Alberta, Canada oil sands of the Athabasca, Peace River, and Cold Lakes areas are the largest oil sand deposits in the world with 142,000 km² of combined surface area and an estimated initial oil of 1.8 trillion barrels (ERCB, 2012). The Athabasca area oil sands are the world’s largest single hydrocarbon reservoir, and Athabasca’s oil-bearing formation is the McMurray Formation (Demaison, 1977). Consolidated point bar deposits in the McMurray Formation contain vast quantities of bitumen and, owing to their fluvial to estuarine depositional environment (Labrecque et al., 2011b; Pemberton et al., 1982; Smith, 1988; Stewart and MacCallum, 1978), are analogous to the structurally undisturbed modern point bars of the lower Mississippi flood plain. A previous study described one such point bar deposit of the McMurray Formation. It was deposited by an ancient channel that was 32-36 meters deep and 500-584 meters across. The point bar deposit was 30-40 meters thick, covered a lateral area of 10.2 km², and was estimated to contain 170 billion barrels of crude bitumen (Labrecque et al., 2011a).

Mud distribution in point bar reservoirs is a critical factor in determining target zones for low API petroleum production. Production of low API petroleum from these reservoirs can be aided by steam flooding processes such as Steam Assisted Gravity Drainage (SAGD) [Figure 1.11] to mobilize heavy oil (JAPEX, 2017), but impermeable layers of fine grained siliciclastic strata in these reservoirs limit expansion of the steam chamber. Reservoir compartmentalization by impermeable mudstones similarly limits the production of petroleum with

![Diagram of Steam Assisted Gravity Drainage process](image-url)

Figure 1.11. Depiction of Steam Assisted Gravity Drainage process utilized to enhance heavy oil recovery (JAPEX, 2017). (Left) Profile view shows typical geometry and orientation of the steam chamber, steam injection well, and production well. (Right) Steam chamber cross section depicting steam and bitumen flow paths.
sufficiently low viscosity to flow to the borehole under the formation’s own internal pressure (Labrecque et al., 2011b). Better prediction of the distribution of these impermeable units would enhance the capability to target zones within point bar reservoirs that are unlikely to experience reservoir compartmentalization. Petrophysical well logging and coring operations are used in the development process to identify locations within a point bar that are unlikely to contain extensive fluid barriers (Martinius et al., 2017), but these processes are slow and expensive compared to seismic methods. A seismic technique for evaluating mud distribution is desired, but often seismic reflection surveys are unable to resolve such interlayering as a result of its fine scale or a lack of impedance contrast between the fine and coarse deposits (Anstey, 1978; Ryder et al., 1982).

1.9. Study Area

False River is an oxbow lake in the alluvial valley of the Lower Mississippi River, and the False River point bar located in Point Coupee Parish, Louisiana between False River to the west and the modern Mississippi River channel to the east [Figure 1.12] was deposited when False River was still a segment of the Mississippi River.

Figure 1.12. Map of United States’ central Gulf Coast centered on the state of Louisiana depicting satellite imagery of False River in the central inset. The inset in the upper-right corner of the figure shows the location of the map on the North American continent. Maps are generated with GeoMapApp (Lamont-Doherty Earth Observatory, 2018)
channel. The False River point bar occupies a surface area of \( \sim 100 \text{ km}^2 \). Although there is much disagreement among historians on any certain date to which cutoff of False River can be said to have begun (Sternberg, 1956), an account of an ascent of the Mississippi River in 1719 describes a fully abandoned meander loop that has almost been entirely filled in with muddy sediment in the reachers near the newly formed channel (du Prat, 1758). The channel has also seen little change in bank-full discharge in recent geologic history as indicated by the similarity in the size of the channels and meanders it maintains (Fisk, 1944). The modern Mississippi River channel maintains a depth of 24-56 meters (with an average depth of 34 meters) between Bayou Sara, LA and Baton Rouge, LA (US Army Corps of Engineers, 2013), which is the stretch of river which contained the False River meander before it was cut off.

The lower Mississippi River Valley is an entrenched valley system consisting of recent unconsolidated modern alluvial sediments deposited in a valley incised into south-dipping preconsolidated substrata of mid-to-late Cenozoic age (Fisk, 1944; Saucier, 1994). At the latitudes of False River, LA, the basal graviliferous facies of the Pleistocene lower Prairie Formation form the substratum underlying the alluvial valley floor (Fisk, 1944). The average depth to the Pleistocene bedrock is just over 40 meters in the region where False River is located, but in some locations the river channel is actively scouring this bedrock (Fisk, 1944). In a seismic image of the upper subsurface, seismic reflectors representing the top of this bedrock are expected at depths in the range of 40-50 m.

Atop the Pleistocene bedrock of the valley floor rest modern Lower Mississippi River alluvium. These modern alluvial deposits are can be divided into two sections: a basal graviliferous layer and an upper non-graviliferous layer (Fisk, 1944). The basal graviliferous sediments are characterized by gravels dispersed in a sandy matrix. The proportions of gravel to sand along with grain size of the gravels and sands decrease both upwards and gulfwards (Fisk, 1944). At the study sites at False River, the depth to the top of the graviliferous lower layer of the modern alluvial deposits ranges from \( \sim 20 \) to 30 meters (Fisk, 1944). The coarse deposits of the graviliferous lower layer are overlain by a non-graviliferous section consisting of a lower unit of mostly permeable sand and an upper impermeable topstratum. As they relate to point bar facies [Section 1.3], the lower section likely corresponds to the sandy lower point bar and channel lag deposits, while the permeable upper section corresponds to the IHS
facies of the upper point bar and the impermeable topstratum corresponds to the mud-rich overbank deposits of the flood plain.

1.10. Survey Site

Horizontally polarized shear (SH) wave seismic data are collected on the southwestern portion of the False River point bar along a 480m transect with a shooting direction to the northeast at an azimuth of 030° [Figure 1.13]. The survey site and seismic transect are designated ‘Bueche’ in accordance with the surname of the landowner of the property on which the survey was completed. The site is chosen on the basis of its accessibility and its predicted ability to provide information on the dynamics of point bar sedimentation. The orientation of the seismic transect is at a high angle to the long axis of the local scroll bar topography. Since scroll bar topography parallels the curvature of the channel (Nanson, 1980) and the strike of inclined point bar stratification is approximately parallel to paleocurrent direction (Mossop and Flach, 1983), this orientation minimizes the

Figure 1.13. LIDAR Digital Elevation Model of False River showing location and orientation of the Bueche survey area (thick white line) across the survey site. Base map sourced from Google Earth. Elevation data available at https://atlas.ga.lsu.edu/datasets/lidar2000/ (Cunningham et al., 2000).
difference between the true dip of the bedding surfaces of the inclined stratification and their apparent dip observed in a seismic section. A transect oriented perpendicular to the local scroll bar topography is preferred but unachievable because of heavy vegetation on the western side of the property, swampy terrain in the low-lying areas, and a lack of permission to cross property lines. Additionally, because well data is available from a previous study [Section 1.11], an effort is made to orient the transect in such a way to minimize the distances between the transect and the wells to facilitate comparison of the seismic and well data.

1.11. Previous Data

Subsurface logging of electrical conductivity and hydraulic injection pressure was performed for previous studies in wells at five locations on the survey site (Lechnowskyj, 2015; Olson, 2017). The well logging was performed by Professional Technical Support Services (Pro-Tech) of Baton Rouge, Louisiana. The five well locations are designated B1 through B5 [Figure 1.14]. The logging project utilizes Geoprobe Systems® direct-push rigs [Figure 1.15] coupled with the Direct Image® Electrical Conductivity (EC) [Figure 1.16] and Hydraulic Profiling Tool (HPT) [Figure 1.17] downhole logging systems from Geoprobe Systems®. The vertical resolution of the EC and HPT tool measurements is 1.5 cm. Wells B3 & B5 are both logged to a depth of 27.7 m. Wells B1, B2, and B4 are logged to depths of 23.1 m, 21.7 m, and 21.0 m, respectively. Wells B4 & B5 are both located ~5 m to the northwest of the seismic transect. Wells B2 & B3 are located to the southeast of the transect. Well B2 is ~65m from the transect and well B3 is ~40 m from the transect. Well B1 is located ~87 m from the final shotpoint along a bearing of 030°.

The well log data is used to examine fining trends by providing information relating to the relative mud content of the sediment at the well locations. Electrical conductivity (EC) of the sediment measures its ability to conduct electric current through its grains and pore fluid. Muddy, fine-grained sediments with high clay content conduct electrical currents more efficiently due to their high ionic content, resulting in higher EC readings than those for coarser, sandier sediments (Revil and Glover, 1998; Shevnin et al., 2006). The Hydraulic Profiling Tool (HPT) readings are a measure of the pressure required to inject water into the sediments of the well wall and correlate directly with mud content because injections pressures increase with decreasing hydraulic conductivity and formation permeability (Lechnowskyj, 2015; Olson, 2017) and hydraulic conductivity and permeability decrease as mud content increases (Fraser, 1935; Klimentos, 1991; Shevnin et al., 2006).
Figure 1.14. True-color map of False River point bar. Inset highlights the study area. The white line shows the position of this study’s seismic transect (B-B’). The white dots show the position of the logged wells (B1-B5).

Figure 1.15. Professional Technical Support Services crew members performing downhole logging at False River using the Geoprobe® 8810DT direct-push rig (Lechnowskyj, 2015).
Figure 1.16. Geoprobe System®s Direct Image® 1.75in Electrical Conductivity (EC) System (Kejr, 2018). Image downloaded from https://geoprobe.com/tool-string-diagrams/ec-sc520-175-15-system.

Figure 1.17. Geoprobe System®s Direct Image® 1.75in Hydraulic Profiling Tool (HPT) System (Kejr, 2018). Image downloaded from https://geoprobe.com/tool-string-diagrams/hpt-k6050-15-175-system.
Electrical conductivity (EC) is logged in wells B1 – B5 [Figure 1.18]. Well B3 shows the greatest baseline EC value (~34 mS/m) as well as the highest degree of signal variability, suggesting the sediments become more mud rich towards the channel to the southwest. I observe a steadily downward-decreasing trend throughout most of B3, from 60 mS/m at ~3 m depth to 30 mS/m at ~27 m depth. The EC value decrease rapidly above ~3 m depth. Well B2 shows the lowest average EC value and the lowest degree of signal variability, with a slight but steady downward-increase from 0-10 m as the value approaches the baseline measurement, below which it remains relatively constant with only a few minor positive excursions. Well B4 exhibits the lowest EC baseline (~13 mS/m). Wells B1, B4, and B5 all display a shallow region in the upper 10 m with increased average EC values when compared to values below 10 m. In well B5, however, there is an additional region of increased EC readings from 23-25 m, depths at which wells B1, B2, and B4 contain no data. All wells display a positive excursion with varying amplitudes in the upper meter of the log. This excursion is largest in B5.

Figure 1.18. Electrical conductivity logs of wells B1 – B5 which are located along this study’s seismic transect. Dashed red line represents baseline EC value observed in each log.

Maximum line pressure of the Hydraulic Profiling Tool (HPT) is also logged in wells B2 – B5 [Figure 1.19]. The highest sustained readings are observed in well B3 at the southwest end of the transect, while the average values observed in the wells to the northeast are lower. Again, this suggests that the sediments become more mud
rich towards the channel to the southwest. Increases in line pressure to values above 400 kP are more common with increasing depth in all four wells, and only B3 registers values over 400 kPA above ~14 m in depth. The largest pressure values for each well are observed near the bottom of their log. Wells B5, B4, and B2 show a downwards decrease pressure at a depth of ~5 m.

Figure 1.19. Maximum line pressure logs of the Hydraulic Profiling Tool in wells B2 – B5 which are located along the seismic transect. Logs are arranged in the same orientation as the seismic cross-section [Figure 1.14], moving to the northeast from left to right on the page.
Chapter 2. Methods

2.1. Research Tasks

I perform a seismic reflection survey on a late-stage deposit of the modern False River point bar at a survey site where geophysical logs of five (5) subsurface wells were obtained for a previous study. Dip angles of inclined seismic reflectors representing laterally accreting sediment package interfaces are calculated from dip-affected reflection hyperbolae offset distance. Trends in the variation of reflector inclinations are compared to trends in grain size interpreted from the electrical logs and anticipated fining trends described in classic point bar models.

2.2. Seismic Acquisition

The Bueche seismic survey geometry and parameters are summarized in Table 2.1. The acquisition process uses an end-on constant offset shot geometry. Two seismic sources are used [Section 2.3], and the sources are alternated between every shotpoint. I collect two records at each shot point. The first record is collected with an east-facing shot to produce a first motion towards the west. The shot direction is rotated 180° before collecting the second record. This rotation results in a west-facing shot with a first motion to the east and yields a second shot record with reversed SH-wave polarity when compared to the first record.

The seismic data are collected with a Geometrics StrataView R-24 seismograph connected through a Rota-Long-Switch to two twenty-four (24) channel take-out cables linked in series for a total of forty-eight (48) available channels which each transmit the signal from one (1) geophone [Figure 2.1]. The StrataView is capable of recording only twenty-four (24) channels simultaneously, half the number of available geophones. The Rota-Long-Switch hastens acquisition by enabling rapid reselection of the twenty-four active channels [Figure 2.2]. This allows acquisition to continue for up to twenty-four consecutive shot points without the need to connect new receivers or move the take-out cables.

I collected the Bueche seismic data during 17 individual survey days distributed over a 9-month period beginning in May 2016 and ending in February 2017 [Table 2.2]. The 17 survey days are categorized into three distinct survey seasons: May 2016, Fall 2016, and Spring 2017. When the survey was resumed on January 9, 2017
at the start of the Spring 2017 season, I misidentified the first shotpoint of the November 12, 2016 survey day (shotpoint 236) for the last shotpoint of that same day (shotpoint 256), resulting in the research team reshooting the same data from the last day of the Fall 2016 season (meters 237-257). I do not use the November 12, 2016 data because the January 9, 2017 data have lower noise levels.

Table 2.1. Bueche Seismic Acquisition Parameters

<table>
<thead>
<tr>
<th>Survey Type</th>
<th>End-On CDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Azimuth</td>
<td>030°</td>
</tr>
<tr>
<td>Shooting Direction</td>
<td>NE</td>
</tr>
<tr>
<td>Line Length</td>
<td>480 meters</td>
</tr>
<tr>
<td>Seismograph</td>
<td>Geometrics StrataView R-24</td>
</tr>
<tr>
<td>Channels</td>
<td>24</td>
</tr>
<tr>
<td>Receivers</td>
<td>Mark Products 30Hz SH Component Geophone (48)</td>
</tr>
<tr>
<td>Receiver Spacing</td>
<td>1 m</td>
</tr>
<tr>
<td>Minimum Receiver Offset</td>
<td>1 m</td>
</tr>
<tr>
<td>Maximum Receiver Offset</td>
<td>24 m</td>
</tr>
<tr>
<td>Shotpoint Spacing</td>
<td>1 m</td>
</tr>
<tr>
<td>Shot Point Total</td>
<td>451</td>
</tr>
<tr>
<td>Sampling Interval</td>
<td>Sampling Frequency</td>
</tr>
<tr>
<td>Nyquist Frequency</td>
<td>1000 Hz</td>
</tr>
<tr>
<td>Record Length</td>
<td>4.096 s</td>
</tr>
<tr>
<td>Sampling Delay</td>
<td>-0.010 s</td>
</tr>
</tbody>
</table>

The Bueche survey contains data gaps from 34-49m and from 445-458m. The first data gap is the result of experimental error and represents 16 missing shotpoints. When returning for the Fall 2016 survey season, I misidentified the reference location to be used for relocating the last shotpoint from May 12, 2016 and resumed acquisition 16 meters to the northeast of the desired location. The second data gap is an intentional component of the survey design and represents 14 missing shotpoints. The seismic transect passes directly over a concrete culvert in a ditch approximately 5-meters wide and centered at 455m from the start of the line. I halted data collection when the maximum offset receiver was approximately 2 meters from this culvert and moved the source forward 15 meters to avoid recording artifacts due to interference from the culvert.
Figure 2.1. (Top) Geometrics StrataView with cover removed showing the display screen and keypad. (Middle) Front view of the Rota-Long-Switch showing the knob and view port used to select the rollalong number. (Bottom) Mark Products 30 Hz Horizontal Component Geophone. Scales at bottom of each image are in inches.
I take GPS readings of reference stations at selected shotpoints every 25 to 50 meters along the seismic transect using three different devices [Table 2.3]. In addition to the GPS readings, I take tape-and-compass measurements of the reference station locations by determining the back-bearing and distance of the reference stations from notable landmarks in the survey area, most often prominent trees near the seismic transect. Multiple tape-and-compass measurements are made for each reference station and an average of the

<table>
<thead>
<tr>
<th>Survey Season</th>
<th>Survey Date</th>
<th>Directory Name</th>
<th>Data Collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 2016</td>
<td>May 7, 2016</td>
<td>050716</td>
<td>0-16m</td>
</tr>
<tr>
<td></td>
<td>May 12, 2016</td>
<td>051216</td>
<td>17-33m</td>
</tr>
<tr>
<td>Fall 2016</td>
<td>September 24, 2016</td>
<td>092416</td>
<td>50-74m</td>
</tr>
<tr>
<td></td>
<td>October 6, 2016</td>
<td>100616</td>
<td>75-96m</td>
</tr>
<tr>
<td></td>
<td>October 7, 2016</td>
<td>100716</td>
<td>98-130m</td>
</tr>
<tr>
<td></td>
<td>October 8, 2016</td>
<td>100816</td>
<td>131-170m</td>
</tr>
<tr>
<td></td>
<td>October 15, 2016</td>
<td>101516</td>
<td>171-195m</td>
</tr>
<tr>
<td></td>
<td>October 22, 2016</td>
<td>102216</td>
<td>196-236m</td>
</tr>
<tr>
<td></td>
<td>November 12, 2016</td>
<td>111216</td>
<td>237-257m</td>
</tr>
<tr>
<td>Spring 2017</td>
<td>January 9, 2017</td>
<td>010917</td>
<td>237-261m</td>
</tr>
<tr>
<td></td>
<td>January 10, 2017</td>
<td>011017</td>
<td>262-286m</td>
</tr>
<tr>
<td></td>
<td>January 14, 2017</td>
<td>011417</td>
<td>287-311m</td>
</tr>
<tr>
<td></td>
<td>January 23, 2017</td>
<td>012317</td>
<td>312-336m</td>
</tr>
<tr>
<td></td>
<td>January 27, 2017</td>
<td>012717</td>
<td>337-372m</td>
</tr>
<tr>
<td></td>
<td>January 28, 2017</td>
<td>012817</td>
<td>373-397m</td>
</tr>
<tr>
<td></td>
<td>February 3, 2017</td>
<td>020317</td>
<td>398-422m</td>
</tr>
<tr>
<td></td>
<td>February 4, 2017</td>
<td>020417</td>
<td>423-444m</td>
</tr>
<tr>
<td></td>
<td>February 4, 2017b</td>
<td>020417b</td>
<td>459-480m</td>
</tr>
</tbody>
</table>
measurements is recorded to minimize the impact of human error. These measurements are more reliable at relocating reference stations than the electronic methods with decimeter-scale precision when performed diligently.

<table>
<thead>
<tr>
<th>Device</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMT MC-GPS</td>
<td>1-3 m</td>
</tr>
<tr>
<td>Garmin Etrex</td>
<td>&lt; 5 m</td>
</tr>
<tr>
<td>iPhone 6, Apple</td>
<td>&gt; 5 m</td>
</tr>
<tr>
<td>Tape &amp; Compass</td>
<td>&lt; 2 m</td>
</tr>
</tbody>
</table>

Table 2.3. Devices for determining seismic station positions. The devices are listed with the error range in their ability to relocate stations.

I input to Google Earth the reference station locations are as measured by all four devices. The GPS coordinates are input as recorded by each device. I input the tape & compass measurement positions by identifying in the satellite image the landmarks from which the measurements were made and using the Ruler tool to measure the distance and back-bearing from that landmark on the screen. I make a final determination of each reference station’s GPS coordinates by selecting a position which represents an average of the locations recorded by each method weighted towards the measurements of the more precise methods. I also verify that the final determinations of reference station location are consistent with the orientation of the transect during the survey relative to the local geography. I determine the location of each shotpoint via linear interpolation between the reference stations at 1-meter intervals. Shotpoint elevation is determined by cross-referencing the shotpoint coordinate with elevation data from the Louisiana Statewide LIDAR Project (Cunningham et al., 2000) at https://atlas.ga.lsu.edu/datasets/lidar2000/. Elevation data are gridded at 5 m x 5 m.

2.3. Seismic Sources

2.3.1. SH-Waves

The Bueche seismic survey uses two sources which generate horizontally polarized shear (SH) waves. SH waves are chosen because of their advantages over compressional (P) waves in imaging shallow, water saturated target zones. It can be difficult to image the upper 100m in modern alluvial settings with compressional (P) waves as a result of a lack of impedance contrasts to produce reflections (Wang et al., 2003). SH-waves have been shown to be effective in imaging shallow (<100m) alluvial targets (Morrison, 2017; Wang et al., 2003; Woolery et al.,
This effectiveness is partially the result of shear waves’ insensitivity to pore fluid content because of their inability to propagate through materials with no resistance to shear strain (Goforth and Hayward, 1992; Haines and Ellefsen, 2010; Pugin et al., 2004; Suyama et al., 1987; Young and Hoyos, 2001).

### 2.3.2. Sheargun

The first SH-wave source is a ground coupled electro-mechanical shear recoil device [Figure 2.3] (Crane et al., 2013) hereafter referred to as the ‘sheargun’. The sheargun generates horizontally polarized shear (SH) waves via horizontal discharge of a blank 12-gauge shotgun shell containing a charge of black powder and an iron oxide ballast. The sheargun is nested to a baseplate in a cradle that permits the device to rotate 180° about a horizontal axis. The ability to rotate the sheargun without recoupling the assembly allows the polarity of the SH waves it generates to be easily reversed. During acquisition, I position the baseplate so that the horizontal axis about which the sheargun rotates is oriented parallel to the seismic line. The baseplate is coupled to the ground by two vertical steel blades that are attached to the bottom of the baseplate and oriented parallel to the axis about which the sheargun rotates. A small hammer is used to drive the blades into the soil at each shotpoint to ensure sound coupling. During operation of the sheargun I place my foot on top of it and apply downward force to further improve coupling and reduce vibration.

### 2.3.3. I-beam

The second source is a steel I-beam struck with a 8 lb (head weight) sledgehammer horizontally in order to generate horizontally polarized shear (SH) waves [Figure 2.4]. The long axis of the I-beam is oriented parallel to the orientation of the seismic transect and the I-beam is coupled to the ground with the use of a small hammer. The operator stands on the I-beam facing in a direction perpendicular to its long axis and strikes the face of the I-beam with the sledgehammer. The operator can turn about-face and strike the opposite face of the I-beam to reverse the polarity of the SH-waves generated by the source without moving or recoupling the I-beam. Three hammer blows are vertically stacked for each record when using the I-beam source to approximate the energy release of a seisgun discharge and enhance signal-to-noise ratio (Levin, 1977).
Figure 2.3. (Top) The sheargun. Scale at bottom of the image is in inches. (Bottom) Sheargun in operation by Blake Odom during an east-facing shot. In both images, the dashed line indicates the horizontal axis about which the sheargun can rotate as well as the orientation of the seismic line during source operation, while the arrow indicates the direction of first motion in the source orientation that is depicted.
Source Bandwidth

I analyze the frequency bandwidth of the seismic sources [Figure 2.5] in the near field (<5 m). The frequency spectrum of the I-beam source has a roughly symmetrical distribution about a dominant frequency of 49 Hz. The frequency amplitude of the I-beam source decays at a rate of approximately 6 dB/octave below this peak and approximately 16 dB/octave above this peak. Whereas the sheargun source has a dominant frequency of 45 Hz, similar to that of the I-beam source, its frequency distribution is more asymmetrical and is skewed toward medium frequency ranges (65-110 Hz). The amplitude of the sheargun source decays much more rapidly below its dominant frequency than the I-beam source, at a rate of approximately 18 dB/octave, but less rapidly above its dominant frequency, at an average rate of approximately 9 dB/octave. The decay in frequency amplitude above the peak is nonlinear, falling rapidly from 45-65 Hz, slowly from 65-110 Hz, then rapidly again above 110 Hz. The frequency amplitudes in the 125-175 Hz range are up to 5 times higher for the sheargun than the I-beam, and the
sheargun continues to produce energy above 500 Hz. The upper frequency limit of the I-beam source in the near field is 205 Hz.

Alternating between the sheargun and I-beam between shot points broadens the signal bandwidth in the seismic data by combining the amplitude distribution profiles of each source. The lower frequencies of the I-beam should experience less attenuation and allow for greater penetration, while the higher frequencies of the sheargun should provide greater vertical resolution (Liner, 2004). This increase in the imaging potential of the survey comes at the cost of increased time, effort, and cost of acquisition.

![Figure 2.5. Single-trace frequency spectra plotted with a fast Fourier transform (sufft) in Seismic Unix. The traces are at 4 m source-receiver offset and represent adjacent shotpoints. I-beam source (left) displays a symmetrical amplitude distribution profile with greater energy concentration below 60 Hz than the sheargun source (right), which displays an uneven, asymmetrical amplitude distribution profile skewed towards higher frequency ranges.](image)
2.4. Main Processing Flow

I process the seismic data with Seismic Unix (Cohen and Stockwell, 2014) to facilitate interpretation by increasing the signal-to-noise ratio and arranging the data in a geologically meaningful manner. The main processing workflow [Figure 2.6] uses Seismic Unix programs incorporated into either Bash or Perl scripts [Table 2.4]. The file structure [Figure A.1] organizes the files run on the data server (zamin.lsu.edu) into three trees: seismic data (.su), Perl scripts (.pl), and Shell scripts (.sh). The three trees are divided into subdirectories named for each date of data acquisition. The scripts contained in the subdirectories within the ‘sh’ and ‘pl’ trees act on the data files contained in the corresponding subdirectory within the ‘data’ tree. The data collected on February 4, 2016 are split between subdirectories ‘020417’ and ‘020417b’ to respectively separate the data collected before and after the intentional data gap that was implemented to avoid interference from the culvert near the end of the line. These two subdirectories are treated as separate acquisition dates in the processing workflow. An additional subdirectory termed ‘All’ contains concatenated files containing data from all acquisition dates. The MATLAB scripts are run externally, but stored on zamin.lsu.edu in 

/home/gadam2/FalseRiver/seismics/matlab/Bueche/All/H/1/gadam2/.

The seismic data are composed of individual seismic traces, i.e., the record of the signal sampled by a receiver following the release of seismic energy by one of the seismic sources. Each trace is associated with a header file containing keywords [Table 2.5] used to identify the trace and record the geometrical parameters that are specific to it. A numerical value is assigned to each keyword in each traces’ header. Seismic Unix programs process the seismic data by performing numerical operations on the samples and header values of traces specified by user-defined keyword values. Common processing terms are explained in Table 2.6.

2.4.1. Upload & Conversion

I download the data files from the seismograph and upload them to the data sever. I convert them from SEG2 (.dat) file format to Seismic Unix (.su) file format with Sseg2su [Section A.3.1]. Each file contains one shot record with 24 traces of data collected from the same shot.
Figure 2.6. Chart of the main processing flow for the Bueche seismic data.
<table>
<thead>
<tr>
<th>Processing Step</th>
<th>Program Name</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Import SEG2 (.dat) files</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Convert from SEG2 (.dat) file format to Seismic Unix (.su) file format</td>
<td>Sseg2su</td>
<td>Files are collected as .dat file type and are converted to .su file type for compatibility with Seismic Unix.</td>
</tr>
<tr>
<td>Reverse selected trace polarity</td>
<td>Reverse_polarity.pl</td>
<td>Reverses polarity from traces 13-24 on all records to account for equipment malfunction.</td>
</tr>
<tr>
<td>Concatenate files sharing acquisition date and source</td>
<td>Sucat2</td>
<td>Data with a common acquisition date and source type are combined into single files to facilitate further processing.</td>
</tr>
<tr>
<td>Set initial trace header geometry</td>
<td>SuClean_geometry.pl</td>
<td>Sets initial values for header keywords.</td>
</tr>
<tr>
<td>Negatively stack common-shot gathers</td>
<td>Sudiff.pl</td>
<td>Records with opposite source polarity collected at each shot point are subtracted from each other to enhance SH-wave signal and reduce P-wave noise.</td>
</tr>
<tr>
<td>Refine trace header geometry (1)</td>
<td>SuGeom2.pl</td>
<td>Refines header keyword values.</td>
</tr>
<tr>
<td>Concatenate and reorder files that differ in source type but share acquisition date</td>
<td>SuWeave.pl</td>
<td>Data with a common acquisition date but differing in source type are combined into single files to facilitate further processing.</td>
</tr>
<tr>
<td>Calculate and assign common midpoint (cmp) values to trace headers</td>
<td>Make_cmp.pl</td>
<td>Header value ‘cdp’ is calculated and set.</td>
</tr>
<tr>
<td>Concatenate all data</td>
<td>Sucat2</td>
<td>Files containing all data from each acquisition day are combined to create a single working file containing all Bueche seismic data.</td>
</tr>
<tr>
<td>Refine trace header geometry (2)</td>
<td>SuLoadHeaders.pl</td>
<td>Refines existing header keyword values. Adds new header keywords.</td>
</tr>
<tr>
<td>Perform static correction for surface topography</td>
<td>static.sh</td>
<td>Arrival times are adjusted to a reference datum to correct for undulating surface topography.</td>
</tr>
<tr>
<td>Pick surface wave arrivals</td>
<td>iTop_Mute3</td>
<td>Parameters for each common shot gather are selected to separate surface wave arrivals from reflection arrivals.</td>
</tr>
<tr>
<td>Mute surface wave arrivals</td>
<td>Sumute.pl</td>
<td>Surface wave arrivals are muted.</td>
</tr>
<tr>
<td>Velocity Analysis</td>
<td>iVA2</td>
<td>Performs semblance analysis to construct $V_{\text{rms}}$ and $V_{\text{int}}$ profiles at each common midpoint.</td>
</tr>
<tr>
<td>Correct for normal moveout then stack</td>
<td>Sustack.pl</td>
<td>Applies a correction for normal moveout and stacks traces with identical cdp header values.</td>
</tr>
</tbody>
</table>
Table 2.5. Seismic Trace Header Keywords

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>trac</td>
<td>Unique identifier that increases sequentially between each trace in the entire dataset.</td>
</tr>
<tr>
<td>tracr</td>
<td>Identifier that increases sequentially between traces within a data directory.</td>
</tr>
<tr>
<td>tracf</td>
<td>Identifier that increases sequentially between traces with a common shot.</td>
</tr>
<tr>
<td>fldr</td>
<td>Identifier that increases sequentially between shotpoints within a data directory.</td>
</tr>
<tr>
<td>duse</td>
<td>Source identifier. 1 -&gt; l-beam source; 2 -&gt; seisgun source.</td>
</tr>
<tr>
<td>ep</td>
<td>Shotpoint location counter. Ep1 represents the first shotpoint location 0m from the start of the line.</td>
</tr>
<tr>
<td>cdp</td>
<td>Common midpoint. cdp = (gx + (ep-1)) / 4</td>
</tr>
<tr>
<td>offset</td>
<td>Source-receiver distance in meters. Equivalent to channel number in a common shot gather.</td>
</tr>
<tr>
<td>gx</td>
<td>Receiver distance from start of the line in meters. gx = (ep-1) + offset</td>
</tr>
<tr>
<td>gelev</td>
<td>Receiver elevation in centimeters above sea level.</td>
</tr>
<tr>
<td>sx</td>
<td>UTM Zone 15 easting coordinate for source position in centimeters.</td>
</tr>
<tr>
<td>sy</td>
<td>UTM Zone 15 northing coordinate for source position in centimeters.</td>
</tr>
<tr>
<td>selev</td>
<td>Source elevation in centimeters above sea level.</td>
</tr>
<tr>
<td>scalel</td>
<td>Scaling factor used to set ‘selev’ and ‘gelev’ units to centimeters.</td>
</tr>
<tr>
<td>scaleco</td>
<td>Scaling factor used to set ‘sx’ and ‘sy’ units to centimeters.</td>
</tr>
<tr>
<td>tstat</td>
<td>Magnitude of arrival time correction in milliseconds to adjust for topographic variability.</td>
</tr>
<tr>
<td>ns</td>
<td>Number of data samples contained in a trace (ns=8191).</td>
</tr>
<tr>
<td>dt</td>
<td>Sampling interval in microseconds (dt=500).</td>
</tr>
<tr>
<td>delrt</td>
<td>Sampling delay in milliseconds (delrt=10)q</td>
</tr>
<tr>
<td>trid</td>
<td>Trace Identification Code – not used</td>
</tr>
<tr>
<td>year</td>
<td>Four-digit year (YYYY) of record</td>
</tr>
<tr>
<td>day</td>
<td>Day of year (1-365) of record</td>
</tr>
<tr>
<td>hour</td>
<td>Hour of day (1-24) of record</td>
</tr>
<tr>
<td>minute</td>
<td>Minute of hour (1-60) of record</td>
</tr>
<tr>
<td>second</td>
<td>Second of minute (1-60) of record</td>
</tr>
</tbody>
</table>

Table 2.6. Processing Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMP</td>
<td>‘Common Midpoint’. Sequential counter of source-receiver midpoints.</td>
</tr>
<tr>
<td>EP</td>
<td>‘Shotpoint’. Sequential counter of source locations.</td>
</tr>
<tr>
<td>trace</td>
<td>The data record of an individual receiver/channel following a shot.</td>
</tr>
<tr>
<td>gather</td>
<td>A collection of seismic traces sharing a common parameter (usually EP or CMP).</td>
</tr>
<tr>
<td>fold</td>
<td>Number of traces sharing a CMP.</td>
</tr>
<tr>
<td>automatic gain control</td>
<td>Equalization by adjusting the amplitude of each sample to that of the average sample amplitude over a window centered on that sample.</td>
</tr>
<tr>
<td>wagc</td>
<td>Width (in seconds) of the automatic gain control window.</td>
</tr>
<tr>
<td>clip</td>
<td>Data clipping by setting the maximum trace amplitude to an absolute value.</td>
</tr>
<tr>
<td>perc</td>
<td>Data clipping by setting the maximum trace amplitude to percentile.</td>
</tr>
<tr>
<td>f</td>
<td>Corner frequencies for the band-pass frequency filter.</td>
</tr>
<tr>
<td>wiggle</td>
<td>Trace display with sample value plotted as offset distance from a vertical axis.</td>
</tr>
<tr>
<td>image</td>
<td>Trace display with sample value plotted as a colorscale value.</td>
</tr>
</tbody>
</table>
2.4.2. Polarity Reversal

As a result of miswiring in the Rota-Long-Switch, the polarity of the signal in channels 13-24 is reversed, i.e. 180° out of phase from traces 1-12 [Figure 2.7]. I correct this by inverting the samples in traces 13-24 in every shot record [Figure 2.8] using Reverse_polarity.pl [Section A.3.2].

2.4.3. Shotgather Concatenation & Geometry

I combine the common-shot gather records by concatenating together all files recorded with a common seismic source in each subdirectory using Sucat2 [Section A.3.3]. This yields two files for each date of data subdirectory, one for the I-beam source and one for the seisgun source. I use suclean_geom.pl [Section A.3.4] to remove the keywords ‘fldr’, ‘trid’, ‘year’, ‘day’, ‘hour’, ‘minute’, and ‘second’ [Table 2.5], which are assigned by the StrataView and unnecessary for this study. I also assign initial values for the header keywords ‘tracf’, ‘ep’, ‘sx’, and ‘gx’, and I correct the values for header keyword ‘tracr’ [Table 2.5].

2.4.4. Negative Stacking

I negatively stack gathers collected at each shotpoint (EP) by performing trace-by-trace subtraction of the east-oriented shot from the west-oriented shot [Figure 2.10] using Sudiff.pl [Section A.3.5]. Negative stacking improves signal-to-noise ratio by increasing the strength of the SH-wave signal (Jolly, 1956; Lankston, 1990) and reducing or eliminating P-wave conversions in the data because their polarity does not depend on source orientation (Hasbrouck, 1991; Lankston, 1990). Reflectors in a negatively stacked common-shot gather [Figure 2.11] are more coherent and easier to identify.

2.4.5. Combining Sources

I restore the header keyword ‘fldr’ and refine the values for header keywords ‘tracf’ and ‘ep’ [Table 2.5] for the negatively-stacked data using SuGeom2.pl [Section A.3.6]. A two-step approach for setting the values of these header keywords is necessary because of the choices to alternate sources between shotpoints and to perform negative stacking. Before negative stacking, the files concatenated by source type contain two data records for each shotpoint. In addition, the I-beam file contains only odd shotpoints, while the seisgun file contains only even shotpoints. It is difficult to set the geometry accurately in a single step for files organized in this manner because of the design of the Seismic Unix programs that modify header keyword values.
Figure 2.7. Wiggle (left) and image (right) plots of the unprocessed common-shot gather of the east-oriented I-beam shot record at shotpoint (EP) 361. The discontinuity at trace 13 (orange arrow) is an artifact of the polarity reversal of traces 13-24. Automatic Gain Control (wagc=0.1) is applied to highlight the artifact. Clip is applied to the wiggle plot (clip=0.1) and image plot (perc=85). The data are filtered (f = 0 Hz, 5 Hz, 75 Hz, 150 Hz). Trace spacing is 1m.
Figure 2.8. Wiggle (left) and image (right) plots of the common-shot gather of the east-oriented record at shotpoint (EP) 361 with the polarity reversal applied to traces 13-24. Not the removal of the artifact visible in Figure 2.7. Automatic Gain Control (wagc=0.1) is applied. Clip is applied to the wiggle plot (clip=0.1) and image plot (perc=85). The data are filtered (f = 0 Hz, 5 Hz, 75 Hz, 150 Hz). Trace spacing is 1m.
I combine the negatively-stacked I-beam and sheargun files by concatenating their data records in order of sequentially increasing shotpoint with SuWeave.pl [Section A.3.7]. This yields a single file for each subdirectory containing all data with twenty-four (24) negatively-stacked traces at each shotpoint. After completing the main processing flow, I compare the seismic section generated from the CMP stacking of both source signals combined to seismic sections generated from stacking each source signal individually to demonstrate that the combination of source signals does not degrade the data as a result of destructive interference [Figure 2.18].

2.4.6. CMP Sorting

I calculate the common midpoint (CMP) positions for each trace-source pair and assign the value to the header keyword ‘cdp’ [Table 2.5] using Make_cmp.pl [Section A.3.8]. Because signal-to-noise ratio increases as the square root of CMP fold (Liner, 2004), I use a 2 m CMP bin size.

2.4.7. Concatenating All Data

I use Sucat [Section A.3.3] to concatenate the outputs of Make_cmp.pl [Section A.3.8] from each subdirectory in order of acquisition date into a single file that I place in the 'All' subdirectory of the 'data' tree.

2.4.8. Elevation Statics Correction

I perform a final operation on the trace headers of the fully concatenated data using SuLoadHeaders.pl [Section A.3.9]. I add header keyword values for ‘scalel’, ‘scaleco’, ‘duse’, ‘offset’, ‘sy’, ‘selev’, ‘gelev’, and ‘tstat’ [Table 2.5], and I convert the keyword ‘sx’ from source distance in meters from the start of the line to the source location as a UTM Easting coordinate in centimeters to match the format of the ‘sy’ keyword [Table 2.5].

I adjust the traces to a horizontal seismic reference datum (SRD) at 7.95 m to set t=0.0 for each trace to a constant elevation, removing the effects of surface topography on reflection arrival time. The keyword ‘tstat’ is the value in milliseconds of the two-way arrival time adjustment for topographic variation along the seismic transect and is calculated with tstat_calc.m [Section A.3.10] according to Equation 2.1 under the assumption of a constant weathering velocity, the seismic velocity above the seismic reference datum (SRD). The weathering velocity is set at 100 m/s, a first-order approximation of the surface wave velocity in the study site [Figure 2.12]. I apply the static correction to the seismic data with static.sh [Section A.3.11]. Traces are shifted upward by the value of T_{stat}. The
static corrections result in a negligible reduction of the undulatory character displayed by many reflections in a common-shot gather [Figure 2.12].

Figure 2.9. Interpreted wiggle (left) and image (right) plots of the common-shot gather of the east-oriented record at shotpoint (EP) 361 after polarity reversal. Clip is applied to the wiggle plot (clip=0.8) and image plot (perc=85). The data are filtered (f = 0 Hz, 5 Hz, 75 Hz, 150 Hz). Trace spacing is 1m. The blue dashed line identifies a refracted wave arrival. The green dashed line identifies a surface wave arrival. Red dashed lines identify reflection arrivals.
Figure 2.10. Wiggle (left) and image (right) plots of the common-shot gather of the west-oriented record at shotpoint (EP) 361 after polarity reversal. Clip is applied to the wiggle plot (clip=0.8) and image plot (perc=85). The data are filtered ($f = 0$ Hz, 5 Hz, 75 Hz, 150 Hz). Trace spacing is 1m. The blue dashed line identifies a refracted wave arrival. The green dashed line identifies a surface wave arrival. Red dashed lines identify reflection arrivals.
Figure 2.11. Wiggle (left) and image (right) plots of the common-shot gather record at shotpoint 361 after negative stacking. Clip is applied to the wiggle plot (clip=0.8) and image plot (perc=85). The data are filtered (f = 0 Hz, 5 Hz, 75 Hz, 150 Hz). Trace spacing is 1m. The blue dashed line identifies a refracted wave arrival. The green dashed line identifies a surface wave arrival. Red dashed lines identify reflection arrivals. I interpret more numerous and coherent reflection arrivals in the negatively stacked common-shot gathers.
\[ T_{\text{stat}} = \left[ \frac{Z_S - Z_{\text{SRD}}}{V_w} \right] + \left[ \frac{Z_R - Z_{\text{SRD}}}{V_w} \right] \times 1000 \]

Equation 2.1. Value in milliseconds of the static correction \( (T_{\text{stat}}) \) is calculated as function of the weathering velocity in meters per second \( (V_w) \), the source elevation in meters \( (Z_S) \), the receiver elevation in meters \( (Z_R) \), and the seismic reference datum elevation in meters \( (Z_{\text{SRD}}) \).

2.4.9. Surface Wave Muting

The earliest reflections in the Bueche data are obscured by the arrivals of Love-waves and refracted waves [Figure 2.11]. I use a top-muting process (Roth et al., 1998; Spitzer et al., 2001) to these arrivals. A top-mute sets the value of all trace samples above a selected path in X-T space to zero, and the removal of the early Love-wave arrivals with a top-mute also removes the air blast because their greater velocity results in an earlier arrival time.

To perform the muting, the data is sorted by shot gather and visually examined. Manual picks are made with iTop_Mute3 [Section A.3.12] to establish a path that separates the data into two regions. The region above the path contains substantial masking of reflection arrivals by surface wave arrivals and is muted. Below the path, the data contains unobscured reflection arrivals and is preserved. The muting is applied to the data [Figure 2.13] with Sumute.pl [Section A.3.13].

2.4.10. Velocity Analysis

I perform NMO-based velocity analysis (Taner and Koehler, 1969) to calculate interval \( (V_{\text{INT}}) \) and root-mean-square \( (V_{\text{RMS}}) \) velocity profiles for each CMP using semblance as a measure of coherency (Yilmaz, 2001). I use iVA2 [Section A.3.14] to calculate and display the velocity spectra for each CMP gather as a contour plot, and to interactively select TWT-velocity pairs with high semblance [Figure 2.14]. The files containing the TWT-velocity pairs for each CMP are concatenated with suCatPar.pl [Section A.3.15]. I calculate the fold of each CMP [Figure 2.15] with cdp_count.sh [Section A.3.16]. The maximum fold is increased to 48 with the use of a 2 m bin size, but reductions in fold are introduced by the data gaps near the start and end of the seismic transect.
Figure 2.12. Wiggle plot of shotpoint 361 before (left) and after (right) static corrections. The data are clipped (clip=0.5) and filtered (f = 0 Hz, 5 Hz, 75 Hz, 150 Hz). Trace spacing is 1m. The dashed red lines trace interpreted reflectors. They display little reduction in undulation after static correction. Maximum static correction is 47.9 ms. The dashed green line in the pre-static data traces a surface wave arrival, and its slope in x-t space between trace 10 (~0.095 s) and trace 20 (~0.192 s) is equivalent to its slowness, the reciprocal of the group velocity calculated below.

\[
\frac{20 \text{ m} - 10 \text{ m}}{0.192 \text{ s} - 0.095 \text{ s}} = \frac{10 \text{ m}}{0.097 \text{ s}} = 103.1 \text{ m/s}
\]
Figure 2.13. Wiggle plots of shotpoint 361 following static corrections before (left) and after (right) top-muting. The data are clipped (clip=0.8) and filtered (f = 0 Hz, 5 Hz, 75 Hz, 150 Hz). Trace spacing is 1m. Orange envelope in the pre-mute data shows the path picked for the top-mute function. The refracted wave (blue dashed line) arrivals are eliminated and the Love-wave (green dashed line) arrivals are all but absent from the muted data.
Figure 2.14. Contour plot of the velocity spectrum of CMP 181 calculated via semblance. Velocity analysis uses an initial velocity value of 50 m/s and 400 velocity increments of 1 m/s per increment. Points 1-7 are TWT-velocity picks [Table 2.7] at high semblance values.

Table 2.7. TWT-velocity pairs from Points 1-7 picked from the velocity spectrum of CMP 181 [Figure 2.14]

<table>
<thead>
<tr>
<th>Point</th>
<th>TWT (s)</th>
<th>Velocity (m/s)</th>
<th>Semblance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.09</td>
<td>171</td>
<td>0.248</td>
</tr>
<tr>
<td>2</td>
<td>0.16</td>
<td>183</td>
<td>0.291</td>
</tr>
<tr>
<td>3</td>
<td>0.19</td>
<td>190</td>
<td>0.366</td>
</tr>
<tr>
<td>4</td>
<td>0.25</td>
<td>200</td>
<td>0.320</td>
</tr>
<tr>
<td>5</td>
<td>0.33</td>
<td>214</td>
<td>0.366</td>
</tr>
<tr>
<td>6</td>
<td>0.47</td>
<td>250</td>
<td>0.448</td>
</tr>
<tr>
<td>7</td>
<td>0.59</td>
<td>279</td>
<td>0.342</td>
</tr>
</tbody>
</table>
I use the velocity analysis results to correct for normal moveout (NMO) of the seismic reflectors resulting from the variability in source-receiver offset distances between the traces of a CMP gather (Yilmaz, 1987). The velocity profile of each CMP is used to account for the increase in travel time from increasing offset and thereby flatten the reflection events observed in each CMP gather [Figure 2.17].

I stack the seismic data by taking the summation of every trace within each CMP gather [Figure 2.16], generating a stacked seismic section consisting of a single stacked trace for each of the 245 non-zero-fold CMPs. CMP-stacked sections [Figure 2.18] generated from the combination of seismic sources [Section 2.4.5] and from each source signal independently show that the combination of source signals does not degrade the data. Ideally, the CMP stack increases signal-to-noise ratio of each CMP by the square root of its fold (Liner, 2004; Yilmaz, 1987). NMO corrections and stacking are applied with Sustack.pl [Section A.3.17].

Figure 2.15. Calculated fold for each common midpoint (CMP) of the Bueche seismic survey. CMP values range from 0 – 246. Maximum fold is 48, and minimum fold is 0. Troughs in fold count are the result of data gaps. CMPs 23 & 24 are zero-fold, containing no data. There are 245 CMPs with a non-zero fold in the stacked seismic section.
Figure 2.16. (Left) CMP 181 before CMP stacking, identical to the right plot in Figure 2.17. (Right) CMP 181 after CMP stacking. Automatic gain control is applied (wagc=0.2). The data are clipped (perc=93) and filtered (f = 0 Hz, 5 Hz, 75 Hz, 150 Hz). The single trace in the stacked data (right) is the sum of all traces in the unstacked data (left). The dashed red lines in the stacked trace highlight the amplitude peaks which correspond to the TWT-velocity picks in Figure 2.14 and the reflection events in Figure 2.17.
Comparison of stacked seismic section generated using with only the sheargun source data (top), only the I-beam source data (center), and data from both sources (bottom) shows that deconstructive interference resulting from any phase shift between the source signals does not significantly degrade the quality of the imaging or hinder interpretation of the section. All seismic data are clipped (perc=95) and filtered (f = 0 Hz, 5 Hz, 75 Hz, 150 Hz). Trace spacing is ~2m.
2.5. Dip Calculation

I calculate the dip angle of the dip-affected seismic reflectors interpreted in the seismic data. A dipping seismic reflector produces a reflection hyperbola in a common-shot gather characterized by an apex offset in the up-dip direction (Liner, 2004) [Figure 2.19]. Equation 2.2 describes the relationship between reflector dip, apex offset distance, and apex depth.

\[ \theta = \sin^{-1} \left( \frac{x}{2z} \right) \]

Equation 2.2. Seismic reflector dip in degrees (\( \theta \)) is calculated as a function of source-apex offset distance (\( x \)) and apex depth (\( z \)) (Liner, 2004).

Figure 2.19. Theoretical effects of seismic reflector inclination on a common shot gather (Liner, 2004). (Left) A horizontal reflector results in no offset of the reflection hyperbola apex. (Right) A dipping reflector results in offset of the reflection hyperbola apex in the up-dip direction.
2.5.1. Apex Picks

I interactively select TWT-offset pairs corresponding to the apices of offset reflection hyperbolae in each common-shot gather [Figure 2.20]. The plots for picking these pairs are generated with ep_picks.sh [Section A.4.1]. Apex offsets are picked with a resolution of 1 m, the trace spacing. Apex TWT are picked with a resolution of 0.1 ms, twice the sampling interval. The error associated with picking offsets is ±1 m, while the error associated with picking TWT is generally ±2 ms.

![Wiggle plot of shotpoint (EP) 327 with an offset reflector hyperbola traced in red. Seismic data are clipped (clip=0.75) and filtered (f = 5 Hz, 15 Hz, 75 Hz, 150 Hz). Trace spacing is 1m. The red X marks the interpreted position of the apex with an offset of 10 m and a TWT of 0.1892 s. Depth conversion must be performed on the picked TWT before dip can be calculated.](image)

2.5.2. Depth Conversion

Two-way time (TWT) values picked for each offset reflector apex must be converted into depth before reflector dips can be calculated. I use dipcalc.m [Section A.4.2] to generate a root-mean-square velocity (VRMS)
model of the seismic section and perform time-to-depth conversions for the two-way time (TWT) associated with the apex of each offset reflection hyperbola.

I use linear interpolation and extrapolation of the root-mean-square velocity profiles calculated during velocity analysis for each CMP [Figure 2.14] to populate every velocity profile with $V_{\text{RMS}}$ values at 0.1 ms intervals from 0.0 s to 1.0 s TWT. This is performed via the MATLAB function ‘interp1’. The CMP-by-CMP concatenation of these resampled velocity profiles results in a TWT-$V_{\text{RMS}}$ model for the seismic section [Figure 2.21]. The TWT-offset apex pairs are converted to depth-offset pairs using the velocity model, and.

![Figure 2.21. Root-mean-square velocity ($V_{\text{RMS}}$) model used to convert TWT picks to depth.](image)

### 2.5.3. Dip Calculation & Contouring

I use dipcalc.m [Section A.4.2] to calculate a dip angle for each depth-offset pair. I use Surfer v11.5 to regrid and contour the dip calculations at a 1 m x 1 m grid spacing across the 480 m length of the seismic transect and to a depth of 60 m. I use a local polynomial interpolation to perform the regridding. The interpolation fits an ordered polynomial against the data using a weighted least squares method (Ruppert and Wand, 1994), and each grid node is assigned the value of the polynomial at that node (Golden Software Inc., 2012).
Chapter 3. Results & Interpretations

3.1. Seismic Cross-Section

The stacked seismic section provides high-resolution subsurface imaging of a late-stage point bar deposit. Mapping the seismic horizons [Figure 3.1] reveals that many of these seismic reflectors are dipping. Most dipping reflectors are inclined towards the paleochannel to the southwest. Reflector coherency and signal-to-noise ratio (SNR) diminish between 155 – 245 m, a domain corresponding to the local elevation minimum along the seismic transect and a low $V_{RMS}$ anomaly in the seismic velocity model [Figure 3.2].

The seismic reflectors are categorized on the basis of their depth, dip magnitude, and dip direction. Inclined reflectors above approximately 0.4 s two-way travel time (TWT) that dip towards the southwest are mapped in red. These reflectors display lateral continuity up to distances of 150 m. More of these reflectors are mapped towards the northeast end of the line due to superior SNR. The deepest reflectors (0.5 – 0.6 s TWT) are mapped in blue. These reflections are undulatory, relatively horizontal, and highly continuous when compared to the shallower, inclined reflections. The continuity of these deep reflections is disrupted by the data gaps with dimished fold and in the region of the low velocity anomaly beneath the local topographic minimum from 155 – 245 m. Mapped in green are reflectors that appear to image a feature that displays a dip direction towards the point bar interior to the northeast.

Figure 3.1. Processed seismic cross-section with reflectors mapped. Seismic data are clipped (perc=95) and filtered ($f = 0$ Hz, 5 Hz, 75 Hz, 150 Hz).
3.2. Interpretation of the Seismic Cross-Section

Interpretation of the stacked seismic section [Figure 3.3] confirms the presence of inclined seismic reflectors which dip in the paleochannel direction. The presence of a semi-symmetric feature defined, in part, by reflectors dipping towards the northeast suggests the presence of a mid-channel bar which has been buried by both overbank and laterally accreting channel deposits.

The red reflectors are interpreted as laterally accreting sediments of the upper and lower point bar is made on the basis of their unilateral dip direction towards the channel to the southwest and the depth range (~5-
45 m) in which they are observed. As lateral accretion deposits, these reflectors represent the submerged inner bank of the channel (Leeder and Bridges, 1975). The interpretation of the blue reflectors as a transitional zone composed of modern alluvium between the overlying deposits of the False River meander and the underlying Prairie Formation is made on the basis of their relatively low dips (> 4°) and their depth (45-55 m), which corresponds well to the average depth to the underlying Prairie Formation of ~50 m (Fisk, 1944). The interpretation of the feature indicated by green reflectors as a mid-channel bar is made based on the feature’s internal stratification and anomalous dip directions that are towards the northeast and away from the channel. The mid-channel bar is interpreted to have been buried beneath the laterally accreting and overbank deposits. The semi-symmetrical shape of the feature indicated by the green reflectors is suggestive of such a bar, which are features that slope conspicuously towards the inner bank found in association with point bars of meandering rivers such as the modern Lower Mississippi River, aggrade vertically in a manner that should result in internal stratification, and could be buried beneath lateral accretion deposits (Hooke, 1986). Similar buried features have been interpreted in previous seismic studies of the False River point bar (Morrison, 2017).

3.3. Model of Late-Stage False River Development

From an analysis of the Bueche seismic data and surface topography of the False River point bar, I interpret the development of the study area. I depict this development in three phases. In Phase 1 [Figure 3.4] the mid-channel bar is well developed with similar channel widths on both sides. The transition to Phase 2 [Figure 3.5] is characterized by a downstream shift in the position of the meander apex and attachment of the mid-channel bar to the inner, accretionary bank via deposition of laterally accreting sediment packages in the gap between them. Flow through this gap decreases as it fills with sediment, eventually interrupting the deposition of then lateral accretion deposits and leaving a topographic depression which begins to fill with fine-grained sediment typical of overbank deposits. The transition to the Phase 3 [Figure 3.6] occurs as the mid-channel bar attaches to the inner bank. Phase 3 is characterized by a continuation of lateral accretion on the outer flank of the mid-channel bar and an upstream shift in the position of the meander apex. During this third phase, outer bank erosion and lateral migration of the point bar slow as the gradual abandonment of the meander loop begins. This reduction in the
Figure 3.4. Map (top) and schematic cross-section (bottom) views of Phase 1 of the study area’s development. Architecture of the accretionary bank is generalized.
Figure 3.5. Map (top) and schematic cross-section (bottom) views of Phase 2 of the study area’s development.
Figure 3.6. Map (top) and schematic cross-section (bottom) views of Phase 3 of the study area’s development.
lateral migration rate enables increased vertical accumulation of the overbank deposits at the southwestern end of the study area. An increase in the thickness of the overbank deposits is supported by the digital elevation model of the False River point bar [Figure 1.13] in which late-stage deposits reach a greater surface elevation and have their undulating ridge-and-swale topography obscured by overbank deposits. A reduction in current velocity during and after cutoff causes the oxbow lake to shallow as it fills with a plug of fine grained sediment.

3.4. Analytical Results

There is general agreement between dip values calculated from the seismic data and from dipmeter measurements in a previous study at the Bueche site. Individual seismic reflectors in the stacked section dip up to 8° over distances greater than 100 m when calculated via trigonometry. Over shorter lateral distances (~20 m), the average dip of an individual reflector reaches values as high as 19° when calculated via trigonometry. In comparison, dip values calculated from dipmeter measurements in the previous study saw a maximum dip of 22.9° (Olson, 2017). The maximum dip values calculated in dipmeter measurements are inferred to be greater those calculated via analysis of the stacked seismic section due to the smaller spatial scale (the diameter of the core sample) over which the dipmeter calculations are made. The lowest dip angles for horizons interpreted as lateral accretion deposits are less than 1°, nearly horizontal. These nearly horizontal lateral accretion deposits are found exclusively near the interpreted base of the modern point bar. The average dip calculated from all dipmeter measurements at the Bueche site in the previous study was 8.7° (Olson, 2017), nearly identical to the 8.6° average of all 754 dip calculations made during the analysis of dip affected reflectors in the Bueche seismic data [Section 2.5].

The 754 dip calculations made via the analysis of offset apices of dip affected reflectors [Section 2.5] are plotted as a function of the depth and distance along the seismic transect associated with their offset reflector apices [Figure 3.7]. Dip directions associated with these calculated values are solely towards the channel to the southwest, as the end-on survey geometry prohibits measuring apex offset values for reflectors dipping towards the northeast. The validity of dip calculations from 180-240 m along the transect is questionable because the mapped reflectors in this domain of the stacked seismic section [Figure 3.1] mainly dip towards the northeast. Dips plotted
at or below ~45 m are unlikely to originate from point bar sediments given an average modern Mississippi River channel depth of ~35 m between Bayou Sara and Baton Rouge (US Army Corps of Engineers, 2013) and a typical depth in the False River area of ~50 m to the underlying substratum comprising the Mississippi Valley (Fisk, 1944).

Figure 3.7. Reflector dips calculated via analysis of dip-affected reflectors plotted against depth and distance along the seismic transect. Warmer colors correspond to lower dip values, while cooler colors correspond to higher dip values. Radii of the plotted data points are inversely proportional to the maximum error of the calculations. The spatial density of calculations is greater towards the northeast end of the cross-section as a result of increased SNR in northeastern half of the section.

### 3.4.1. Dip Calculation Error – Apex Picks

Calculation of seismic reflector dip via analysis of their offset hyperbola apices [Section 2.5.2; Equation 2.2] has inherent error that is largely the result of imprecision in the process of picking apex TWT and offset values. The effect of the error in picking apex two-way time (TWT) values on the calculated dips is insignificant because of the high resolution for TWT picks resulting from the 0.0005 s sampling interval. A maximum error of under 0.01° is contributed to the dip calculations by imprecision in apex TWT picks even in the highest velocity areas where the precision of TWT picks has the largest impact. Apex offset picks have an inherent error range of ±1 m because of the seismic survey’s 1 m trace spacing. The effect of this error on the result of the dip calculation is significant at very shallow depths (< 5 m), but it decreases with increasing depth [Figure 3.8]. Maximum error contributed to the dip calculations as a result of imprecision in picking apex offset values is calculated according to Equation 3.1.

\[
E = \left[ \sin^{-1}\left(\frac{2}{2z}\right) - \sin^{-1}\left(\frac{1}{2z}\right) \right]
\]

Equation 3.1. Error in reflector dip calculations (E) from imprecision in the apex picking process is calculated as the difference between the dip angles calculated for apices at 1 m and 2 m offsets for a given depth (z).
Figure 3.8. Maximum dip calculation error resulting from reflector hyperbola apex offsets picks [Equation 3.1] plotted as a function of reflector depths up to 50 m. Maximum error decreases as depth increases. Errors are less than 5° below ~5.5 m, less than 3° below ~9 m, and below 1° below ~27 m.

3.4.2. Dip Calculation Error – Velocity Model

Additional error in the dip calculations is introduced by uncertainty in the seismic velocity model. NMO based velocity analysis [Section 2.4.10] relies on the presence of coherent seismic reflectors within common midpoint (CMP) gathers in order to pick the velocity-TWT values used to calculate a velocity-depth profile. This domain corresponds to the northeastern edge of the prominent low velocity anomaly that is visible between CDP 80 and CDP 125. Uncertainty in the accuracy of these profiles resulting from a lack of coherent seismic reflectors occurs for CMP gathers 104-123 [Figure 3.9], corresponding to a spatial interval on the order of 40 m wide located roughly 200 m from the southwest end of the seismic transect and 245 m from the northeast end of the seismic transect. This interval lies entirely within the northeast half of a large swale which contains the local topographic minimum along the seismic transect. Velocity-TWT picks for this interval are made under the assumptions that in the study area, SH-wave velocities are near 100 m/s near the surface and that velocity profiles do not vary significantly over short lateral distances (<10m) (Benton, 2018; Morrison, 2017). If the true seismic velocity profile does differ significantly from the calculated seismic velocity profile in this interval of poor confidence, it is most likely that the true velocities are greater than the calculated velocities, as the seismic velocity of unconsolidated
sediments are rarely lower than ~85 m/s, even for clay-rich sediment at the surface (Hamilton, 1976). An estimation of the maximum error contribution of the uncertainty in the seismic velocity model to the dip calculations can be made by calculating dips in this interval under the assumption that seismic velocities are instead at the maximum values for seismic velocity profiles calculated from CMP gathers with coherent reflectors present. Doing so yields a maximum error contribution of ~9.5° for the shallowest inclined reflectors in the upper 5 m. This error decreases to ~1.5° for reflectors at a depth of 50 m. A similar low-velocity anomaly was detected at the surface in the same location using multichannel analysis of surface waves (MASW) methods (Odom, 2018). The uncertainty then lies with the position and magnitude of the low-velocity anomaly, especially that of its northeastern edge, but not its presence.

Figure 3.9. Velocity spectrum for CMP 104 with low semblance values illustrating a lack of coherent seismic reflectors necessary for performing accurate velocity analysis observed for CMP gathers 104-123.
3.5. Dip Trends

Given the expected fining trends [Section 1.4] and the commonly described relationship between fining and dip magnitude [Section 1.5] for point bars, dip values are expected to increase both upwards and towards the channel to the southwest. Dip values increase upwards across the entire lateral length of the seismic section. A trend of increasing dip towards the channel to the southwest can be seen over most of the lateral extent of the section, especially in the 5-35 m depth range. The trend of increasing dip towards the southwest is punctuated by a decrease in dips towards the southwest from roughly 240-280 m from the start of the of the seismic transect. Beyond this domain the decreasing trend towards the southwest resumes.

Figure 3.10. Contour plot of regridded reflector dip calculations [Section 2.5.3] with a 3° contour interval. Warmer colors correspond to lower dips, while cooler colors correspond to greater dips. The upper 5 m of data are unreliable because of the increasing calculation error as depth decreases [Figure 3.8] and because calculations in the upper 5 m mostly represent extrapolation into the TWT ranges which were muted in order to remove the surface wave signals [Section 2.4.9].

3.6. Evidence for Fining

The seismic velocity model and well logs of both electrical conductivity (EC) and the Hydraulic Profiling Tool (HPT) can be used evaluate the fining trends expressed at the survey site. I expect to observe evidence for vertical fining in the upwards direction and lateral fining in the paleochannel direction (towards the SW). I base these expectations on predictions from simple models of point bar architecture [Section 1.4] and because reflector dips have been shown to increase in those directions. The well logs and seismic velocity model provide evidence of lateral fining towards the channel, especially near the surface where the mud-rich overbank deposits have been interpreted to have thickened in response to waning flow during meander abandonment, but that there is no convincing evidence of a gross upwards fining trend in the study area.
3.6.1. Well Log Data

Logs of electrical conductivity [Figure 3.11] provide evidence of lateral fining in the upper 25 m. Lateral fining is indicated by an increase in baseline EC values at B3, the well site further towards the southwest and closest to the channel. Baseline log values are determined by inspection and selected as the average value within the intervals over which the log response demonstrates the least variation. Baseline EC in well B3 is just over 40 mS/m, more than twice the baseline value in any other well. This increase in baseline EC indicates more mud-rich sediment at the southwesternmost well site. Although all other wells share similar baseline EC values of ~20 mS/m, positive excursions in the log response beyond this baseline value in well B4 and B5 (both located near the center of the transect) are much more common and of greater amplitude than in well B2, which is located towards the northeastern end of the transect.

![Figure 3.11. Electrical conductivity logs of wells B1 – B5 which are located along this study's seismic transect. Dashed red line represents baseline EC value observed in each log.](image)

Logs of the Hydraulic Profiling Tool response [Figure 3.12] also provide evidence of lateral fining in the upper 25 m. In much the same way as the EC logs, average values for HPT log response are higher for well B3 than for the other wells to the northeast, indicating again that mud content in the upper point bar increases towards the channel. Evidence that this fining is progressive is weaker for the HPT logs than the EC logs, as well B2 can be seen to display greater average values than wells B4 or B5 in the upper 20m.
The well logs fail to provide evidence of fining in the upwards direction. Although all wells excepting B2 have increased EC log responses in the upper ~5 when compared to the deeper intervals, this is attributed to mud-rich overbank deposits covering the point bar and is not indicative of upward fining of the inclined point bar sediments. This attribution of increased EC log response in the uppermost log intervals is supported by the increased depths to which this upper interval extends in well B3, which is located in an area interpreted to have accumulated an exceptionally thick layer of overbank deposits.

A possible explanation for the failure of the well logs to provide evidence of upwards fining of the inclined point bar sediment packages is limited log depth. Log depth ranges from 20.8 m to 27.5 m, but interpretation of the seismic data suggests that gently inclined deposits of the lower point bar are present at depths of 40 - 45 m. Given the tendency for the thickness of the more mud-rich upper point bar facies to increase relative to the lower point bar facies in the direction of the channel (Fustic, 2007) and the proximity of the survey site to the cutoff channel, it is likely that the logs are not sampling the lower point bar facies and therefore failing to capture the gross upwards fining trend.

Figure 3.12. Maximum line pressure logs of the Hydraulic Profiling Tool in wells B2 – B5 which are located along the seismic transect. Logs are arranged in the same orientation as the seismic cross-section [Figure 1.14], moving to the northeast from left to right on the page.
3.6.2. Velocity Model

The seismic velocity model [Figure 2.21] supports the lateral fining trend suggested by the well log data. Seismic velocities in unconsolidated sediment tend to increase with increasing grain size (Hamilton, 1976). The suppressed seismic velocities in the southwestern half of the velocity model (0 – 240 m) compared to those characterizing the northeastern half (240-480 m) indicates that the southwestern end is likely more mud-rich.

As with the well log data, the expected vertical fining trend cannot be confirmed by the seismic velocity model. While the ubiquitous upwards decrease in seismic velocity may seem to suggest the prevalence of upwards fining across the seismic section, the effects of compaction with progressive burial will result in an increase in seismic velocity without any change in lithology, so vertical velocity trends cannot be used as evidence for changes in grain size or mud content.

Figure 3.13. Root-mean-square velocity ($V_{RMS}$) generated via velocity analysis of the seismic data [Section 2.4.10].
Chapter 4. Discussion

4.1. Mid-Channel Bar Model Justification

I have interpreted a feature in the stacked seismic section as a mid-channel bar based on its internal stratification and semi-symmetric form defined in part by reflectors dipping towards the northeast, opposite of the paleochannel direction [Section 3.2]. I have interpreted that the deposition of this mid-channel bar resulted in the formation of a secondary channel between the mid-channel bar and the inner bank of the meander [Section 3.3]. This secondary channel has been termed the ‘bar-bank gap’ [Figure 4.1]. The interpretation that this secondary channel formed as the result of the deposition of a mid-channel bar is supported by the its depth and the characteristics of the seismic reflections produced by the sediments which have filled it. An alternative but unlikely explanation for the formation of the bar-bank gap is as a chute formed by erosion of the existing point bar, which would challenge the validity of mid-channel bar interpretation.

![Figure 4.1. Interpretation of the seismic reflectors. The location bar-bank gap is indicated along with the average depth to the reflector defining its base. Internal stratification of the interpreted mid-channel bar is identified as well.](image)

The depth of the bar-bank gap supports the mid-channel bar model. The seismic reflector interpreted to represent the base of the bar-bank gap corresponds to depths of up to 35 m [Figure 4.1], a value which represents a maximum depth within the usual range for the modern Mississippi River channel in the region (US Army Corps of Engineers, 2013). This suggests that the mid-channel bar was deposited in deeper waters away from the inner bank, forming a secondary channel (the bar-bank gap) between it and the inner bank with a depth similar to that of the main channel. The depth of the base of the bar-bank gap provides evidence it was not formed by erosion of the existing point bar because chutes are not typically observed to carve point bars to depths on par with
maximum channel depth except for cases in which chutes cut across the neck of the bar, initiate meander cutoff, and develop into the main channel (Edwards et al., 1983; McGowen and Garner, 1970). The continued lateral migration of the point bar over and past the bar-bank gap is evidence that cut off did not occur at the time this gap was formed.

Additionally, the bar-bank gap is characterized by reflectors which indicate the presence of inclined, laterally accreting point bar deposits [Figure 4.1], not chute fill sediments. The reflectors dip in the direction of the paleochannel and are characterized by relatively high SH-wave velocities. This suggests that the bar-bank gap was indeed a secondary channel, as it filled with sediments with similar seismic characteristics to the inclined deposits seen to the southwest of the mid-channel bar, a region interpreted to represent the main Mississippi River channel after the mid-channel bar had formed. Point bar chute fill facies are similar to cut-off channel fill, characterized by an absence of accretionary bank facies and abrupt fining to clay-rich sediment (Nijman and Puigdefabregas, 1977). If the bar-bank gap were a chute, the sediment filling it would be expected to be characterized by low SH-wave velocities typical of clay-rich sediment.

4.2. Problems with Cohesion as a Link between Grain Size and Dip

Disagreement between the strengths of the fining and dip trends in the vertical and lateral directions casts doubt on the cohesive effect of decreasing grain size or increasing clay mineral content as the primary mechanism responsible for this relationship. With cohesion as the primary mechanism, dip would be dependent on grain size and thus increase in response to fining. The data do not suggest this is the case. The trend of upwards increasing reflector dips is ubiquitous and strongly pronounced with typical value for the upwards rate of dip increase of ~0.25°/m, but the data fail to support upwards fining. In contrast, while the well log data and velocity model do support lateral fining and reflector dips do trend towards an increase in the fining direction, the lateral trend in reflector dip angle is inconsistent at times and only weakly pronounced compared to the vertical dip trend. Rates of dip increase in the lateral fining direction reach a maximum of only ~0.10°/m from 360-390 m along the seismic transect, with typical rates of lateral dip even lower. Mechanisms for the relationship between grain size and reflector dip for which changes in one attribute do not directly affect changes in the other are preferred due to the disagreement in the directions that the trends are most strongly expressed in late-stage deposits of the
False River point bar. A prime example of such a mechanism for the relationship between grain size and dip in the lateral direction is meander radius of curvature, which tends to decrease as meanders develop over time and produce both fining and dip increases in the direction of the paleochannel independently of one another [Section 1.6]. Additionally, in the late-stage setting of the point bar deposits surveyed in this study, waning flow velocity associated with gradual meander abandonment may be a contributing factor to tendency for the dip angles of reflectors interpreted as lateral accretion deposits to increase towards the paleochannel, where the well log data indicate fining [Section 1.6].

The inconsistency of the lateral dip trends may be explained by the large swale centered at ~200 m from the start of the seismic transect. This swale appears to have formed in response to the presence of the mid-channel bar and is interpreted to have filled with a thick accumulation of mud-rich sediment [Figure 3.6]. One factor contributing to the weakness of the lateral dip trend is a sharp lateral decrease in dip moving towards the southwest, 240 m from the start of the seismic transect. This decrease in dip represents a reversal from the expected trend. This position coincides with the edge of this large swale, as well as the low velocity anomaly that characterizes its location along the seismic transect. The low velocity anomaly appears to confirm the interpretation that this swale is characterized by an abundance of fine grained sediment. According to the predicted relationship between sediment fining and reflector dip, we might predict an increase in reflector dip in this domain, but instead a sharp decrease is observed. This discrepancy can be resolved by noting that the relationship is predicted for the point bar’s inclined lateral accretion deposits, which are not interpreted in the shallow subsurface between 160 – 240 m from the start of the seismic transect [Figure 3.1]. The relationship is not predicted to hold for the fine-grained swale fill which characterizes this location. Additionally, many of the calculations that represent an interruption in the trend of increasing dip towards the southwest are unreliable as they original from a domain in the data characterized mainly by reflectors dipping towards the northeast. Dip values should not be able to be calculated via the analysis of dip-affected reflectors for reflectors dipping towards the northeast given the geometry of the experiment’s survey.

Although the limited depth of the well log data relative to the interpreted thickness of the point bar channel deposits prevents a confirmation of vertical fining trends in the study area, it is still possible that an
upwards fining trend is expressed over the point bar’s full vertical section. Cohesion between sediments need not be invoked to explain an upwards increase in dip for point bars that do exhibit upwards fining. Vertical fining is in part the result of decreasing water depth and flow velocity from the channel thalweg towards the inner bank, up the transverse slope of the point bar surface [Section 1.4]. Upslope fining along a transverse slope with a concave-upward geometry often observed in point bars (Durkin et al., 2015; Hickin, 1974; Labrecque et al., 2011a; Leopold and Wolman, 1960; Nanson, 1980; Puigdefabregas, 1973; Thomas et al., 1987; Visser, 1986) produces a direct correlation between transverse bed slope and mud content.
Chapter 5. Conclusions & Recommendations

5.1. Conclusions

A 480 m seismic line images late-stage deposits of the False River point bar in Pointe Coupee Parish, Louisiana. The seismic imaging confirms inclined stratigraphy dipping channelwards, representing laterally accreting point bar sediment packages. In addition, a subsurface feature characterized by seismic reflectors dipping towards the point bar interior is imaged and interpreted as a mid-channel bar that has been buried by the point bar complex. These features are rarely included in models of point bar architecture or stratigraphy, but their common occurrence in active meandering channels suggests they should be included as expected features.

Vertical and lateral changes in seismic reflector dip can be visualized through the analysis of dip-affected reflectors in common-shot gathers. The analysis of reflector dip trends in the seismic data and fining trends suggested by the seismic velocity model and by well logs from previous studies challenges suggestions that cohesion between sediment particles is the sole mechanism for a relationship between dip angle and mud content in inclined point bar deposits. Whereas reflector dips trend toward an increase in the fining directions predicted by typical models of point bar architecture, the increasing trend is most strongly expressed in the vertical direction. In contrast, the data suggest the predicted fining trends are most strongly expressed in the lateral direction. The disagreement between the directions in which reflector dip and mud content exhibit the greatest change suggests sediment cohesion is an incomplete explanation for the relationship between these attributes. Changes to meander radius of curvature in combination with a waning of flow velocity related to meander abandonment are suggested as additional or alternative mechanisms for the relationship between mud content and dip angle in inclined point bar strata.

5.2. Recommendations

1. Extend the Bueche seismic line approximately 600 m further towards the northeast in order to image the entire width of the interpreted bar-bank gap that has been filled with inclined sediment packages as well as the inclined sediment packages which should comprise the body of the point bar on the accretionary
bank to the northeast of the interpreted bar-bank gap. Doing so will allow for a confirmation of the interpreted point bar and mid-channel bar architecture in the study area.

2. Drill and log additional wells along the Bueche seismic transect at closer spatial intervals in order to increase the resolution of attempts to further validate the existence of the expected and observed lateral fining trends.

3. Log Bueche wells to depths of at least 60 m in order to confirm the interpreted location of the contact between the modern alluvium and the Pleistocene substratum. Doing so would also enhance the ability to determine if the expected fining upwards trends can be observed over the entire vertical thickness of the False River point bar in the study area.

4. Repeat the experiment using a split-spread survey design in order to allow for the analysis of dip-affected reflectors resulting from subsurface horizons inclined towards the paleochannel to the southwest.

5. Repeat the experiment in locations representing deposition over similar time periods but further upstream or downstream in order to analyze the presence downstream fining and its effect on reflector dip.

6. Analyze LIDAR data in order to interpret how the meander shape and radius of curvature has changed over time to further evaluate its validity as the primary link between mud content and dip angle in inclined point bar strata.
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Appendix A. Data and Programs

A.1. Directory Structure

Seismic data is stored and processed on a server named Zamin [Figure A.1]. File transfer between Zamin and any local system is accomplished with the FileZilla® software.

![Diagram](image.png)

Figure A.1. Directory structure for the Bueche seismic data and processing scripts on zamin.lsu.edu. Seismic data in .su format is stored within the ‘data’ directory. The ‘pl’ directory contacts perl programs. The ‘sh’ directory contains Bash scripts.
A.2. Seismic Data Upload

Seismic data must be uploaded from the Geometrics StrataView R-24 to removable media before it can be uploaded to the Zamin server. A standardized workflow was developed for the transfer of the seismic data to a flash drive via an intermediate transfer to a floppy disc.

Table A.1. Workflow for the upload of seismic data from the Geometrics StrataView R-24 to a flash drive in preparation for upload to zamin.lsu.edu. The steps must be performed in the order listed, and command line entries (steps beginning with “Type:”) must be input precisely as listed. A username and password is required to progress past step 9 for the system used in this study. Replace the string “[directoryname]” with the directory name of the directory on the Geometrics R-24 to which the seismic data was saved during acquisition.

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Connect “SCSI ONLY” zip disk drive into Geometrics and to power</td>
</tr>
<tr>
<td>2</td>
<td>Turn on Geometrics StrataView R-24</td>
</tr>
<tr>
<td>3</td>
<td>Insert floppy disk into ‘SCSI ONLY’ zip drive</td>
</tr>
<tr>
<td>4</td>
<td>Exit to DOS on Geometrics StrataView R-24</td>
</tr>
<tr>
<td>5</td>
<td>Type: “xcopy D:[directoryname] E:[directoryname] /S”</td>
</tr>
<tr>
<td>6</td>
<td>Connect power cord to both laptop and ‘parallel port’ zip disk drive</td>
</tr>
<tr>
<td>7</td>
<td>Connect ‘parallel port’ zip disk drive to computer</td>
</tr>
<tr>
<td>8</td>
<td>Insert floppy disk in ‘parallel port’ zip disk drive</td>
</tr>
<tr>
<td>9</td>
<td>Turn on laptop</td>
</tr>
<tr>
<td>10</td>
<td>Type: “/sbin/modprobe ppa”</td>
</tr>
<tr>
<td>11</td>
<td>Type: “cd /mnt/zip”</td>
</tr>
<tr>
<td>12</td>
<td>Connect flash drive into laptop usb port</td>
</tr>
<tr>
<td>13</td>
<td>Type: “mount –t vfat /dev/sda4 /mnt/zip”</td>
</tr>
<tr>
<td>14</td>
<td>Type: “mount –t vfat /dev/sdb /mnt/flash”</td>
</tr>
<tr>
<td>15</td>
<td>Type: “cd /mnt/flash”</td>
</tr>
<tr>
<td>16</td>
<td>Type: “cp –r /mnt/zip/[directoryname] ./”</td>
</tr>
<tr>
<td>17</td>
<td>Remove flash drive from laptop usb port</td>
</tr>
<tr>
<td>18</td>
<td>Type: “/sbin/shutdown now –h”</td>
</tr>
</tbody>
</table>

A.3. Main Processing Flow Programs

The main seismic processing flow contains Perl and Bash programs which execute transforms on the seismic data or their header files via Seismic Unix modules in order to facilitate interpretation by increasing the signal-to-noise ratio and arranging the data in a geologically meaningful manner [Section 2.4]. These programs were written by either the author or by Dr. Juan Lorenzo of Louisiana State University’s Department of Geology and Geophysics. Programs written by Dr. Juan Lorenzo have been adapted for this study.
# A.3.1. Sseg2su

```perl
#!/usr/bin/perl -w
```

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: Sseg2su
AUTHOR: Juan Lorenzo

=head2 CHANGES and their DATES

DATE: Aug 9, 2011
Version 1.1 July 29 2016
   Introduced pure textual configuration files

=head2 DESCRIPTION

File format conversion
Data format change from Seg2 ("DAT")
or geometrics format to su

=head2 REQUIRES

siosseis
local configuration file called Sseg2su_config

=head2 Examples

For example, total number of files =74 first file is "1000.su"

=head2 STEPS

1. use the local library of the user
   1.1 bring is user variables from a local file
2. create instances of the needed subroutines

=head2 NOTES

We are using Moose.
Moose already declares that you need debuggers turned on
so you don't need a line like the following:
use warnings;

USES the following classes:
ireadfiles
   and packages of subroutines
System_Variables
SeismicUnix

# 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.'/lsu/libAll';
}

use lib $library_location;

=cut

use Moose;
use System_Variables;
use readfiles;

my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();
my ($DATA_SEISMIC_SEG2) = System_Variables::DATA_SEISMIC_SEG2();

=head2 Instantiate classes:

Create a new version of the package
with a unique name

=cut

my $read = new readfiles();

my ($err,$CFG) = $read->cfg('/usr/local/pl/Sseg2su_config.pl');

my $number_of_files = $CFG->{seg2su}{1}{number_of_files};
my $first_file_number = $CFG->{seg2su}{1}{first_file_number};

print("values are $number_of_files,$first_file_number\n\n");

=head2 Check configuration file for errors

=cut

if ( $err) {
    print(STDERR $err, "\n");
    exit(1);
}

=head2 Declare variables

in local memory space

=cut
my ($i,$j,$j_char);
my (@file_name,@cp_dat2DAT,@segyclean);
my (@sioseis,@flow);

for ($i=1,$j=$first_file_number; $i <=$number_of_files; $i += 1,$j +=1){
    $j_char                 = sprintf("%u",$j));
    $file_name[$i]          = $j_char;
}

#START FOR LOOP
#
for ($i=1; $i<=$number_of_files; $i++) {

    =pod
Convert *dat file names to DAT file names for conversion by sioseis

=cut

    $cp_dat2DAT[$i] = (" cp $DATA_SEISMIC_SEG2/$file_name[$i].dat \ $DATA_SEISMIC_SEG2/$file_name[$i].DAT\ 
                  ");

    =pod INPUT FILE NAMES
convert seg2 files to su files

=cut

    $sioseis[$i] = ("      \cd $DATA_SEISMIC_SEG2;      \echo 'pwd';      \sioseis << eof
      procs seg2in diskoa end
      seg2in      ffilen $file_name[$i]  lfilen $file_name[$i]  end
    end
    diskoa      opath $DATA_SEISMIC_SU/$file_name[$i].su      ofmt 1      format su end
    end
    eof      
    ");

    =pod Clean

    su output
for ($i= 1 ; $i <= $number_of_files; $i += 1) {

=pod
DEFINE FLOW(S)

=cut

    $flow[1][$i] =        $cp_dat2DAT[$i];
    $flow[2][$i] =        $sioseis[$i];
    $flow[3][$i] =        $segyclean[$i];

=pod

RUN FLOW(S)

=cut

    system $flow[1][$i];
    system 'echo', $flow[1][$i];

    system $flow[2][$i];
    system 'echo', $flow[2][$i];

    system $flow[3][$i];
    system 'echo', $flow[3][$i];

}

A.3.2. Reverse_polarity.pl

#!/usr/bin/perl
#
use Moose;

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: Reverse_polarity
=head3 Steps are as follows:

=cut
=pod

1. Use packages:

   (for subroutines)
   manage_files_by
   System_Variables (for subroutines)

   (for variable definitions)
   SeismicUnix (Seismic Unix modules)

   Use classes:
   flow
   message
   suximage

=cut
=pod

LOAD GENERAL PERL LIBRARIES

=cut

use SU;

=pod

import system variables

=cut

my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();
use SeismicUnix qw ($on $off $to $in $go $out);

=pod

2. Instantiate classes
   and declare variables
my $cat = new cat();
my $suxwigb = new suxwigb();
my $sugain = new sugain();
my $sufilter = new sufilter();
my $suop = new suop();
my $suwind = new suwind();
my $log = new message();
my $run = new flow();

my (@su_inbound, @su_outbound);
my (@cat);
my (@suop_in, @suop_outbound, @su_outbound);
my (@items, @flow);
my (@ref_to_items);
my (@sugain, @sufilter, @suxwigb);
my (@suop, @suwind, @log, @run);
my ($i);

=head3
Set file names:
  a. reverse file out
  b. raw file names in
  c. make a list of input files
  d. make a list of output files
=cut

my $first_file = 1000;
my $last_file = 1050;
my $num_shots = 51;

for ($i=$first_file; $i<=$last_file; $i++) {
  $su_inbound[$i] = $DATA_SEISMIC_SU.'/'.$i.'_clean'.'.su';
  $su_outbound[$i] = $DATA_SEISMIC_SU.'/'.$i'_clean'_rev'.'.su';
}

for ($i=$first_file; $i<=$last_file; $i++) {
  $suwind_pos_outbound[$i] = $DATA_SEISMIC_SU.'/.temp_positive_'.$i.' ';
  $suwind_neg_outbound[$i] = $DATA_SEISMIC_SU.'/.temp_negative_'.$i.' ';
}

=head3
make the patterns for selecting traces
for the positive traces
traces 1 to 12 and 25 to 35 etc

for the negative traces
for traces 13 to 24 and 36 to 48 etc.

=cut

$sugain  -> clear();
$sugain  -> agc($on);
$sugain  -> wagc(0.1);
$sugain[1]  = $sugain->Step();

$sufilter  -> clear();
$sufilter  -> freq('3,6,100,160');
$sufilter[1]  = $sufilter->Step();

$suxwigb  -> clear();
$suxwigb  -> absclip(1);
$suxwigb  -> windowtitle('uncorrected');
$suxwigb[1]  = $suxwigb->Step();

$suxwigb  -> clear();
$suxwigb  -> absclip(1);
$suxwigb  -> windowtitle('corrected');
$suxwigb[2]  = $suxwigb->Step();

$suwind  -> clear();
$suwind  -> setheaderword('tracr');
$suwind  -> min(1);
$suwind  -> max(12);
$suwind[1]  = $uwind->Step();

$suwind  -> clear();
$suwind  -> setheaderword('tracr');
$suwind  -> min(13);
$suwind  -> max(24);
$suwind[2]  = $uwind->Step();

$suop  -> clear();
$suop  -> neg();
$suop[1]  = $suop->Step();

$cat  ->clear();
$cat[1]  = $cat->Step();

#print("cat is $cat[1] \n\n");
=pod

=head4 Assemble the flows
from the individual modules

how to dereference a complicated array reference
print("items are @{$ref_to_items[$i]}\n\n");
1. extract positive traces (unchanged)
2. extract and make negative traces
3. concatenate the extracted positive (1) and negative (2) traces
4. view uncorrected data
5. view the results

=cut

for ($i=$first_file; $i <= $last_file; $i++) {
    $ref_to_items[$i] = [$suwind[1],$in,$su_inbound[$i],
    $out,$suwind_pos_outbound[$i] ];
    $flow[$i][1] = $run ->modules($ref_to_items[$i]);

    $ref_to_items[$i] = [$suwind[2],$in,$su_inbound[$i],
    $to,$suop[1],$out,$suwind_neg_outbound[$i] ];
    $flow[$i][2] = $run ->modules($ref_to_items[$i]);

    $ref_to_items[$i] = [$cat[1],$suwin_pos_outbound[$i],
    $suwind_neg_outbound[$i],$out,$su_outbound[$i] ];
    $flow[$i][3] = $run ->modules($ref_to_items[$i]);

    $ref_to_items[$i] = [$sugain[1],$in,$su_inbound[$i],
    $to,$sufilter[1],$to,$suxwigb[1],$go ];
    $flow[$i][4] = $run ->modules($ref_to_items[$i]);

    $ref_to_items[$i] = [$sugain[1],$in,$su_outbound[$i],
    $to,$sufilter[1],$to,$suxwigb[2],$go ];
    $flow[$i][5] = $run ->modules($ref_to_items[$i]);
}

=cut

=head4 RUN FLOW(S)

=cut

for ($i=$first_file; $i <= $last_file; $i++) {
    $run->flow($flow[$i][1]);
    $run->flow($flow[$i][2]);
    $run->flow($flow[$i][3]);
    $run->flow($flow[$i][4]);
    $run->flow($flow[$i][5]);
}

=head4 LOG FLOW(S)TO SCREEN AND FILE

=cut
for ($i=$first_file; $i <= $last_file; $i++) {

    print $flow[$i][1]."\n\n";
    #$log->file($flow[$i][1]);

    print $flow[$i][2]."\n\n";
    #$log->file($flow[$i][2]);

    print $flow[$i][3]."\n\n";
    #$log->file($flow[$i][3]);

    print $flow[$i][4]."\n\n";
    #$log->file($flow[$i][4]);

    print $flow[$i][5]."\n\n";
    #$log->file($flow[$i][5]);
}

A.3.3. Sucat2

#!/usr/local/bin/perl -w

our $VERSION = '2.10';

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: Sucat2
Purpose: Concatenate a series files
AUTHOR: Juan M. Lorenzo DEPENDS: cat from bash
DATE: May 25 1

Includes access to a simple configuration file
Simple file is called Sucat.config
Access to simple file is via Sucat2_config.pl
Sucat2_config.pl uses Config::Simple (jdhedden)
as well as SeismicUnix and SystemVariables
packages

DESCRIPTION:

=head2 USAGE

Sucat2

=head2 NEEDS

~libAll/Sucat.config
/usr/local/pl/Sucat2_config.pl
/usr/local/pl/libAll/read.pm
EXAMPLES

Sucat_config.pl
Builds a hash of the configuration parameters

NOTES

We are using Moose.
Moose already declares that you need debuggers turned on
so you don’t need a line like the following:
use warnings;

USES the following classes:
floow
message
sucat
and packages of subroutines
#System_Variables

=cut

use Moose;
use readfiles;
use flow;
use message;
use sucat;
use manage_files_by;
use SeismicUnix qw ($in $out $on $go $to $suffix_ascii $off $suffix_su);

=cut

my (@file_out,@flow, @items, @cat,@sufile_out,@outbound);

=cut

my $log = new message();
my $run = new flow();
my $cat = new sucat();
my $read = new readfiles();

Get configuration information

=cut
my ($err,$CFG) = $read->cfg("/usr/local/pl/Sucat_config.pl");

my $first_file_number = $CFG->{sucat}{1}{first_file_number};
my $last_file_number = $CFG->{sucat}{1}{last_file_number};
my $number_of_files = $CFG->{sucat}{1}{number_of_files};
my $inbound_directory = $CFG->{sucat}{1}{inbound_directory};
my $list = $CFG->{sucat}{1}{list};
my $list_directory = $CFG->{sucat}{1}{list_directory};
my $output_file_name = $CFG->{sucat}{1}{output_file_name};
my $input_suffix = $CFG->{sucat}{1}{input_suffix};

# print("$inbound_directory\n\n");
# print("$first_file_number\n\n");

=head2 Check configuration file for errors
=cut

if ( $err) {
    print(STDERR $err, "\n");
    exit(1);
}

=head2 3. Declare file names

In this version inbound and outbound directories are identical.
If a list exists then read it

=cut

$file_out[1] = $output_file_name;
$sufile_out[1] = $file_out[1].$suffix_su;
$outbound[1] = $inbound_directory.'/'.$sufile_out[1];

my @ref_array;
my $ref_array;
my $num_rows;

if($list) {
    ($ref_array,$num_rows) = $read->cols_1($list);
    print("ref_array is @$ref_array num_rows is $num_rows\n\n");
}

=head2 4. create script to concatenate files

files can be sequential and have numeric names or they can be in a list;
either way supply a directory

=cut
$cat -> clear();

if ($list) {
    $cat -> list_array($ref_array);
    $cat -> list_directory($list_directory);
} else {
    $cat -> first_file_number($first_file_number);
    $cat -> last_file_number($last_file_number);
    $cat -> number_of_files($number_of_files);
}

$cat -> inbound_directory($inbound_directory);
$cat -> input_suffix($input_suffix);
$cat[1] = $cat->Step();

=head2 A. DEFINE FLOW(S)

=cut

@items = ($cat[1], $out, $outbound[1], $go);
$flow[1] = $run->modules(@items);

=head2 B. RUN FLOW(S)

=cut

$run->flow($flow[1]);

=head2 C. LOG FLOW(S) TO SCREEN AND FILE

=cut

print "$flow[1]\n";
#log->file($flow[1]);

A.3.4. Suclean_geom.pl

#!/usr/bin/perl
use Moose;

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: Suclean_geom.pl
AUTHOR: Juan Lorenzo
DESCRIPTION: script to clean and add geometry to headers
DATE Version 1 June 3, 2012
DATE Dec 31 2014 converting to Moose
perl classes container and system variables

=cut

use SU;
my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();
my ($DATA_SEISMIC_SEGY) = System_Variables::DATA_SEISMIC_SEGY();
use SeismicUnix qw ($suffix_segy $suffix_su $suffix_ascii $suffix_bin $suffix_geom $suffix_hyphen $suffix_lsu $go $in $to $out);

=head2 Instantiate classes

message,flow,suchw,sushw

=cut

my $log = new message();
my $run = new flow();
my $suchw = new suchw();
my $sushw = new sushw();

=head2 Declare variables

Make them local

=cut

my ($endian,$num_files,$i);
my (@segyfile,@segyfile_in,@segyfile_out);
my (@segyread,@segyread_inbound,@segyread_outbound);
my (@file,@sufile);
my (@sufile_inbound,@sufile_outbound);
my (@file_in,@file_out);
my (@flow,@suchw,@sushw);
my (@sushw_outbound,@sushw_headers_to_wipe,@sushw_replace_w_);
my (@sushw_inbound);
my (@items);

=head2 Establish

file names and directories
inbound and outbound refer to complete paths

=cut

$file[1] = 'All_seisgun_clean_rev';
#$file[1] = 'All_Ibeam_clean_rev';
$sufile_in[1] = $file[1].$suffix_su;
$sufile_inbound[1] = $DATA_SEISMIC_SU.'/'. $sufile_in[1];
$sufile_outbound[1] = $DATA_SEISMIC_SU.'/$file[1].$suffix_geom.$suffix_su;

=head2 sushw information

clean the unused header values
but keep field traces fldr

cut

$sushw_inbound[1] = $sufile_inbound[1];
$sushw_outbound[1] = $sufile_outbound[1];

$sushw_headers_to_wipe[1] = 'trac, trac, tracf, cdp, cdp, trid, nvs, nhx, duse, swdep, scalel, scalco, counit, sx, sy, ep, fldr, year, day, minute, hour, sec';
$sushw_replace_w_[1] = '0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0';

=head2 Information about data files

1049.su was a bad file so 1048_clean_rev.su -1 was included instead

maximum of traces = 17 sp x 2 hammer-blow-l-beam shotgathers x 24 traces = 816
maximum of traces = 17 sp x 2 seisgun shotgathers x 24 traces = 816

sushw makes trace counters all equal
traces go from 1-816

sushw add shotpoints (ep)
sp 1, 2, 3, 4, 5, 6, ..... 8 incrementing by 1 every 48 traces

sp #99 (first of day) lies at x=98 m
SP# 99 (seisgun) sx = 98 for 2 sp gathers (48 traces)
use shotshell blast
increment sx=1 meters between new SP locations
SP# 100 (l-beam) sx = 99 for 2 more sp gathers (48 traces) uses l-beam
SP# 101 (seisgun) sx = 100 for 2 more sp gathers (48 traces) uses seisgun

suchw add spacing
total traces = 816
geophone spacing is 1 m
sp spacing is 1 m
The smallest SP-geophone offset is 1 m

G 1 is to S and G 24 lies to N

For SP# 99: (sx=98)
   rotalong=1
G 1 is given a gx value = 99 m
G 2 is given a gx value = 100 m
G 3 is given value = 101 m
G 4 is given value = 102 m
G .....
G 21 is given a gx value = 119 m
G 22 is given a gx value = 120 m
G 23 is given a gx value = 121 m
G 24 is given a gx value = 122 m

For SP# 100: (sx=99)
all geopones advance 1 m northward
rotalong=2
G 1 is given a gx value = 100
G 2 is given a gx value = 101 m
G 3 is given a gx value = 102 m
G ....
G 23 is given a gx value = 122 m
G 24 is given a gx value = 123 m

ep is the shot point number, which increments by 2
for every increase in sp location-- because we
have both a shot to east or hit from E (ep = a)followed by
a shot to west or hit from W (ep = a+1)

Mark Products SH 28 Hz geophones have orange plastic to the E
we use an small l-beam and sledge hammer (3 stacked blows per side)
or the seisgun (one shotshell per side)

sushw for seisgun

$sushw->clear();
$sushw->key('trac1,tracf,tracr');
$sushw->first_val('1,1,1');
$sushw->intra_gather_inc('1,1,1');
$sushw->inter_gather_inc('0,0,0');
$sushw->gather_size('528,24,48');
$sushw[2] = $sushw->Step();

$sushw->clear();
$sushw->key('sx');
$sushw->first_val('237');
$sushw->intra_gather_inc(0);
$sushw->inter_gather_inc('2');
$sushw->gather_size('48');
$sushw[4] = $sushw->Step();

$sushw->clear();
$sushw->key('gx');
$sushw->first_val('238');
$sushw->intra_gather_inc(1);
$sushw->inter_gather_inc('2');
$sushw->gather_size('48');
$sushw[5] = $sushw->Step();

$sushw->clear();
sushw for l-beam

$sushw->clear();
$sushw->key('tracf,tracf,tracr');
$sushw->first_val('1,1,1');
$sushw->intra_gather_inc('1,1,1');
$sushw->inter_gather_inc('0,0,0');
$sushw->gather_size('480,24,48'); # number of field traces = 816
$sushw[2] = $sushw->Step();

$sushw->clear();
$sushw->key('sx');
$sushw->first_val('238');
$sushw->intra_gather_inc(0);
$sushw->inter_gather_inc('2');
$sushw->gather_size('48');
$sushw[4] = $sushw->Step();

$sushw->clear();
$sushw->key('gx');
$sushw->first_val('239');
$sushw->intra_gather_inc(1);
$sushw->inter_gather_inc('2');
$sushw->gather_size('48');
$sushw[5] = $sushw->Step();

$sushw->clear();
$sushw->key('ep');
$sushw->first_val('1');
$sushw->intra_gather_inc(0);
$sushw->inter_gather_inc('1');
$sushw->gather_size('24');
$sushw[3] = $sushw->Step();

= cut

$sushw->clear();
$sushw->key($sushw_headers_to_wipe[1]);
$sushw->first_val($sushw_replace_w_[1]);
$sushw[1] = $sushw->Step();

$sushw->clear();

= cut
$sushw\rightarrow\text{key('tracl, tracf, tracr')};$
$sushw\rightarrow\text{first_val('1,1,1')};$
$sushw\rightarrow\text{intra\_gather\_inc('1,1,1')};$
$sushw\rightarrow\text{inter\_gather\_inc('0,0,0')};$
$sushw\rightarrow\text{gather\_size('624,24,48')};$
$sushw[2] = \text{Step}();$
$sushw\rightarrow\text{clear}();$
$sushw\rightarrow\text{key('sx')};$
$sushw\rightarrow\text{first_val('373')};$
$sushw\rightarrow\text{intra\_gather\_inc(0)};$
$sushw\rightarrow\text{inter\_gather\_inc('2')};$
$sushw\rightarrow\text{gather\_size('48')};$
$sushw[4] = \text{Step}();$
$sushw\rightarrow\text{clear}();$
$sushw\rightarrow\text{key('gx')};$
$sushw\rightarrow\text{first_val('374')};$
$sushw\rightarrow\text{intra\_gather\_inc(1)};$
$sushw\rightarrow\text{inter\_gather\_inc('2')};$
$sushw\rightarrow\text{gather\_size('48')};$
$sushw[5] = \text{Step}();$
$sushw\rightarrow\text{clear}();$
$sushw\rightarrow\text{key('ep')};$
$sushw\rightarrow\text{first_val('1')};$
$sushw\rightarrow\text{intra\_gather\_inc(0)};$
$sushw\rightarrow\text{inter\_gather\_inc('1')};$
$sushw\rightarrow\text{gather\_size('24')};$
$sushw[3] = \text{Step}();$

=\text{pod}\n$

\text{DEFINE FLOW(S)}$

=\text{cut}\n$

@items = ($sushw[1], $sin, $sushw\_inbound[1], $to, $sushw[2], $to, $sushw[3], $to, $sushw[4], $to, $sushw[5], $out, $sushw\_outbound[1], $go);$

$flow[1] = \text{run}\rightarrow\text{modules}(@items);$  

# RUN FLOW (s)
$run\rightarrow\text{flow}($flow[1]);$

# LOG FLOW
print $flow[1]."\n\n";
# $log\rightarrow\text{file}($flow[1]);
A.3.5. Sudiff.pl

#!/usr/bin/perl
use Moose;

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: Sudiff.pl
AUTHOR: Juan Lorenzo
DESCRIPTION: script to subtract panels
Used to difference SH panels
DATE Version 1 Feb 19 2015
False River case

=cut

LOAD GENERAL PERL LIBRARIES

=cut

use SU;

=cut

import system variables

=cut

my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();
use SeismicUnix qw ($suffix_segy $suffix_su $suffix_ascii $suffix_bin $suffix_geom $suffix_hyphen $suffix_lsu $go $in $to $out);

=cut

2. Instantiate classes
   and declare variables

=cut

my $log = new message();
my $run = new flow();
my $suwind = new suwind();
my $sudiff = new suop2();

my ($endian,$num_files,$i);
my (@sudiff);
my (@suwind,@suwind_inbound,@suwind_outbound);
my (@toE_ep, @toW_ep);
my (@file, @sufile, @temp_file);
my (@sufile_inbound, @sufile_outbound);
my (@sufile_in, @sufile_out);
my (@sudiff_inbound, @sudiff_outbound);
my (@flow);
my (@items);

# sufile names
$sfile[1] = 'All_Ibeam_clean_rev_geom';
#$file[1] = 'All_seisgun_clean_rev_geom';
$sufile_in[1] = $file[1].$suffix_su;

# outgoing
$file[2] = '30HzHit_fromE';
$file[3] = '30HzHit_fromW';
$file[4] = '30Hz_Ibeam';
#$file[2] = '30HzShoot_toE';
#$file[3] = '30HzShoot_toW';
#$file[4] = '30Hz_seisgun';

# sufile information

# sufile with directory information
$sufile_inbound[1] = $DATA_SEISMIC_SU.'/'.$sufile_in[1];
$sufile_outbound[1] = $DATA_SEISMIC_SU.'/'.$sufile_out[1];
$sufile_outbound[2] = $DATA_SEISMIC_SU.'/'.$sufile_out[2];
$sufile_outbound[3] = $DATA_SEISMIC_SU.'/'.$sufile_out[3];

=head2 Notes on data

for seisgun
maximum of 816 traces = 17 shotpoints x 2 shots per point x 24 traces

@toE_ep = (1,3,5,7,9,11,13,15,17,19,21,23,25,27,29,31,33);
@toW_ep = (2,4,6,8,10,12,14,16,18,20,22,24,26,28,30,32,34);

for l-beam
maximum of traces = 17 sp x 2 hammer-blow-l-beam shotgathers x 24 traces = 816
@toE_ep = (1,3,5,7,9,11,13,15,17,19,21,23,25,27,29,31,33);
@toW_ep = (2,4,6,8,10,12,14,16,18,20,22,24,26,28,30,32,34);

cut

@toE_ep = (1,3,5,7,9,11,13,15,17,19,21,23);
$suwind->clear();
\$suwind->setheaderword('ep');
\$suwind->accept_only_list("@toE_ep");
\$suwind[1] = \$suwind->Step();

\$suwind_inbound[1] = \$sufile_inbound[1];
\$suwind_outbound[1] = \$sufile_outbound[1];

@toW_ep = (2,4,6,8,10,12,14,16,18,20,22,24);
\$suwind->clear();
\$suwind->setheaderword('ep');
\$suwind->accept_only_list("@toW_ep");
\$suwind[2] = \$suwind->Step();

\$suwind_inbound[2] = \$sufile_inbound[1];
\$suwind_outbound[2] = \$sufile_outbound[2];

\$sudiff_inbound[1] = \$sufile_outbound[1];
\$sudiff_inbound[2] = \$sufile_outbound[2];

\$sudiff->clear();
\$sudiff->AminusB();
\$sudiff->fileA("\$sudiff_inbound[1]");
\$sudiff->fileB("\$sudiff_inbound[2]");
\$sudiff[1] = \$sudiff->Step();

\$sudiff_outbound[1] = \$sufile_outbound[3];

=pod

DEFINE FLOW(S)

=cut

@items = (\$suwind[1],\$in,\$suwind_inbound[1],\$out,
         \$suwind_outbound[1],\$go);
\$flow[1] = \$run->modules("@items");

@items = (\$suwind[2],\$in,\$suwind_inbound[2],\$out,
         \$suwind_outbound[2],\$go);
\$flow[2] = \$run->modules("@items");

@items = (\$sudiff[1],\$out,\$sudiff_outbound[1]);
\$flow[3] = \$run->modules("@items");

# RUN FLOW (s)
\$run->flow("\$flow[1]");
\$run->flow("\$flow[2]");
\$run->flow("\$flow[3]");

# LOG FLOW
print $flow[1]."\n\n";
print $flow[2]."\n\n";
print $flow[3]."\n\n";

# $log->file($flow[1]);
# $log->file($flow[2]);
# $log->file($flow[3]);

A.3.6. SuGeom2.pl

#!/usr/bin/perl
use Moose;

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: SuGeom2.pl
AUTHOR: Juan Lorenzo
DESCRIPTION: script add geometry to headers
DATE Version 1 June 1, 2016

=head2 Import

perl classes container and system variables

cut
use SU;
my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();
my ($DATA_SEISMIC_SEGY) = System_Variables::DATA_SEISMIC_SEGY();
use SeismicUnix qw ($suffix_segy $suffix_su $suffix_ascii $suffix_bin $suffix_geom $suffix_hyphen $suffix_lsu $go $in $to $out);

=head2 Instantiate classes

message,flow,suchw,sushw

cut
my $log = new message();
my $run = new flow();
my $suchw = new suchw();
my $sushw = new sushw();

=head2 Declare variables

Make them local

cut
my ($endian,$num_files,$i);
my (@segyfile,@segyfile_in,@segyfile_out);
my (@segyread,@segyread_inbound,@segyread_outbound);
my (@file,@sufile);
my (@sufile_inbound,@sufile_outbound);
my (@sufile_in,@sufile_out);
my (@flow,@suchw,@sushw);
my (@sushw_outbound,@sushw_headers_to_wipe,@sushw_replace_w_);
my (@sushw_inbound);
my (@items);

=head2 Establish file names and directories
inbound and outbound refer to complete paths

cut

$file[1]    = '30Hz_seisgun';
$file[1]    = '30Hz_Ibeam';

$sufile_in[1] = $file[1].$suffix_su;
$sufile_inbound[1] = $DATA_SEISMIC_SU.'/'.sufile_in[1];
$sufile_outbound[1]   = $DATA_SEISMIC_SU.'/'.file[1].$suffix_geom.$suffix_su;

=head2 sushw information

=cut

$sushw_inbound[1] = $sufile_inbound[1];
$sushw_outbound[1] = $sufile_outbound[1];

=head2 Information about data files

files have already been differenced and have only 24 traces for each shotpoint

hammer-blow-I-beam
maximum of traces = 17 sp x 2 hammer-blow-I-beam shotgathers x 24 traces = 816

seisgun (first shotpoint of day)
maximum of traces = 17 sp x 2 hammer-blow-I-beam shotgathers x 24 traces = 81
sushw makes trace counters all equal
traces go from 1-816

sp spacing is 1 m

sp # 99/100 lie at sx=98/99

The smallest SP-geophone offset is 1 m
G 1 is to S and G 24 lies to N

For SP# 99: (sx=98)
rotalong=1
G 1 is given a gx value = 99 m
G 2 is given a gx value = 100 m
G 3 is given value = 101 m
G 4 is given value = 102 m
G ..... G 21 is given a gx value = 119 m
G 22 is given a gx value = 120 m
G 23 is given a gx value = 121 m
G 24 is given a gx value = 122 m

For SP# 100: (sx=99)
all geopones advance 1 m northward
rotalong=2
G 1 is given a gx value = 100
G 2 is given a gx value = 101 m
G 3 is given a gx value = 102 m
G ..... G 23 is given a gx value = 122 m
G 24 is given a gx value = 123 m

Mark Products SH 28 Hz geophones have orange plastic to the E

we use an small I-beam and sledge hammer (3 stacked blows per side)
or the seisgun ( one shotshell per side)

sushw for seisgun

new ep = sp # = 99, 101, 103, etc
sx = 98, 100, 102, etc.
$sushw->clear();
$sushw->key('sx,gx,ep,fldr,tracf');
$sushw->first_val(98,99,99,1,1);

sushw for I-beam with hammer
new ep = sp # = 100, 102, 104, etc.
sx = 99, 101, 103, etc.
$sushw->clear();
$sushw->key('sx,gx,ep,fldr,tracf');
$sushw->first_val(99,100,100,2,2);

For the purpose of surrestat later on
set the fldr to a unique shot number sequence (=ep) and
tracf (=gx) to a unique trace receiver station number
=cut
$sushw->clear();
$sushw->key('sx,gx,ep,fidr,tracf');
$sushw->first_val(374,375,375,2,2);
$sushw->intra_gather_inc(0,1,0,0,1);
$sushw->inter_gather_inc(2,2,2,2);
$sushw->gather_size(24,24,24,24,24);
$sushw[1] = $sushw->Step();

=cut

DEFINE FLOW(S)

=cut

@items = ($sushw[1],$in,$sushw_inbound[1],
$sout,$sushw_outbound[1],$go);

$flow[1] = $run->modules(@items);

# RUN FLOW (s)
$run->flow($flow[1]);

# LOG FLOW
print $flow[1]."\n\n";
# $log->file($flow[1]);

A.3.7. SuWeave.pl

#!/usr/bin/perl
use Moose;

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: SuWeave.pl
AUTHOR: Juan Lorenzo
DESCRIPTION: script to mix seisgun and Ibeam shotgathers together
DATE Version 1 June 1, 2016

=head2 Import

perl classes container and system variables
take variables and packages directly from
the path to the library, so as to minimize memory use

=cut
use SU;

my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();
use SeismicUnix qw ($suffix_geom $suffix_su $go $in $to $out);

=head2 Instantiate classes
message,flow,susort,sucat,readfiles
=cut

my $log    = new message();
my $run    = new flow();
my $sort   = new susort();
my $cat    = new sucat();
my $read   = new readfiles();

=head2 Declare variables
Make them local
=cut

my ($num_rows,$ref_array);
my (@file);
my (@sort_inbound,@cat_outbound,@sort_outbound);
my (@flow,@sort,@cat);
my (@items);

=head2 Establish
file names and directories
inbound and outbound refer to complete paths
=cut

$file[1]   = '30Hz_All';
$cat_outbound[1] = $DATA_SEISMIC_SU.'/'.$file[1].$suffix_geom.'unsorted'.$suffix_su;
$sort_inbound[1] = $DATA_SEISMIC_SU.'/'.$file[1].$suffix_geom.'unsorted'.$suffix_su;
$sort_outbound[1] = $DATA_SEISMIC_SU.'/'.$file[1].$suffix_geom.$suffix_su;

=head2 Information about data files
files have already been differenced and have only 24 traces for each shotpoint

hammer-blow-l-beam
maximum of traces = 13 sp x 24 traces = 312
ep=1,3,5,7,etc
(Reason: will use ep for sorting and interweaving lbeam and seisgun differenced shotgathers)

seisgun
maximum of traces = 12 sp x 24 traces = 288
ep=2,4,6,8,10,etc
(Reason: will use ep for sorting and interweaving Ibeam and seisgun differenced shotgathers
ep starts at one because the first field shotpoint of the day used the seisgun)

sp spacing is 1 m sp#51/75 lies at x=52,76
The smallest SP-geophone offset is 1 m

Sh 28 Hz geophones have orange to the E

we use an small I-beam and sledge hammer (3 stacked blows per side)
or the seisgun ( one shotshell per side)

=cut
=head2 Read files

from a named list
this list contains one Ibeam and one seisgun file

=cut

($ref_array,$num_rows) = $read->cols_1('cat_list');

=head2 Files by using a list array

=cut

$cat->clear();
$cat->list_directory('./');
$cat->inbound_directory($DATA_SEISMIC_SU);
$cat->input_suffix($suffix_su);
$cat->list_array($ref_array);
$cat[1] = $cat->Step();

=head2 Sort files

by ep and by tracf

=cut

$sort->clear();
$sort->headerword('ep');
$sort->headerword('gx');
$sort[1]= $sort->Step();

=head2
DEFINE FLOW(S)

=cut

@items = ($cat[1],$out,$cat_outbound[1]);
$flow[1] = $run->modules(\@items);

@items = ($sort[1],$in,$sort_inbound[1],$out,$sort_outbound[1],$go);
$flow[2] = $run->modules(\@items);

=head2

RUN FLOW(S)

=cut

$run->flow($flow[1]);
$run->flow($flow[2]);

=head2

LOG FLOW(S)

=cut

print $flow[1]."\n\n";
print $flow[2]."\n\n";
# $log->file($flow[1]);
# $log->file($flow[2]);

A.3.8. Make_cmp.pl

#!/usr/bin/perl

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: Make_cmp.pl
AUTHOR: Juan Lorenzo
DATE: Oct. 25 2007 V1.1
DATE: Nov 3 2013
Version 1.2
V 1.3 June 1 2016

=cut

=head2 DESCRIPTION

Purpose: To generate CMP values in the headers, headers must already have the correct geometry
values inserted for
the seismic experiment (See header_geom.pl for this)
We use the basic relation that

\[ CMP = \frac{(sx+gx)}{2} \]

where sx is the shot location, and gx is the receiver location. We use suchw to calculate the CMP using offset and other key words as input.

\[ \text{value(key1)} = \frac{(a + b \times \text{value(key2)} + c \times \text{value(key3)})}{d} \]
can be rewritten as:

If we choose the first CMP to be equal to, say, 101

then 
\[ a = 304 \]
\[ a = \frac{(101 \times \text{(first CMP number)} + 51 \times \text{(absolute value of half the longest offset on the first shot gather)})}{2} \]
You can choose other numbers to be the first CMP.

\[ \text{value(cdp)} = \frac{(304 + 1 \times \text{value(sx)} + 1 \times \text{value(gx})}{2} \]
=cut
=head2 Use the following libraries

Some of these libraries or packages contain groups of subroutines for example: SU

use lib explicitly locates packges
=cut
use Moose;
use SeismicUnix qw ($in $on $go $to $out $suffix_su);
use SU;
=head2 Declare local

arrays
scalars
=cut

my (@file_outbound,@file_inbound);
my (@flow,@items,@makecmp);
my ($log,$messages,$makecmp,$run);

my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();
my ($TEMP_DATA_SEISMIC_SU) = System_Variables::TEMP_DATA_SEISMIC_SU();

=head2 Create new instances of classes
message, flow, suchw

=cut

$log = new message();
$run = new flow();
$makecmp = new suchw();

=head2 Declare file names

with their complete paths: inbound and outbound

=cut

$file_inbound[1] = $DATA_SEISMIC_SU.'/'.'30Hz_All_geom'.$suffix_su;
$file_outbound[1] = $DATA_SEISMIC_SU.'/'.'All_cmp_div4'.$suffix_su;

=head2 Example in shell script

suchw <$DATA_IN/1001_head_geom.su \n   key1=cdp \n   key2=sx \n   key3=gx \n   a=0 \n   b=1 \n   c=1 \n   d=2 \n $DATA_OUT/all_geom_CMP.su

=cut

=head2 set up suchw

To calculate cdp number and offset geometry

=cut

$makecmp -> clear();
$makecmp -> result_header('cdp,offset');
$makecmp -> first_header('sx,gx');
$makecmp -> second_header('gx,sx');
$makecmp -> multiply_hdr1_by('1,1');
$makecmp -> multiply_hdr2_by('1,-1');
$makecmp -> divide_all_by('4,1');
$makecmp[1] = $makecmp->Step();

=head2 DEFINE FLOW(S)

=cut

@items = ($makecmp[1],$in,$file_inbound[1],$out,$file_outbound[1],$go);
$flow[1] = $run->modules(@items);

=head2 RUN FLOW(S)

cut

$run->flow($flow[1]);

=head2 LOG FLOW(S) TO SCREEN AND FILE

cut

print "$flow[1]\n";
#$log->file($flow[1]);

A.3.9. SuLoadHeaders.pl

#!/usr/local/bin/perl

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: SuLoadHeaders.pl
Purpose: add traces
AUTHOR: Juan M. Lorenzo
DEPENDS: Seismic Unix modules from CSM
DATE: V0.1
       Nov. 7 2016
DESCRIPTION:

=head2 USES

=head2 NOTES

=head2 STEPS

cut

=head2 Bring classes into namespace

cut

use SeismicUnix qw ($in $out $on $go $to $suffix_ascii $off $suffix_su $suffix_bin);
use flow;
use message;
use a2b;
use sushw;
use sufilter;
use sugain;
use susort;
use sunmo;
use suwind;
use sustack;
use suxwigb;

=head2 Instantiate classes

Use classes:
  flow
  log
  message
  a2b
  sushw

=cut

my $log = new message();
my $run = new flow();
my $sufilter = new sufilter();
my $sushw = new sushw();
my $sugain = new sugain();
my $susort = new susort();
my $sunmo = new sunmo();
my $suwind = new suwind();
my $sustack = new sustack();
my $suxwigb = new suxwigb();

=head2 Incorporate important

Project work variables

DATA='/home/gom/FalseRiver/seismics/data/Bueche/092416/H/1/su'

=cut

my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();

=head2 Declare

local variable in memory

=cut

my (@flow,@items);
my (@a2b,@a2bNote,$a2bVersion,$floats_per_line,);
my (@inbound_sufile_sushw,@file_in_sushw);
my (@headerfile_in_sushw,@sufile_in_sushw);
my ($sushw_headerword);
my (@ outbound_sushw);
my (@file_in_a2b,@inbound_a2b,@outbound_a2b);
=head2 Declare

file names

cut

$file_in_a2b[1] = 'tstat_list';
$floats_per_line = 1;
$inbound_a2b[1] = $DATA_SEISMIC_SU.'/'.$file_in_a2b[1];
$outbound_a2b[1] = $inbound_a2b[1].$suffix_bin;

$file_in_sushw[1] = 'All_cmp_div4_utm_sz_source_gz';
$sushw_headerword = 'tstat';
$headerfile_in_sushw[1] = $outbound_a2b[1];
$sinbound_sufile_sushw[1] = $DATA_SEISMIC_SU.'/'.$sufile_in_sushw[1];
$soutbound_sushw[1] = $DATA_SEISMIC_SU.'/'.$sufile_in_sushw[1].'_tstat'.$suffix_su;

=head2 Set

a2b
a2b n1=2 outpar=/dev/tty < $header_file > $binary_file

cut

a2b -> clear();
a2b -> floats_per_line($floats_per_line);
a2b -> outpar('/dev/tty');
$a2b[1] = a2b -> Step();

=head2 Set

sushw

sushw < $sufile_in key=cdp infile=$binary_file > $sufile_out

cut

$sushw -> clear();
$sushw -> key($sushw_headerword);
$sushw -> infile("$headerfile_in_sushw[1]);
$sushw[1] = sushw -> Step();

=head2 DEFINE FLOW(S)

cut

@items = ($a2b[1],$in,$inbound_a2b[1],$out,
$outbound_a2b[1]);
$flow[1] = $run->modules(\@items);
@items = ($sushw[1],$in,$inbound_sushw[1],$out,$outbound_sushw[1]);

$flow[2] = $run->modules\(@items\);

=head2 RUN FLOW(S)

=cut

$run->flow\($flow[1]);
$run->flow\($flow[2]);

=head2 LOG FLOW(S)

TO SCREEN AND FILE

=cut

print "$flow[1]\n";
print "$flow[2]\n";
#log->file($flow[1]);
#log->file($flow[2]);

A.3.10. tstat_calc.m

%Title: tstat_calc.m
%Author: Adam Gostic
%Purpose: Calculate seismic two-way time correction (tstat) for topography

elev = load('elev.txt');  %shotpoint-by-shotpoint elevation in cm above sea level
gelev_list = cat(1, gelev_1_34,gelev_51_445,gelev_460_481); %calculates trace-by-trace elevation in cm above sea level

selev = load('selev_list'); %trace by trace source elevation in cm above sea level
gelev = load('gelev_list'); %trace by trace receiver elevation in cm above sea level
delev = repmat(795,10824,1); %sets seismic reference datum to 795 cm above sea level

wvel = 100 %input velocity of weathered (surface) layer in m/s
tstat = (((gelev-delev)+(selev-delev))./wvel).*10 %calculates trace-by-trace two-way time correction

A.3.11. static.sh

#!/bin/bash
#Title: static.sh
#Author: Adam Gostic
#Date: September 12 2017
#Purpose: Apply static corrections for topographic variation to seismic data.

folder='/home/gadam2/FalseRiver/seismics/data/Bueche//All/H/1/su/gadam2/'
file='All_cmp_div4_utm_sz_source_gz_tstat'
suffix='su'
append='_statics'

hdrs=1
sign=1

sustatic < $folder$file$suffix > $file$append$suffix hdrs=$hdrs sign=$sign &

A.3.12. iTop_Mute3

#!/usr/bin/perl -w
=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: iTM (interactive Top Mute)
AUTHOR: Juan Lorenzo

=head2 CHANGES and their DATES

DATE: April 2 2009
Version 2.0
Version: 3.0
    September 2015:
        updated to oop
        introduced Tk widgets
        Made all event-driven
    July 27 2016

NEW: read iTop_Mute3.config text file
OLD: import perl variables from
     *.pm configuration file xi
     within ta local libAll
     subdirectory
     binheader is used for everything serious
     gather is to be used to texting
     correct offset is essential for applying the mute

=head2 DESCRIPTION

Interactively pick muting parameters

=head2 USE

=head2 Examples

=head2 SEISMIC UNIX NOTES

=head2 STEPS

1. use the local library of the user
1.1 bring is user variables from a local file
2. create instances of the needed subroutines

=head2 NOTES

We are using Moose.
Moose already declares that you need debuggers turned on
so you don't need a line like the following:
use warnings;

USES the following classes:
sucat
#$suxwigb-> box_Y0(0);
and packages of subroutines
System_Variables
SeismicUnix

=cut

use Moose;
use LSU_Tk_global_constants;
use readfiles;
use Tk;
use iTop_Mute3;
use SeismicUnix qw ($true $false);
use xk;

my $iTm_Tk = {
    _prompt => ''
};

=head2 Instantiate classes:

Create a new version of the package
with a unique name

=cut

my $iTm = new iTop_Mute3();
my $read = new readfiles();
my $get = new LSU_Tk_global_constants();
my $var = $get->var();

=head2 Get configuration information

=cut

my ($err,$CFG) = $read->cfg("/usr/local/pl/iTop_Mute3_config.pl");

my $binheader_type = $CFG->{sumute}{1}{binheader_type};
my $offset_type = $CFG->{sumute}{1}{offset_type};
my $file_name = $CFG->{file_name};
my $first_gather = $CFG->{sumute}{1}{first_gather};
my $last_gather = $CFG->{sumute}{1}{last_gather};
my $gather_inc = $CFG->{sumute}{1}{gather_inc};
my $freq = $CFG->{sugain}{1}{freq};
my $gather_type = $CFG->{sumute}{1}{gather_type};
my $min_amplitude = $CFG->{sumute}{1}{min_amplitude};
my $max_amplitude = $CFG->{sumute}{1}{max_amplitude};

# print("offset type -1 $offset_type\n\n");
#
=head2 Check configuration file for errors

=cut
if ($err) {
  print(STDERR $err, "\n");
  exit(1);
}

=head2 Declare variables
in local memory space

=cut

my ($calc_rb,$exit_rb,$pick_rb,$next_rb,$saveNcont_rb);
my $rb_value = "red";
my $gather = $first_gather;
my $next_step = 'stop';
my $number_of_tries = 0;
my $there_is_old_data;
our $mw;

$iTM
  ->number_of_tries($number_of_tries);
$iTM
  ->file_in($file_name);
$iTM
  ->gather_type($gather_type);
$iTM
  ->binheader_type($binheader_type);
$iTM
  ->offset_type($offset_type);
$iTM
  ->freq($freq);
$iTM
  ->min_amplitude($min_amplitude);
$iTM
  ->max_amplitude($max_amplitude);
$iTM
  ->gather_num($gather);
$iTM
  ->set_message('iTopMute');

=head2
Check for old data
check to see if prior mute parameter files exist for this project
if (($$old_data[1] eq $true) && $$old_data[2] eq $false) {
  print ("mute picks exist, but ...
  print ("mute parameters should exist but can not be found
  print ("resetting the existence file
  manage_files_by::write_one($check_if_iTopMute_exist);

=cut

$there_is_old_data = $iTM->type('TopMute');

if($there_is_old_data) {
  print("Old picks already exist.\n");
  print("Delete \"rm \"old\"") or Save old picks, and then restart\n";
  exit;
}

=head2 Create Main Window
Start event-driven loop
Interaction with user
initialize values
If picks are new, show
message on how to pick data

=cut

if (!there_is_old_data) {

    print("NEW PICKS\n");    
    $iTM ->message('first_top_mute');  
    $iTM ->number_of_tries($false);    
    $iTM ->gather_num($gather);
=head2 Display
    data first time
=cut

    $iTM ->iSelect_tr_Sumute_top();
=head2 Decide whether to
    PICK or move on to NEXT CDP
    Place window near the upper left corner
    of the screen
    Changing geometry of the toplevel window
    my $h = $mw->screenheight();
    my $w = $mw->screenwidth();
    print("width and height of screen are $w,$h\n\n");  
    print("geometry of screen is $geom\n\n");  
=cut

    $mw = MainWindow -> new;  
    $mw -> geometry("400x50+40+0");
    $mw -> title("Interactive Top Mute");
    $mw -> configure(
        -background => $var->{_my_purple});

$calc_rb = $mw->Radiobutton(  
    -text =>'CALC',
    -background =>$var->{_my_yellow},
    -value =>'calc',
    -variable => \$rb_value,
    -command => [\&set_calc] )->pack(-side => 'left');

$next_rb = $mw->Radiobutton(  
    -text =>'NEXT',
    -background =>$var->{_my_yellow},
-value => 'next',
-variable => \$rb_value,
-command => \&set_next} )->pack(-side => 'left');

$pick_rb = $mw->Radiobutton(
-text => 'PICK',
-background => $var->{_my_yellow},
-value => 'pick',
-variable => \$rb_value,
-command => \&set_pick} )->pack(-side => 'left');

$saveNcont_rb = $mw->Radiobutton(
-text => 'Save and Continue',
-background => $var->{_my_yellow},
-value => 'saveNcont',
-variable => \$rb_value,
-command => \&set_saveNcont} )->pack(-side => 'left');

$exit_rb = $mw->Radiobutton(
-text => 'EXIT',
-background => $var->{_my_yellow},
-value => 'exit',
-variable => \$rb_value,
-command => \&set_exit} )->pack(-side => 'left');

MainLoop; # for Tk widgets
} # for new data

=head2 Set the prompt value according to which button is pressed then exit the MainLoop destroy the main window after the prompt is properly set =cut

=head2 sub set_pick callbacks

send gather number to $iTM delete output of previous semblance plus more callbacks following...
=cut

sub set_pick {
  my $pick = 'pick';
  $pick_rb->configure(-state => 'normal');
  $iTM_Tk->{_prompt} = $pick;
print("Picking...\n");

$ITM ->gather_num($gather);

=head2 Delete output of previous muting

cut

xk::kill_this('suximage');
xk::kill_this('suxwigb');

=head2
-replot 1st data
-PICK X-T pairs
-Increment number of tries to make data display interact with user (number_of_tries = 1)

cut

$ITM ->message('pre_pick_mute');
$number_of_tries++; 
$ITM ->number_of_tries($number_of_tries);
$ITM ->iSelect_tr_Sumute_top();
}

=head2 sub set_calc

-PRESS the CALC button
-Increment number of tries to make display and show old picks (if number_of_tries >1)

cut

sub set_calc {
  my $calc = 'calc';
  $calc_rb->configure(-state => 'normal');
  $ITM_Tk->{_prompt} = $calc;
  print("Calculating...\n");

=cut

xk::kill_this('suximage');
xk::kill_this('suxwigb');
$iTM  > iPicks2par();
$iTM  > iSave_top_mute_picks();
$iTM  > iApply_top_mute();
$number_of_tries++;
$iTM  > number_of_tries($number_of_tries);

=head2 Message

to halts flow
when number_of_tries >0
=cut
  $iTM  > message('post_pick_mute');
}

=head2 sub set_saveNcont

  same as next
=cut

sub set_saveNcont {
  my $saveNcont = 'saveNcont';
  $saveNcont_rb->configure(state => 'normal');
  $iTM_Tk->[_prompt] = $saveNcont;
  print("Saving and Continuing...\n");
  #$iTM->icp_sorted2oldpicks();
  &set_next();
}

=head2 sub set_next

  In this case $self is empty
  1. increment gather
      Exit if beyond last gather
  2. reset prompt
  3. Otherwise display the first semblance
  4 ... see following callbacks
=cut

sub set_next {
  print("Next...\n");
  $next_rb->configure(state => 'normal');
  my $next = "";
  $iTM_Tk->[_prompt] = $next;
  $gather = $gather + $gather_inc;
#print("new gather is $gather \n\n");

=head2 Delete output of previous top mute

=cut

$xk::kill_this('suximage');
$xk::kill_this('suxwigb');
$xk::kill_this('xgraph');

if($gather > $last_gather) {
  set_exit();
}

=head2 Display

  update gather number in memory
  first top mute
  Show user message
  Select the mute values

=cut

$ITM->gather_num($gather);
$ITM->message('first_top_mute');
$ITM->iSelect_tr_Sumute_top();

}

=head2 sub set_exit

  saying goodbye
  clear old images
  kill window
  stop script

=cut

sub set_exit {
  my $exit = 'exit';
  $exit_rb->configure(-state => 'normal');
  $ITM_Tk->{_prompt} = $exit;
  print("Good bye.\n");
  print("Not continuing to next gather\n");
  $xk::kill_this('suximage');
  $xk::kill_this('suxwigb');
  $xk::kill_this('xgraph');
  $mw->destroy() if Tk::Exists($mw);
  exit 1;
}

# print ("Old top mute parameters MAY NOT exist\n\n");
# while ($response eq 'n') {
#     print ("Select new top mute parameters \n\n") ;
#     iTM->iSelect_tr_Sumute_top2()
#     iTM->iTopMutepicks2par2()
#     iTM->itemp_Sumute_top2());
#     print ("4. Are picks OK y/n or q-quit?\n") ;
#     $response = <>;
##     chomp($response);

A.3.13. Sumute.pl

#!/usr/bin/perl

use Moose;

=head2 SYNOPSIS

PROGRAM NAME: Sumute.pl
Purpose: Mute of Data
AUTHOR: Juan M. Lorenzo
DEPENDS: Seismic Unix modules from CSM
DATE: April 2 2009
      Modified to work with erine Isu1 Nov 21, 2009
      July 31 2013 V0.1
      Oct. 31, 2016 V0.2 for nmo
      Nov 3 2016, V0.3 made oops

=head2 USES

=head2 NOTES

=head2 STEPS

=cut

=head2 Import classes

and variables into namespace

=cut

use flow;
use message;
use sucat;
use sufilter;
use sugain;
use sumute;
use suwind;
use suximage;
use suxwigb;
use SeismicUnix qw ($in $itop_mute_par_ $out $on $go $to $suffix_ascii $off $suffix_su);
=head2 Instantiate classes

Use classes:
flow
log
message
sucat
sugain;
sumute;
suwind;
suximage;
suxwigb;

=cut

my $cat = new sucat();
my $log = new message();
my $run = new flow();
my $sufilter = new sufilter();
my $sugain = new sugain();
my $sumute = new sumute();
my $suwind = new suwind();
my $suximage = new suximage();
my $suxwigb = new suxwigb();

my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();

=head2 Declare local variables

=cut

my (@flow,@file_in,@file_out,@sufile_in);
my (@gatherType,@offset_type,@gatherNumber,@gatherNumberRange);
my (@inbound,@outbound_cat);
my (@items,@mute_par_file_in);
my (@sugain,@sugainNote,$sugainVersion);
my (@sumute,@sumuteNote,$sumuteVersion);
my (@sufilter,@sufilterNote,$sufilterVersion);
my (@suximage,@suximageNote,$suximageVersion);
my (@suxwigb,@suxwigbNote,$suxwigbVersion);
my (@suwind,@suwindNote,$suwindVersion);
my ($ref_sumute,$sumute_number_of_par_files,$ref_gather_number,$ref_inbounds,$i);
my ($ref_cat_array,$top_mute_list);
my (@cat,@gather_number);
my (@min_gatherNumber,@max_gatherNumber);

=head2 Default values
$gatherNumber[1] = "";

=head2 Assign specific input and output file names

cut

$file_in[1] = 'All_cmp_div4_utm_sz_source_gz_tstat_statics';
gatherType[1] = 'ep';
$offset_type[1] = 'tracr';

cut

=head2 Use only one of the following sets of values below

The min and max set is used both in a naming convention and for data selection.

if there is more than one gather_number i then there multiple X-T pick files are assumed and the results will be concatenated

top-mute list of parameter files lies in local PL directory

cut

$gatherNumber[1] = 1;
$min_gatherNumber[1] = $gatherNumber[1];
$max_gatherNumber[1] = $gatherNumber[1];

$min_gatherNumber[1] = 1;
$max_gatherNumber[1] = 481;
$top_mute_list = 'top_mute_list';

=head2 Set file names

=cut

$gatherNumberRange[1] = $min_gatherNumber[1].'_'.$max_gatherNumber[1];
$sufi1e_in[1] = $file_in[1].$suffix_su;
$file_out[1] = $file_in[1].'_mute';
$inbound[1] = $DATA_SEISMIC_SU.'/'.$file_in[1].$suffix_su;
$outbound_cat[1] = $DATA_SEISMIC_SU.'/'.$file_out[1].'_'.$gatherType[1].'_'.$gatherNumberRange[1].$suffix_su;
# text_file names
#$mute_xfile_in[1] = 'mute_xfile_picks';
#$mute_tfile_in[1] = 'mute_tfile_picks';
$mute_par_file_in[1] = $itop_mute_par_.$file_in[1].'_'.gatherType[1].gatherNumber[1];
#$mute_x_picks[1] = $DATA_SEISMIC_SU.'/'.$mute_xfile_in[1].'.su';
#$mute_t_picks[1] = $DATA_SEISMIC_SU.'/'.$mute_tfile_in[1].'.su';

=head2 Set

suwind

=cut

$suwindVersion = 1;

$suwind -> clear();
$suwind -> setheaderword($gatherType[1]);
$suwind -> min($min_gatherNumber[1]);
$suwind -> max($max_gatherNumber[1]);
$suwind[$suwindVersion] = $suwind->Step();
$suwindNote[$suwindVersion] = $suwind->note();

$suwindVersion = 2;

$suwind -> clear();
$suwind -> tmin(0);
$suwind -> tmax(2);
$suwind[$suwindVersion] = $suwind->Step();
$suwindNote[$suwindVersion] = $suwind->note();

=head2 Set

sugain

=cut

$sugainVersion = 1;
$sugainVersion = 2;

$sugain -> clear();
$sugain -> agc($on);
$sugain -> width(0.1);
# $sugain -> setdt(1000);
$sugain[1] = $sugain->Step();
$sugainNote[1] = $sugain->note();

$sugain -> clear();
$sugain -> pbal($on);
$sugain[2] = $sugain->Step();
$sugainNote[2] = $sugain->note();
filtering parameters

$sufilter -> clear();
$sufilter -> freq("0,3,200,400");
$sufilter[1] = $sufilter->Step();
$sufilterNote[1] = $sufilter->note();

muting parameters

print("number of par files is $sumute_number_of_par_files\n\n");
for (my $i=1; $i<=$sumute_number_of_par_files; $i++) {
    print(" mute case #$i is @$ref_sumute[$i]\n\n");
    # $mute_above[1] = 0;
    # $kill_velocity[1] = 330;
    # $xfile=$mute_x_picks[1] \n
    # $t0file=$mute_t_picks[1] \n
    # $linvel=$kill_velocity[1] \n
    @sumute contains all the many sumute flows
    for (my $i=1; $i<=$sumute_number_of_par_files; $i++) {
        print ("$sumute[$i]\n\n");
    }
}
if ($min_gatherNumber[1] != $max_gatherNumber[1]) {
    $sumute -> clear();
    $sumute -> headerword('tracr');
    $sumute -> type('top');
    $sumute -> parfile($mute_par_file_in[1]);
    $sumute -> ntaper(50);
    $sumuteNote[1] = $sumute->note();
    $sumute[1] = $sumute->Step();
    ($ref_sumute, $sumute_number_of_par_files, $ref_gather_number, $ref_inbounds) = $sumute->Steps();
    $sumuteNote[1] = $sumute->note();
    @sumute = @$ref_sumute;
    @gather_number = @$ref_gather_number;
}
else {
    $sumute -> clear();
    $sumute -> headerword('tracr');
    $sumute -> parfile($mute_par_file_in[1]);
$sumute -> ntaper(50);
$SumuteNote[1] = $sumute->note();
$Sumute[1] = $sumute->Step();

)

=head2 Set

$sucat
from a list

=cut

if ($sumute_number_of_par_files) {
  $cat -> clear();
  $ref_cat_array = $ref_inbounds;
  $cat -> list_array($ref_cat_array);
  $cat -> list_directory($list_directory);
  # $cat -> inbound_directory($inbound_directory);
  $cat[1] = $cat->Step();
}

=head2 Set

$suximage parameters

=cut

$suximage-> clear();
$suximage-> title(quotemeta($sufilterNote[1].$sugainNote[$sugainVersion].$sumuteNote[1]));
$suximage-> xlabel(quotemeta('No. traces'));
$suximage-> ylabel(quotemeta('TWTT s'));
$suximage-> box_width(800);
$suximage-> box_height(700);
$suximage-> legend($on);
$suximage-> box_X0(825);
$suximage-> box_Y0(0);
# $suximage-> absclip(3);
$suximage-> loclip(-1);
$suximage-> hiclip(1);
$suximage-> windowtitle($sufile_in[1]);
$suximage[1] = $suximage->Step();

=head2 DEFINE FLOW(S)

run all the sumute flows
concatenate the results of all the sumute flows (output)
plot the output
save teh raw output

$sugain[$sugainVersion],$to,
if ($min_gatherNumber[1] != $max_gatherNumber[1]) {
    print("#mute pick files= $sumute_number_of_par_files\n\n");
    for ($i=1; $i <=$sumute_number_of_par_files ; $i++) {
        $flow[$i] = $sumute[$i];
    }
}

@items = ($cat[1],$out,$outbound_cat[1]);
$flow[($i+1)] = $run->modules(@items);

@items = ($suwind[1],$in,$outbound_cat[1],$to,
          $suwind[2],$to,
          $sufilter[1],$to,
          $suximage[1]);
$flow[($i+2)] = $run->modules(@items);

} else {

@items = ($suwind[1],$in,$inbound[1],$to,
          $suwind[2],$to,
          $sumute[1],$to,
          $sufilter[1],$to,
          $suximage[1],$go);
$flow[(1)] = $run->modules(@items);

@items = ($suwind[1],$in,$inbound[1],$to,
          $suwind[2],$to,
          $sumute[1],$out,
          $outbound_cat[1]);
$flow[(2)] = $run->modules(@items);
}

=head2 RUN FLOW(S)

1. for all sumute flows
2. for concatenated flows
3. for images of the concatenated flow
4. for raw output of sumute flow

=cut

if ($min_gatherNumber[1] != $max_gatherNumber[1]) {
    for ($i=1; $i <=$sumute_number_of_par_files ; $i++) {
        $run->flow($flow[$i])
    }
}

$run->flow($flow[($i+1)]);
$run->flow($flow[(1)]);
else {
    $run->flow($flow[1]);
    $run->flow($flow[2]);
}

=head2 LOG FLOW(S)

TO SCREEN AND FILE

=cut

if ($min_gatherNumber[1] != $max_gatherNumber[1]) {
    for ($i=1; $i <=$numute_number_of_par_files; $i++) {
        print "$flow[$i]
";
        $log->file($flow[$i]);
    }

    print "$flow[$i+1]
";
    $log->file($flow[$i+1]);

    print "$flow[$i+2]
";
    $log->file($flow[$i+2]);
} else {

    print "$flow[1]
";
    $log->file($flow[1]);

    print "$flow[2]
";
    $log->file($flow[2]);

}

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: IVA2
AUTHOR: Juan Lorenzo
DATE:  April 2 2009
October 2014
July 2015 updated to oop
August 2015 introduced Tk widgets
August 16 made all event-driven
Aug 18 2016 made configuration files simple

DESCRIPTION: Interactively test NMO in data
Version 2.0 MainWIndow in subroutine
leads to multiple segmentation faults
when MainWindow is destroyed > 1
Version: 2.1 is fully event driven

=head2 USE

=head3 NOTES

=head4 Examples

=head3 SEISMIC UNIX NOTES
=head4 CHANGES and their DATES

=cut

=head2 STEPS

1. use the local library of the user
1.1 bring is user variables from a local file
2. create instances of the needed subroutines

=cut

=head2 Import

packages

=cut

use Moose;
use Tk;
use iVA2;
use SeismicUnix qw ($true $false);

=head2 instantiante methods

=cut

my $iva = new iVA2();

=head2 Declare variables

in local memory space

=cut
my $IVA_Tk = {
    _prompt => ""
};

my ($calc_rb,$exit_rb,$pick_rb,$next_rb,$saveNcont_rb);
my $rb_value = "red";
my $old_data;
my $next_step = 'stop';
my $number_of_tries = 0;
our $mw;

=head2 Check

for old data
=cut

$old_data = $iva->old_data('velan');

=head2 Create Main Window

and start event-driven loop
Interaction with user
initialize values
If oicks are new, show
message to user on how to pick data
-Based on semblance,
    decide whether to PICK or move on to NEXT CDP
-radio_buttons stop flow
Must be AFTR semblance

set the prompt value according
to which button is pressed
then exit the MainLoop
destroy the main window after the prompt
is properly set
=cut

if (!$old_data) {
    $iva->start();
    $mw = MainWindow->new;
    $mw->title("Options");
    $mw->geometry("300x50+40+0");
    $mw->title("iVA");
    $calc_rb = $mw->Radiobutton(
        -text => 'CALC',
        -value => 'calc',
        -variable => \
            \$rb_value,
        -command => \&set_calc
    )->pack(side => 'left');
$next_rb = $mw->Radiobutton(  
  -text =>'NEXT',  
  -value =>'next',  
  -variable => \$rb_value,  
  -command => \&set_next )->pack(-side => 'left');

$pick_rb = $mw->Radiobutton(  
  -text =>'PICK',  
  -value =>'pick',  
  -variable => \$rb_value,  
  -command => \&set_pick )->pack(-side => 'left');

$exit_rb = $mw->Radiobutton(  
  -text =>'EXIT',  
  -value =>'exit',  
  -variable => \$rb_value,  
  -command => \&set_exit )->pack(-side => 'bottom');

MainLoop; # for Tk widgets

) # for new data

=pod

sub set_pick

A callback to:
send cdp number to $iva
delete output of previous semblance
plus more callbacks following...

=cut

sub set_pick {  
  my $pick = 'pick';  
  $next_rb->configure(-state => 'disabled');  
  #$pick_rb->configure(-state => 'normal');  
  $calc_rb->configure(-state => 'normal');  
  $IVA_Tk->{_prompt} = $pick;  
  $iva->pick();
}

=pod

sub set_calc

-PRESS the CALC button
-increment number of tries to make
  semblance display interact and show old picks
  (number_of_tries >1)
-radical_buttons stop flow
  Must be AFTR semblance
sub set_calc {
    my $calc = 'calc';
#pick_rb->configure(-state => 'disabled');
$next_rb->configure(-state => 'normal');
$IVA_Tk->_prompt = $calc;
$iva->calc();
}

sub set_next {
    print("Next...
");
$next_rb->configure(-state => 'normal');
$calc_rb->configure(-state => 'disabled');
my $next = ''; 
$IVA_Tk->_prompt = $next;
$iva->next();
}

sub set_exit {
    my $exit = 'exit';
$exit_rb->configure(-state => 'normal');
$IVA_Tk->_prompt = $exit;
$mw->destroy() if Tk::Exists($mw);
$iva->exit();
}
sub prompt{
    our $variable = $IVA_Tk->{_prompt};
    return($variable);
}

A.3.15. suCatPar.pl

#!/usr/local/bin/perl
use Moose;

=head1 DOCUMENTATION

=head2 SYNOPSIS

PROGRAM NAME: SuCatPar.pl P
Purpose: add traces
AUTHOR: Juan M. Lorenzo
DEPENDS: Seismic Unix modules from CSM
DATE: July 31 2013 V0.1
       Oct. 31, 2016 V0.2 for nmo
DESCRIPTION:

=head 2 USES

=head2 NOTES

=head2 STEPS

1. Read list of cdp file numbers
e.g.,
   11
   12

2. Add a prefix and read in the cdp file parameters
   $ivpicks_sorted_par_file_name_cdp11
       tnmo=a,b,c
       vnmo=A,B,C

   $ivpicks_sorted_par_file_name_cdp12
       tnmo=d,e,f
       vnmo=D,E,F
3. Rearrange parameters in memory

cdp=11,12
tnmo=a,b,c
vnmo=A,B,C
tnmo=d,e,f
vnmo=D,E,F

4. Write out final composite parameter file

use SeismicUnix qw ($in $out $on $go $to $suffix_ascii $off $suffix_su);
use flow;
use message;
use manage_files_by;

=head2 Instantiate classes

Use classes:
flow
log
message

=head2 Declare local variables

my (@flow,@file_in);
my (@suCatPar,@suCatParNote,$suCatParVersion);
my ($par_file,$row,$file_number);
my (@cdp,@output,@outbound);
my ($numberOfFiles);
my $ref_file_names;
my ($ref_values,$ref_numberOfValues,$par_file_list);

=head2 Declare file names

=head2
$file_in[1] = 'All_cmp_div4_utm_sz_source.gz_tstat_statics_mute_ep_1_481';

$par_file_list = 'cdp_list';

$outbound[1] = $PL_SEISMIC.'/'.$file_in[1].'_stkvel';

=head2 DEFINE FLOW(S)
=cut

=head2 RUN FLOW(S)
=cut

=head2
read a list of file names
=cut

($ref_file_names,$numberOfFiles) = manage_files_by::read_1col($par_file_list);

=pod testing
print(" number of files is $numberOfFiles\n");
for (my $i=1; $i<=$numberOfFiles;$i++) {
    print(" file $i is $$ref_file_names[$i]\n");
    print(" file $i is $$ref_file_names[$i]\n");
}

print(" number of files is $numberOfFiles\n");
for (my $i=1; $i<=$numberOfFiles;$i++) {
    print(" file $i is $PL_SEISMIC/ivpicks_sorted_par_file_in[1]_cdp$ref_file_names[$i]\n");
}
=cut

=head2
read contents of each file in the list
into arrays
each line of the list is a cdp number as well as an
indicator of what file the velocity picks are in
=cut
my $line=1;

for ($file_number=1; $file_number <=$numberOfFiles; $file_number++) {
    $par_file = $$ref_file_names[$file_number];
    $cdp[$file_number] = $$ref_file_names[$file_number];
    $par_file = $PL_SEISMIC.'/ivpicks_sorted_par.'_file_in[1].'_cdp'.$par_file;
    ($ref_values,$ref_numberOfValues) = manage_files_by::read_par($par_file);

    =pod testing

    $row = scalar @$ref_numberOfValues;
    print("\nfor file #$file_number, number of rows is $row\n");
    for (my $i=0; $i<$row; $i++) {
        print("\n row $i contains $$ref_values[$i]"");
        print(" i.e., $$ref_numberOfValues[$i] values\n");
    } 

    =cut
    =head2

    place contents of each file in the list
    into an array

    print("$output[$line]\n\n");

   =cut
    $row = scalar @$ref_numberOfValues;
    for (my $i=0; $i<$row; $i++, $line++) {
        $output[$line] = $$ref_values[$i];
    }

    =head2

    write output to a file

    testing

    print("\ncdp=");
    print("$cdp[1]"');
    for (my $i=2; $i<=$file_number; $i++) {
        print("$cdp[$i]"');
    }

    print("\n");

    for (my $i=1; $i<=$line; $i=$i+2) {
        print("tnmo=$output[$i]\n");
        print("vnmo=$output[($i+1)]\n");
        print("\n");
    }

    =cut
A.3.16. cdp_count.sh

#!/bin/bash
set -x #echo on

# Title: cdp_count.sh
# Author: Adam Gostic
# Purpose: Calculate fold at each CMP and write to text file.
# Created: May 3, 2017

folder='/home/gadam2/FalseRiver/seismics/data/Bueche//All/H/1/su/gadam2'
file='All_cmp_div4_utm_sz_source_gz_tstatStatics_mute_ep_1_481_sort'
suffix='.su'
sukeycount < $folder$file$suffix key=cdp > $folder/foldcount_$file.txt

[1]+ Done                     gedit cdp_count.sh
69 gadam2@zamin:~/FalseRiver/seismics/sh/Bueche/All/H/1/gadam2 %

A.3.17. Sustack.pl

PROGRAM NAME: Sustack.pl
Purpose: add traces
AUTHOR: Juan M. Lorenzo
DEPENDS: Seismic Unix modules from CSM
DATE: July 31 2013 V0.1
      Oct. 31, 2016 V0.2 for nmo
DESCRIPTION:

=head2 USES

=head2 NOTES

=head2 STEPS
use SeismicUnix qw ($in $out $on $go $to $suffix_ascii $off $suffix_su);
use flow;
use message;
use sufilter;
use sugain;
use susort;
use sunmo;
use suwind;
use sustack;
use suxwigb;
use suximage;
use manage_files_by;

=head2 Instantiate classes

Use classes:
flow
log
message
sufilter
sugain
suxwigb
suwind
suximage

=cut

my $log = new message();
my $run = new flow();
my $sufilter = new sufilter();
my $sugain = new sugain();
my $susort = new susort();
my $sunmo = new sunmo();
my $suwind = new suwind();
my $sustack = new sustack();
my $suxwigb = new suxwigb();
my $suximage = new suximage();

my ($DATA_SEISMIC_SU) = System_Variables::DATA_SEISMIC_SU();

=head2 Declare

local variables

=cut

my (@flow,@file_in,@sufile_in,@inbound);
my (@suxwigb,@suximage,@sufilter,@sufilterNote);
my (@sugain,@sugainNote,$sugainVersion,@items,@suximage);
my (@suwind,@suwindNote,$suwindVersion);
my (@susort, @susortNote, $susortVersion);
my (@sustack, @sustackNote, $sustackVersion);

=head2 Declare

file names

cut

=head2

susort cdp offset <All_cmp.su \
| suwind key=cdp min=1 max=100 \n| sufilter f=10,20,230,280 \n| sudipfilt dt=1 dx=1 slopes=3,8,17,25,80 amps=1,1,0,1,1 \n| sunmo vnmo=150 | sustack \n| suwind tmin=0 tmax=1 \n| sustolt cdpmin=1 cdpmax=100 dxcdp=1 vmig=50,100 tmig=0,1 \n| suximage clip=1

cut

$file_in[1] = 'All_cmp_div4_utm_sz_seisgun_gz_tstatStatics_mute_ep_1_481';
$par_file[1] = $file_in[1].'_stkv';
$sufile_in[1] = $file_in[1].$suffix_su;
$inbound[1] = $DATA_SEISMIC_SU.'/'.$sufile_in[1];

=head2 Set

sunmo

cut

$sunmoVersion = 1;

$sunmo -> clear();
#$sunmo -> vnmo('100,300');
#$sunmo -> tnmo('0,1');
$sunmo -> par($par_file[1]);
$sunmo[1] = $sunmo->Step();
$sunmoNote[1] = $sunmo->note();

=head2 Set

sugain

cut

$sugainVersion = 1;

$sugain -> clear();
$sugain -> agc($on);
$sugain  \rightarrow \text{width}(0.1);
$sugain[1] = \text{sugain} \rightarrow \text{Step}();
$sugain\text{Note}[1] = \text{sugain} \rightarrow \text{note}();

=\text{head2 Set}
\text{sugain}
=\text{cut}

$sugain\text{Version} = 1;
$sugain  \rightarrow \text{clear}();
$sugain  \rightarrow \text{agc}(\text{Soff});
$sugain  \rightarrow \text{width}(0.08);
$sugain[1] = \text{sugain} \rightarrow \text{Step}();
$sugain\text{Note}[1] = \text{sugain} \rightarrow \text{note}();

=\text{head2 Set}
\text{suwind}
=\text{cut}

$suwind\text{Version} = 1;
$suwind  \rightarrow \text{clear}();
$suwind  \rightarrow \text{key}(\text{cdp});
$suwind  \rightarrow \text{min}(1);
$suwind  \rightarrow \text{max}(500);
$suwind[\text{suwindVersion}] = \text{suwind} \rightarrow \text{Step}();
$suwind\text{Note}[\text{suwindVersion}] = \text{suwind} \rightarrow \text{note}();

$suwind\text{Version} = 2;
$suwind  \rightarrow \text{clear}();
$suwind  \rightarrow \text{tmin}(0);
$suwind  \rightarrow \text{tmax}(1);
$suwind[\text{suwindVersion}] = \text{suwind} \rightarrow \text{Step}();
$suwind\text{Note}[\text{suwindVersion}] = \text{suwind} \rightarrow \text{note}();

=\text{head2 Set}
\text{susort}
=\text{cut}

$susort\text{Version} = 1;
$susort  \rightarrow \text{clear}();
$susort  \rightarrow \text{headerword}(\text{cdp offset});
$susort[\text{susortVersion}] = \text{susort} \rightarrow \text{Step}();
$susort\text{Note}[\text{susortVersion}] = \text{susort} \rightarrow \text{note}();
=head2 Set

stacking parameters

=cut

$sustack ->clear();
sustack ->headerword('cdp');
sustack[1] = $sustack->Step();
sustackNote[1] = $sustack->note();

=head2 Set

filtering parameters

=cut

$sufilter -> freq("0,5,75,150");
sufilter[1] = $sufilter->Step();
sufilterNote[1] = $sufilter->note();

=head2 Set

suxwigb parameters

=cut

$suxwigb -> clear();
suxwigb -> title(quotemeta($sufilterNote[1].$sugainNote[$sugainVersion]));
suxwigb -> xlabel(quotemeta('CDP'));
suxwigb -> ylabel(quotemeta('TWTT (s)'));
suxwigb -> box_width(1500);
suxwigb -> box_height(1000);
suxwigb -> box_X0(0);
suxwigb -> box_Y0(0);
suxwigb -> absclip(2);
suxwigb -> xcur(2);
suxwigb -> windowtitle($sufile_in[1]);
suxwigb[1] = $suxwigb->Step();

$suximage -> clear();
suximage -> title(quotemeta($sufilterNote[1].$sugainNote[$sugainVersion]));
suximage -> xlabel(quotemeta('CDP'));
suximage -> ylabel(quotemeta('TWTT (s)'));
suximage -> box_width(1000);
suximage -> box_height(700);
suximage -> box_X0(0);
suximage -> box_Y0(0);
suximage -> absclip(0.2);
suximage -> windowtitle($sufile_in[1]);
suximage[1] = $suximage->Step();
A.4. Dip Calculation Flow

The dip calculation flow is composed of original Bash and MATLAB scripts in order to calculate the dip angle of seismic reflectors with offset apices in common-shot gathers [Section 2.5]

A.4.1. ep_picks.sh

# Title: ep_picks.sh  
# Author: Adam Gostic  
# Purpose: Pick and save x-t coordinates by shot gather  
# Created: October 17, 2017
# Update: October 18, 2017
# Added option for adjusting plot height and width

# Specify File Paths & Names

path=/home/gadam2/FalseRiver/seismics/data/Bueche/All/H/1/su/gadam2/  # path to the directory containing both the data and the directory in which the picks will be saved
dir=dip_picks
filein=All_cmp_div4_utm_sz_source_gz_tstat_stats_mute_ep_1_481.su  # name of the .su file to be picked

# Specify Parameters

ep=95
trace_header=offset  # trace header value used to label traces within each shot gather
tmin=0  # minimum time value of the shot gather window
tmax=0.75  # maximum time value of the shot gather window

width=350  # width of plot in pixels
height=700  # height of plot in pixels
clip=1.8  # clip width

agc=1  # automatic gain control switch (1 -> agc ON ; 0 -> agc OFF)
wagc=0.08  # automatic gain window in seconds
perc=99  # set the percentage of lowest amplitudes to retain (EXAMPLE: perc=99 will exclude out the top 1% of highest amplitudes from the display)

filter=5,20,80,100  # frequency filter cutoffs
amps=0,1,1,0  # frequency filter cutoff amplitudes

# Execution

suwind < $path$filein key=ep min=$ep max=$ep tmin=$tmin tmax=$tmax | sufilter f=$filter amps=$amps | sugain agc=$agc wagc=$wagc | suxwigb key=$trace_header clip=$clip perc=$perc mpicks=$path/$dir/pick_ep$ep windowtitle=EP$ep title=EP$ep f=$(filter) clip=$clip perc=$perc wagc=$wagc label1=TWTT label2=$trace_header \(m\) width hbox=$height

A.4.2. dipcalc.m

% Title: dipcalc.m
% Purpose: Convert Offset-Time pairs to dip values and plot for display.
% Author: Adam Gostic
% Created on: October 25, 2017

% Instructions:

% A - HOW TO CALCULATE AND PLOT VELOCITY MODEL:

% A1) Run iVA on seismic data that has CDP values assigned to every trace:
~/FalseRiver/seismics/pl/Bueche/All/H/1/gadam2/iVA2
% There will be one parameter file output for each CDP in the seismic data file. Output files take the form ivpicks_sorted_par_XXX_cdpYYY where XXX is the seismic data file name and YYY is the CDP #.
% Output files are located in ~/FalseRiver/seismics/pl/Bueche/All/H/1/gadam2/.

% A2) Copy these ivpick parameter files to \Google Drive\False River Project\MATLAB\Dip Calculation\iv_picks\.
% A3) Rename all files to the form cdpYYYpicks (where 'YYY' is the CDP number)!
% A4) Populate empty cdpYYYpicks files. I just copied the data from the previous or next CDP, whichever was closest.
% A5) Open MATLAB script dipcalc.m located at 'D:\Google Drive\False River Project\MATLAB\Dip Calculation\dipcalc.m'.
% A6) Set the value of the variable 'cdp_count' on line 64 to the total number of CDP pick files. CDP numbers must start at 1 and increase monotonically with no gaps.
% A7) Run dipcalc.m OR continue to next phase: ‘HOW TO CALCULATE AND PLOT DIPS’

% B - HOW TO CALCULATE AND PLOT DIPS:
% B1) Run ep_picks.sh on seismic data: ~/FalseRiver/seismics/sh/Bueche/All/H/1/gadam2/ep_picks.sh
% The program will run on one shot gather (EP) at a time, the script must be modified at ep=ZZZ (line 16) for each shotgather to pick where ZZZ is the number of the desired shot gather.
% Picks are saved to ~/FalseRiver/seismics/data/Bueche/All/H/1/su/gadam2/dip_picks in the form pick_epZZZ.
% B2) Run add_ep.sh to append the EP number to end of each line of the pick_epZZZ files: ~/FalseRiver/seismics/data/Bueche/All/H/1/su/gadam2/dip_picks/add_ep.sh
% This associates a shot gather (EP) with each apex pick and is needed for the MATLAB script.
% The range of the forloop on line 7 must be equal to the apex pick file with the largest EP value. For a max EP of 481 in the Bueche line, my line 7 was: for ((i=1;i<=481;i++)).
% There will be errors for missing EP files. This is OK, the files that are present will be properly appended.
% B3) Copy these pick_epZZZ files to \Google Drive\False River Project\MATLAB\Dip Calculation\apex_picks\.
% B4) Open MATLAB script dipcalc.m located at 'D:\Google Drive\False River Project\MATLAB\Dip Calculation\dipcalc.m'.
% B5) Set the value of the variable 'ep_count' on line 63 to the total number of apex pick files. NOT the largest EP value!
% B6) Set the value of the variable 'apex_picks_count' on line 65 to the total number of apex picks, which is the sum of the line count from all of the pick_epZZZ files combined.
% This will be equal to the length of an array ending in the tag '_all': apex_cdp_all, apex_depth_all, apex_dip_all, apex_ep_all, apex_offset_all, apex_vel_all
% 'apex_all' is a combination of the above single-column arrays.
% B7) Run dipcalc.m

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%% Assign File Variables

clear

addpath('D:\Google Drive\False River Project\MATLAB\Dip Calculation\iv_picks');  % path to directory containing individual
addpath('D:\Google Drive\False River Project\MATLAB\Dip Calculation\apex_picks');  % path to directory containing apex pick files. One file for each shot gather picked.
apex_picks = dir('D:\Google Drive\False River Project\MATLAB\Dip Calculation\apex_picks');

ep_count = 451;             % Total number of apex pick files. NOT the largest EP value!
cdp_count = 245;            % Total number of CDP pick files. CDP numbers must start at 1 and increase monotonically with no gaps.
apex_picks_count = 754;     % Total number of apex picks, which is the sum of the line count from all of the pick_epZZZ files combined

%% Build Velocity Model
% iv_picks files contain tnmo values in row 1 and vnmo values in row 2

for i3=1:cdp_count
    F = strcat('cdp',num2str(i3),'picks');
    iv_picks{i3}=transpose(load(F));
end
timescale = transpose(0.0001:0.0001:1);  % Sets the limits and interval of the two way time scale (lowerlimit:interval:upperlimit)
cdpscale = transpose(1:1:cdp_count);

for i2=1:cdp_count
    vel_model_cell{i2} = interp1(iv_picks{i2}(:,1),iv_picks{i2}(:,2),timescale,'linear','extrap');
end
vel_model_array = cell2mat(vel_model_cell);

%% Plot Velocity Model

figure(1),clf;
model = surf(vel_model_array);
set(model,'LineStyle','none')
c=colorbar;
colormap jet;
c.Label.String = 'V_{rms} (m/s)';
axis tight;
set(gca,'XAxisLocation','top','YAxisLocation','left','ydir','reverse');
set(gca,'XTick',[2000 4000 6000 8000 10000]);
set(gca,'YTick',[0.2 0.4 0.6 0.8 1.0]);
title('Velocity Model');
xlabel('CDP');
ylabel('Two Way Time (s)');

%% Extract Apex TWT, EP, and Offset values
% apex_picks files contain twt in column 1, offset in meters in column 2, and EP number in column 3
for i3=1:(ep_count+3)
    if (i3==1 || i3==2 || i3==3)
        continue;
    end

    check = isempty(load(apex_picks(i3).name));
    if check == 1
        continue;
    end

    inFile=dlmread(apex_picks(i3).name);
    apex_twt=inFile(:,1);
    apex_offset=inFile(:,2);
    apex_ep=inFile(:,3);
    if (i3==4)
        apex_twt_all = apex_twt;
        apex_offset_all = apex_offset;
        apex_ep_all = apex_ep;
    end

    apex_twt_all = cat(1,apex_twt_all,apex_twt);
    apex_offset_all = cat(1,apex_offset_all,apex_offset);
    apex_ep_all = cat(1,apex_ep_all,apex_ep);
end

%% Peform EP -> CDP transform

apex_cdp_all = fix(((apex_ep_all+apex_offset_all) - 1)./2);

%% Calculate Dips

for i4=1:apex_picks_count
    apex_vel = vel_model_array(round(apex_twt_all(i4)*10000),apex_cdp_all(i4)); % multiplier for apex_twt_all equals number of values in variable 'timescale'
    if (i4==1)
        apex_vel_all = apex_vel;
    else
        apex_vel_all = cat(1,apex_vel_all,apex_vel);
    end
end

apex_depth_all = (apex_vel_all.*apex_twt_all)/2;
apex_dip_all = asind((apex_offset_all)./(2*apex_depth_all));
dip_average = mean(apex_dip_all)

%% Combine Attributes into a single Array

apex_all =
[apex_ep_all(:,1),apex_cdp_all(:,1),apex_twt_all(:,1),apex_offset_all(:,1),apex_vel_all(:,1),apex_depth_all(:,1),apex_dip_all(:,1)];

%% Calculate Error from Offset Picks

dip1 = asind((1)./(2*apex_depth_all)); % dip for each apex if offset equals 1m
% dip for each apex if offset equals 2m
dip2 = asind((2)./(2*apex_depth_all));    % dip for each apex if offset equals 2m

dip_error = (dip2 - dip1);               % difference between dip calculations with a 1m change in offset

% dip_error_inv = (3 ./ nthroot(dip_error,3));    % inverse of the dip_error calculation to be used for sizing data
% points in dip plot, this gives smaller errors larger circles. Denominator exponent and numerator are both scaling
factors.
dip_error_inv = (10 - dip_error).*((12 - dip_error)
dip_error_max = max(dip_error)
dip_error_min = min(dip_error)

%% Plot Dips against TWT

figure(2)
cf
scatter(apex_cdp_all,apex_twt_all,dip_error_inv.*1.5,apex_dip_all,'filled');
c=colorbar;
colormap hsv;
c.Ticks = [5,10,15,20,25,30,35,40,45];
c.TickLabels = {'5°','10°','15°','20°','25°','30°','35°','40°','45°',};
c.Label.String = 'Reflector Dip';
set(gca,'TickDir','out','XAxisLocation','top','YAxisLocation','left','ydir','reverse');
title('Bueche Reflector Dips');
xlabel('CDP');
ylabel('Two Way Time (s)');

%% Plot Dips against Depth

figure(3)
cf
scatter(apex_cdp_all,apex_dept_all,dip_error_inv.*1.5,apex_dip_all,'filled');
c=colorbar;
colormap hsv;
c.Ticks = [5,10,15,20,25,30,35,40,45];
c.TickLabels = {'5°','10°','15°','20°','25°','30°','35°','40°','45°',};
c.Label.String = 'Reflector Dip';
set(gca,'TickDir','out','XAxisLocation','top','YAxisLocation','left','ydir','reverse');
title('Bueche Reflector Dips');
xlabel('CDP');
ylabel('Depth (m)');

A.5. Scripts for Generating Plots for Data Comparison

The following programs are original Bash scripts used to facilitate comparison of seismic data in various
formats by specifying parameters for Seismic Unix modules.

A.5.1. plot_ep.sh

#!/bin/bash
#Title: plot_ep.sh
#Author: Adam Gostic
#Date: April 30 2018
#Purpose: Generate suxwigb and suximage plots of a single shot gather
folder='/home/gadam2/FalseRiver/seismics/data/Bueche/All/H/1/su/gadam2/'
file='All_cmp_div4_utm_sz_source_gz_tstat_statics_mute_ep_1_481_nmo.su'

filter='0.5,75,150'

agc='1'
wagc='0.1'
wbox='400'
hbox='600'
wigclip='0.1'
xcur='1'
perc='85'
imgclip='1'
wclip='3'
bclip='3'

suwind < $folder$file key=ep min=361 max=361 tmin=0.0 tmax=1.0 | sufilter f=$filter | sugain agc=$agc wagc=$wagc | suxwigb title='<f01>(\text{TWTT (s)})' label1=TWTT label2=Trace

suwind < $folder$file key=ep min=361 max=361 tmin=0.0 tmax=1.0 | sufilter f=$filter | sugain agc=$agc wagc=$wagc | suximage title='<f01>(\text{TWTT (s)})' label1=TWTT label2=Trace

A.5.2. plot_cdp.sh

#!/bin/bash
#Title: plot_cdp.sh
#Author: Adam Gostic
#Date: May 4 2018
#Purpose: Generate suxwigb and suximage plots of a single common midpoint gather

folder='/home/gadam2/FalseRiver/seismics/data/Bueche/All/H/1/su/gadam2/'
file='All_cmp_div4_utm_sz_source_gz_tstat_statics_mute_ep_1_481_nmo.su'

filter='0.5,75,150'

agc='0'
wagc='0.01'
wbox='400'
hbox='600'
wigclip='0.8'
xcur='1'
perc='93'
suwind < $folder$file key=cdp min=$cdp max=$cdp tmin=0.0 tmax=1.0 | sufilter f=$filter | sugain agc=$agc wagc=$wagc | suxwigb title=\( f = (\text{filter}) \) agc=$agc wagc=$wagc clip=$wigclip label1=TWTT \( s \) label2=Trace \# wbox=$wbox hbox=$hbox xbox=0 ybox=0 perc=$perc xcur=$xcur windowtitle=$file &

suwind < $folder$file key=cdp min=$cdp max=$cdp tmin=0.0 tmax=1.0 | sufilter f=$filter | sugain agc=$agc wagc=$wagc | suximage title=\( f = (\text{filter}) \) agc=$agc wagc=$wagc perc=$perc label1=TWTT \( s \) label2=Trace \# wbox=$wbox hbox=$hbox xbox=0 ybox=0 perc=$perc windowtitle=$file &

---

### A.5.3. view_ep.sh

```
#!/bin/bash
#Title: view_ep.sh
#Author: Adam Gostic
#Date: March 21 2018
#Purpose: Generate suxwigb plots of many shot gathers at once

for i in {385..385}             #specify range of shot gathers (EPs)
do
  echo Drawing EP$i
  suwind <All_cmp_div4_utm_sz_source_gz_tstat_statics_mute_ep_1_481.su key=ep min=$i max=$i
tmin=0.0 tmax=0.35 | sufilter f=25,40,60,120 amps=0,1,1,0 | suxwigb clip=1 title=EP$i
((25,40,60,120) bandpass)
&
done
  echo Done
```

---

### A.5.4. view_fft.sh

```
#!/bin/bash
#Title: view_fft.sh
#Author: Adam Gostic
#Date: March 23 2018
#Purpose: Generate suxwigb plots of many Fourier transformed shot gathers simultaneously to compare dominant source frequencies.

dirname='/home/gadam2/FalseRiver/seismics/data/Bueche/All/H/1/su/gadam2/
filename="All_cmp_div4"
suffix=".su"

for i in {361..361}             #specify range of shot gathers (ep)
do
  for j in {1..4}             #specify range of traces within shot gather (offset: 1-24)
do
    echo Drawing EP$i Trace$j FFT
  done
done
```

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suwind < $dirname$file$filename$suffix key=ep min=$i max=$i | suwind key=offset min=$j max=$j | suft | suamp mode=amp | suxwigb f2=$j x1beg=0 x1end=500 label1=Frequency\(\text{Hz}\) label2=Trace\# title=EP$\j$ trace$j$ FFT &
  done
  done
echo Done
Vita

Adam Gostic was born in Corpus Christi, Texas in 1989 and raised in Spring, Texas. In 2015 he received the degree of Bachelor of Science in Geology with a minor in Mathematics from Sam Houston State University. After completing a geoscience consulting internship with GWS Consulting, he moved to Baton Rouge, Louisiana in 2016 to begin a graduate degree at Louisiana State University. He anticipates graduating with the degree of Master of Science from the Department of Geology & Geophysics in May 2019.