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Sedimentology of a Lower Middle Pleistocene Reservoir in Garden Banks Area,
Northern Gulf of Mexico: Integration of 3D Seismic, Cores, and Well
Logs

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Science
in
Earth and Environmental Sciences
Geology

By
Sean Patrick O'Brien
B.S., Louisiana State University, 2001
B.S., University of New Orleans, 2007
May, 2010

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DEDICATION

For Stephanie and Maisy

ACKNOWLEDGEMENTS

The research presented in this thesis would not have been possible without the help of numerous individuals. I would like to first show my gratitude to my major professor Dr. Sarwar, who allowed me to study under him after the untimely death of my first major professor Dr. Penland. Dr. Sarwar did not hesitate, and he provided me a great opportunity that few people ever receive.

I owe a great deal of thanks to my committee members Dr. Gani and Dr. Kulp. Both have been influential in my progression as a student and thesis candidate. Each has dedicated an enormous amount of attention to me through my years at the University of New Orleans.

I am indebted to Dane Fischer my friend, who has helped me through this master's thesis with both advice and an unwavering steadiness. His friendship and knowledge of geology has helped me become a better geologist.

I would like to thank Diamond Service Corporation for the donation of the 3D seismic data used in this study. Thanks are also due to Landmark for the donation of the Geographix software, and Seismic Micro-Technology for the donation of the KINGDOM Suite to the University of New Orleans that was used to interpret seismic and well log data.

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ABSTRACT

Garden Banks field 236, known as Pimento, is part of a lower middle Pleistocene submarine-fan deposit in the north central Gulf of Mexico. Pimento field represents a classic example of a prograding fan across the continental shelf continuing across the continental slope filling and spilling minibasins. Channel complexes cut through the field as sediment migrated across the shelf and slope to the basin floor.

This thesis consists of two papers which utilized donated 3D seismic data on six of the blocks in Pimento field. Public domain data was incorporated with these data to explore the producing reservoir sand in the field. Mapped horizons revealed the overall structural elements of the field including the fill and spill facies of the minibasin that directly influences the deposition of the field. In these papers, channel complexes have been resolved using seismic geomorphological techniques and cross sections. Two potential drilling targets have also been discovered and one has been initially investigated as a drilling target.

Pimento Field, Garden Banks, Horizons, Shelf, Slope, 3D Seismic, Mini-Basin

COMPREHENSIVE INTRODUCTION

This thesis is a collection of two papers that investigate the Pimento Field located in the Garden Banks Area. The first paper entitled “Integrated 3D Seismic, Cores, and Well Log Study of Upper Pleistocene Submarine Fan Reservoir in Garden Banks Area, Northern Gulf of Mexico”, focuses on the reservoir sand in one well. This paper was published in the Gulf Coast Association of Geological Societies, volume fifty-nine August 2009. In this paper a channel was mapped using seismic geomorphologic techniques and a potential drilling target was identified. The reservoir sand is identified as Upper Pleistocene sand deposit. This designation is accurate, but in 2003 the Minerals Management Service updated their biostratigraphy chart delineating the Upper Pleistocene into three categories: the upper, middle, and lower Pleistocene Chronozones. The second paper is titled: “Integrated Study of the Reservoir Sand and Depositional Setting of Garden Banks Field 236, North Central Gulf of Mexico”, which has been accepted by the Gulf Coast Association of Geological Societies for publication in October of 2010. This paper investigates the 4500 foot reservoir sand in the whole study area utilizing six wells. The depositional setting for the field was explored in depth as well as the depositional style of the reservoir sand. This paper displays a channel complex and a potential drilling target. The drilling target has a basic investigation of an amplitude map, isopach map and a structure map.

From the inner-continental shelf to the deep-water plays, South Louisiana's geology and sedimentological styles have provided many avenues for hydrocarbon traps. The Upper Pleistocene slope apron and submarine fan deposit in the Northern Gulf of Mexico is one of the best hydrocarbon plays stretching from the East Breaks to the Grand Isle area. This play has proven reserves of 185.466 MMboe of oil and condensate and 1.776 Tcf of gas from 128 sandstone bodies (Hentz et al., 1997).

This thesis focuses on the Garden Banks area specifically Field 236 which has producing hydrocarbon wells in the lower middle Pleistocene delta-fed slope-apron deposits (Galloway et al., 2000). Although various data were published on this area including stratigraphic and structural settings, there is no published reservoir-scale sedimentological mapping of the area using 3D seismic data. The main objective of this thesis is to map, using a combination of proprietary and public 3D seismic and well data, a channel-lobe complex and potential drilling targets for continued exploration of Field 236.

**FIRST PAPER:
INTEGRATED 3D SEISMIC DATA, CORES, AND WELL LOG STUDY OF
UPPER PLEISTOCENE SUBMARINE FAR RESERVOIR IN GARDEN
BANKS AREA, NORTHERN GULF OF MEXICO**

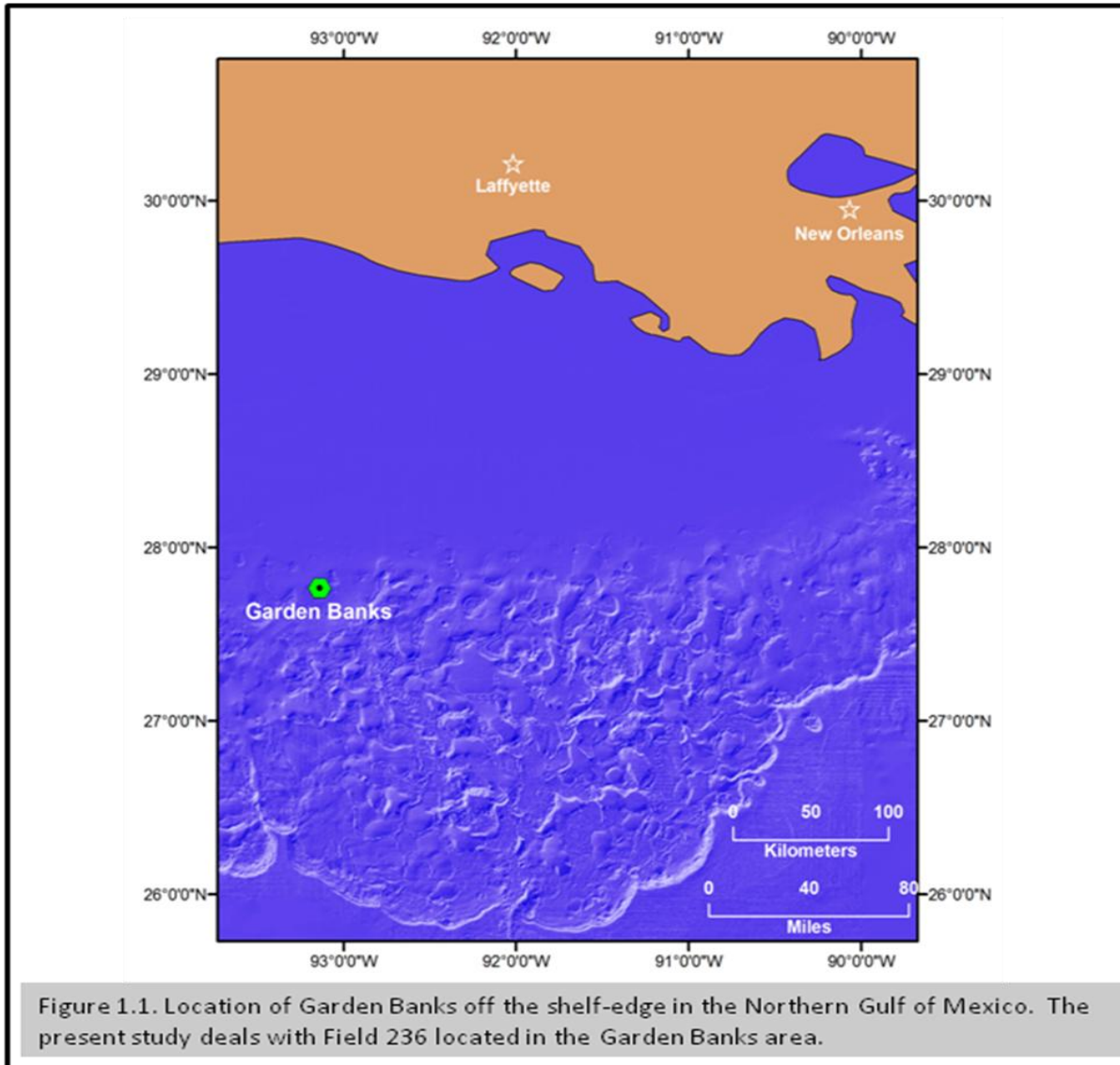
Abstract

The Upper Pleistocene submarine fan deposits in the Northern Gulf of Mexico have proven to be valuable targets for hydrocarbon exploration and extraction. The Garden Banks Area, 170 miles Southwest of Lafayette, Louisiana, is situated on the western flank of a submarine fan complex in the Northern Gulf of Mexico. The Garden Banks Area has producing wells in the Upper Pleistocene deep marine sandstones. Proprietary 3D seismic data, along with public-domain logs (gamma and resistivity) of ~25 wells and velocity data, for six blocks in the Garden Banks Area, totaling 54 square miles, has been used to map depositional packages and subsea morphology. Using the proprietary and public data we were able to map and describe the lithology of the depositional setting of an existing producing channel sand in the Garden Banks Field 236. This producing sand has been described on a regional scale, but not on a localized scale before. Using our method we were able to quickly show the depositional environment of the Pleistocene age sandstone and look for potential new drilling targets within the area.

Introduction

Hydrocarbon discoveries have proven to be a major economic engine throughout the world including Southern Louisiana. From the inner-continental shelf to the deep-water plays, South Louisiana's geology and sedimentological styles have provided many avenues for hydrocarbon traps. The Upper Pleistocene apron and fan deposit in the Northern Gulf of Mexico is one of the best hydrocarbon plays stretching from the East Breaks to the Grand Isle are. This play has proven reserves of 185.466 MMboe of oil and condensate and 1.776 Tcf of gas from 128 sand-stone bodies (Hentz et. al., 1995).

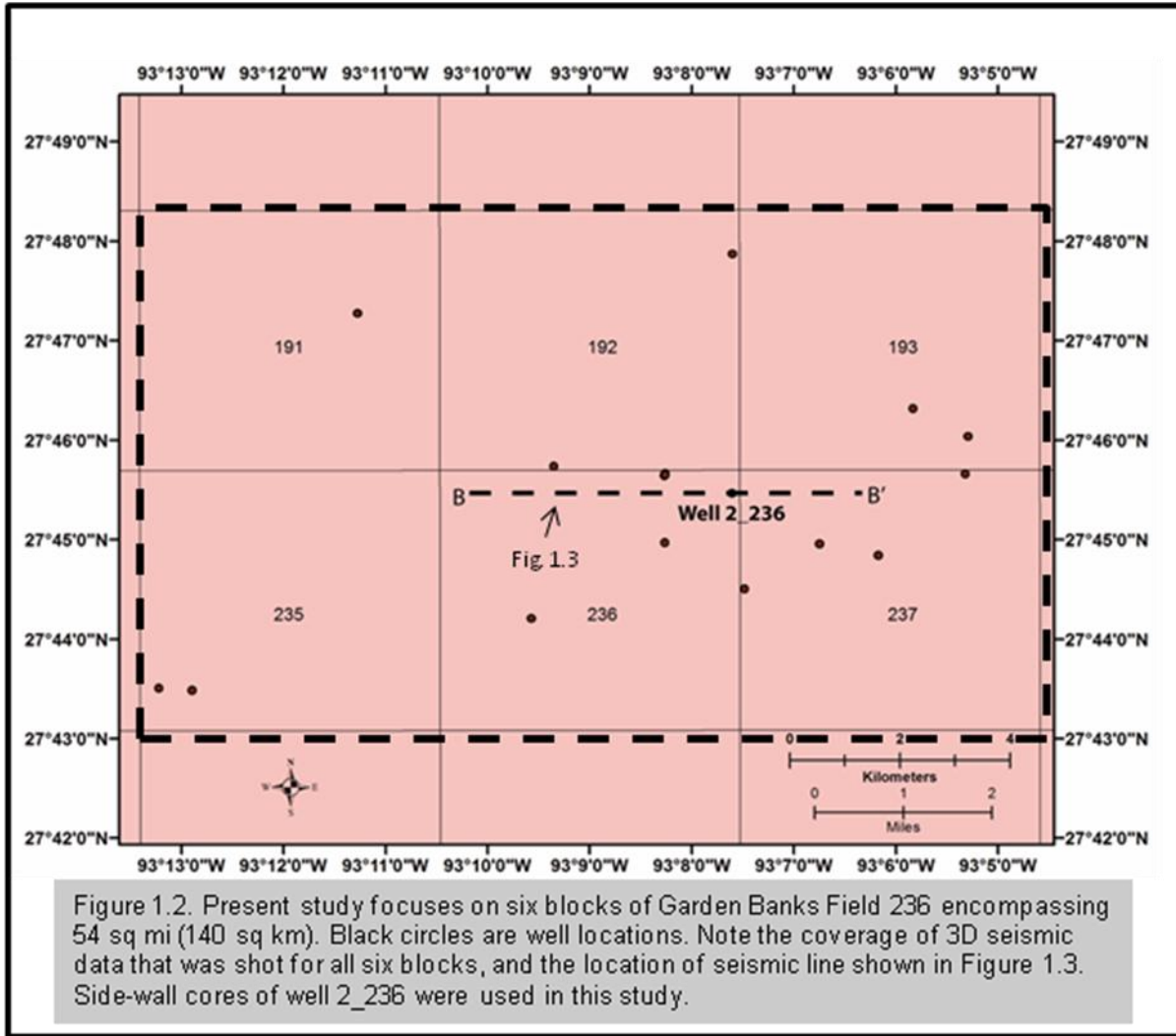
This paper focuses on the Garden Banks area (Figure 1.1), specifically Field 236, which has producing hydrocarbon wells in the Upper Pleistocene progradational delta-fed apron deposits (Galloway et. al., 2000). Although there are extensive data published on this area including stratigraphic and structural settings, there is no published reservoir-scale and high resolution mapping of the area using 3D seismic data. Using a combination of proprietary and public 3D seismic and well log data, the main objective of this paper is to map a channel-lobe complex and potential drilling targets for continued exploration of field 236.



Study Area

The Garden Banks Field 236 is located roughly 170 miles (273 kilometers) southwest of Lafayette, Louisiana in an average water depth of 700 feet (213 meters). The study area is comprised of six blocks in the field; blocks 191, 192, 193, 235, 236, and 237 (Figure 1.2). Each block is nine square miles (24 square kilometers) for a total of 54 square miles (140 sq kilometers). The known

reservoirs of this field lay in the Upper Pleistocene progradational delta-fed apron sand-stone deposits (Galloway et. al., 2000).



Regional Geology

The Northern Gulf of Mexico basin has been extensively studied for decades. Petroleum companies and researchers alike have compiled a very detailed data set on this present day tectonically passive basin. Two rifting episodes formed the Gulf of Mexico, one in the Late Triassic and the other in the

Middle Jurassic (Buffler, 1991). During the Middle Jurassic rifting, deposition of Callovian (Louann) salt took place across the basin. This salt, when remobilized later due to the overburden pressure of thick Cenozoic strata, played a critical role in the maturation, migration, and entrapment of petroleum in the northern Gulf of Mexico (Weimer, 1998). During the Middle Jurassic to Early Cretaceous deepwater shales and marls were deposited in this province. This sediment has served as the source rock for hydrocarbons in the deepwater.

By early Cenozoic, regionally-extensive shallow water to continental siliciclastic depocenters developed in the northwestern Gulf Basin, reflecting the drainage of sediments from the Laramide Orogeny in the western United States (Weimer, 1998; Martin, 1978). A relative lowering of sea level, enhanced the amounts of material removed from the continent and inner shelf by river transport, because the fluvial system must attain and maintain equilibrium in its downriver section (Bouma, 1981). The amount of sediment transported by rivers is related to the amount of erosion of the soil, caving river banks, and other fluvial processes (Mossa, 1996). The sediments deposited during this time have formed important reservoirs in both offshore and onshore basins. These depocenters switched during the Miocene in such a way that the center portion of North America was draining through Louisiana into the north central Gulf of Mexico Basin.

The coeval bathyal sediments deposited in a series of minibasins on top of and between allochthonous salt bodies. Structural petroleum traps have formed due to salt tectonics. Theory tells us that continuous diapirism cannot occur in a tectonically passive environment until the sediment immediately above the salt has a density that is greater than the density of salt (Nelson, 1989). This salt is commonly found in deep-marine systems which commonly hold the reservoirs for the northern deepwater Gulf subprovince (Weimer, 1998; Weimer et al., 1994).

Datasets and Methodology

This research was conducted using a combination of proprietary and public domain data. Proprietary 3D seismic data provided by Diamond Service Corporation covers the entire six blocks in the study area. The data acquisition parameters are as follows: Acquisition bin: 25 ft x 150 ft (8 m x 46 m); Record length: 9.6 seconds; and Nominal fold: 34 and Frequency: 23 Hertz. The public data acquired from Minerals Management Service consists of wire line logs (gamma and resistivity), check-shot velocity surveys from ~25 wells, geology reports, side-wall core descriptions, and some biostratigraphic reports. Seismic and well data were loaded into Landmark's seismic interpolation software Geographix. We mapped several horizons, generated isopach maps, amplitude maps, and correlated well logs, seismic, and side wall core data. Velocity surveys of the wells were used to generate interval-velocity maps for the 3D survey that were

instrumental in producing isopach maps from isochore maps. Techniques of seismic geomorphology were also used to identify paleogeomorphic units.

Results

Five horizons, each represented as distinct reflectors, were picked in 3D seismic data (Figure 1.3). Horizon 1 (H1) and 5 (H5) correspond to the top and bottom of our studied interval, respectively. A detailed investigation was conducted between H3 and H4, which is a distinct package with high amplitude and believed to represent a potential channel-lob complex.

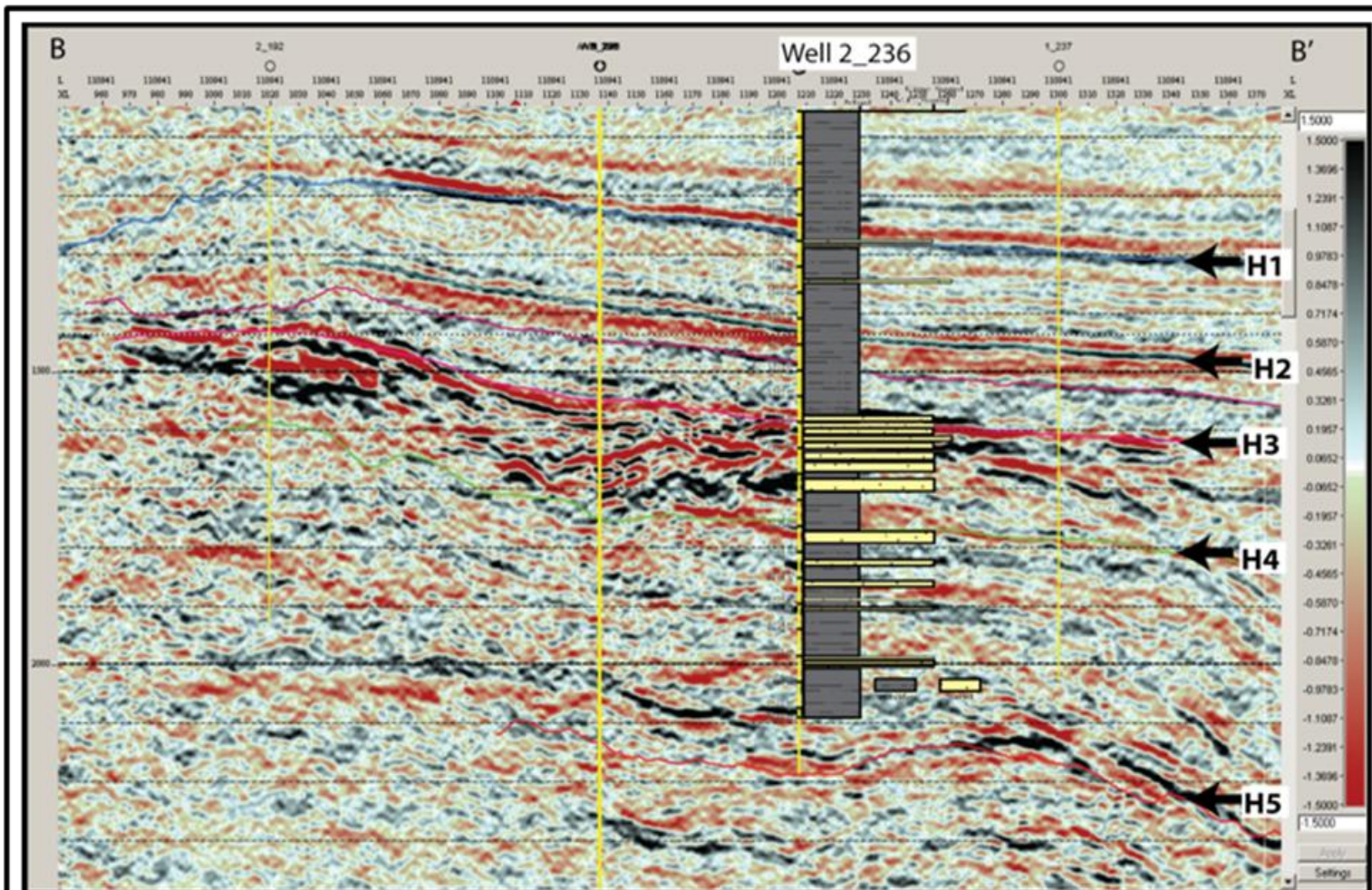
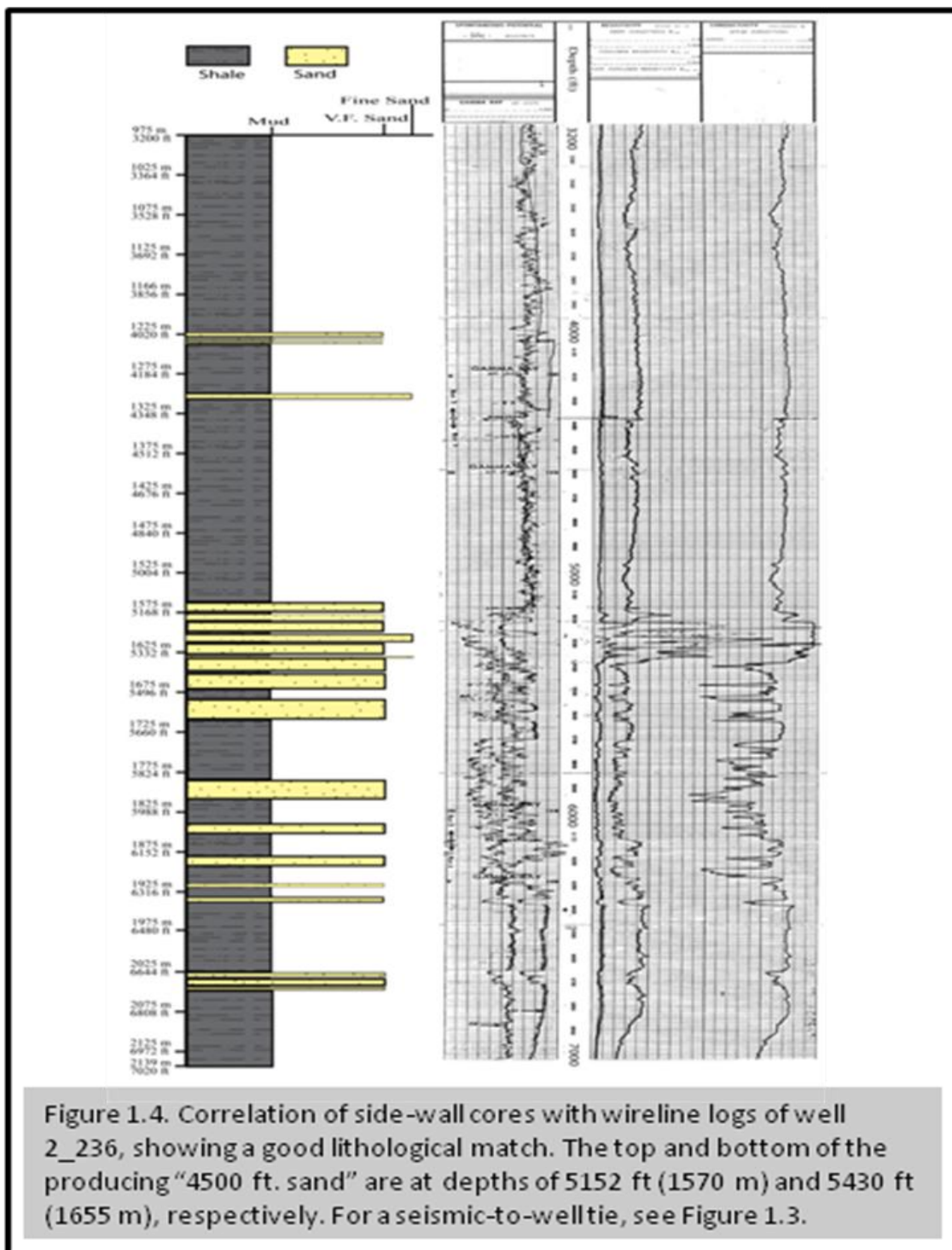


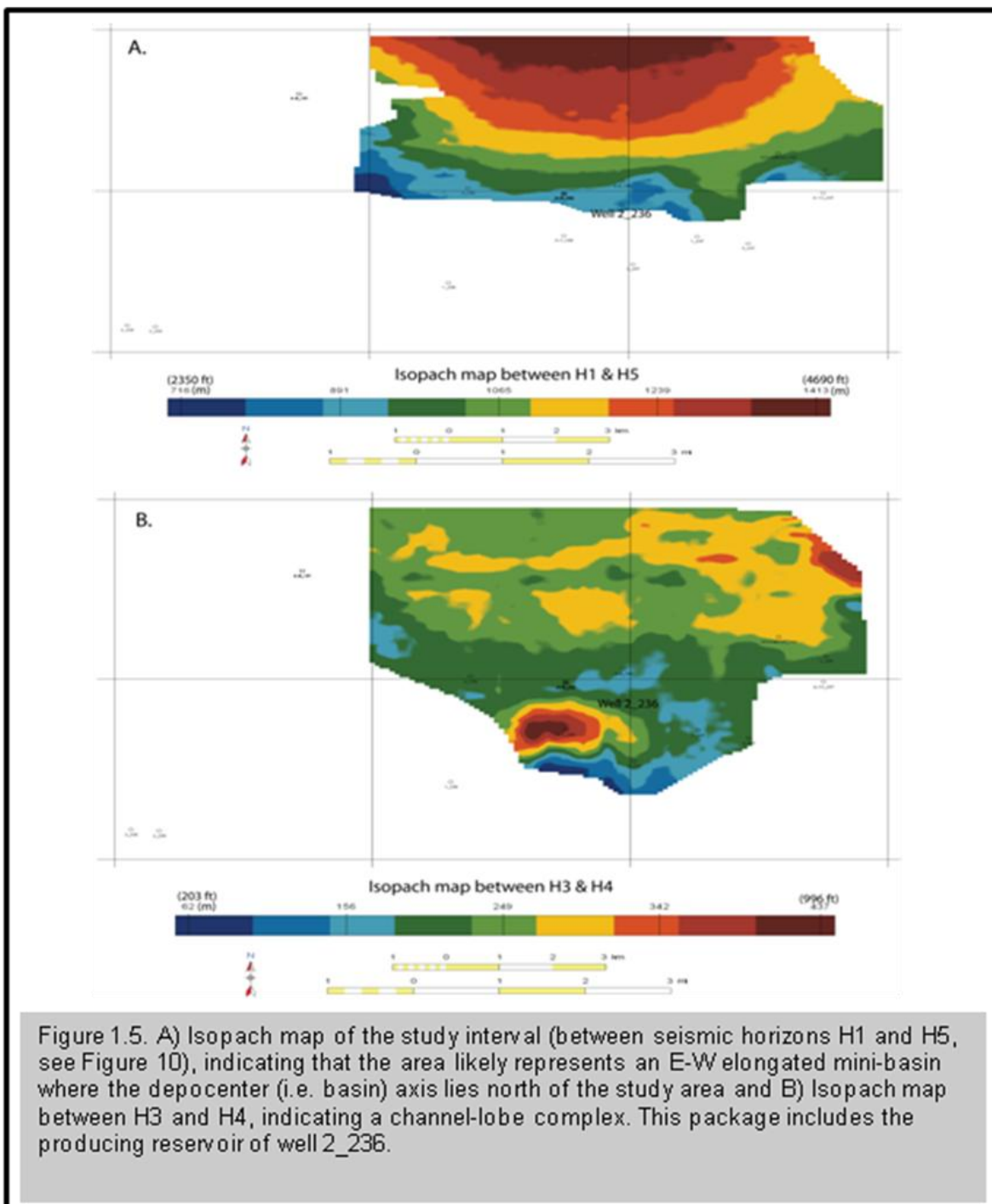
Figure 1.3. Seismic inline 11094-1 showing five picked horizons (H1 through H5) in the Upper Pleistocene study interval. Using velocity survey, side-wall core litholog of well 2_236 was correlated with the seismic section. The sandy package between H3 and H4, the producing reservoir in well 2_236, is the focus of this study. For location of the inline, see Figure 1.2.

This package was penetrated completely by well 2_236 (i.e. well #2 in block 236), for which there are wireline logs, velocity data, side-wall core data, and geology reports to further correlate our seismic observations. A sand-shale litholog was generated for well 2_236 based on the descriptions of the side-wall cores of this well. The interval between 5154 feet (1570 m) and 5600 feet (1706 m) is mostly very fine (to fine) sandstones with thinner mudstone interbeds. When correlated with the gamma and resistivity logs of this well, the side-wall cores show a good lithological match (Figure 1.4). Using the velocity survey for well 2_236, the litholog was also correlated with seismic inline 11094_1 that crosses this well. The sandy interval of the litholog (between 5154 feet and 5600 feet) nicely matches with the package between H3 and H4 in the seismic section as shown in Figure 1.3.



Isopach maps were generated between H1 and H5 and between H3 and H4. H1 and H5 Isopach map shows the total thickness of our study interval (Figure 1.5A). The thickness trend of this map indicates that the area potentially represents an E-W elongated mini-basin where the depocenter (i.e. basin) axis lies north of the study area. This mini-basin could be the result of deformations from a large salt body to the west and two smaller salt diapirs to the southeast of the study area.

The second isopach map between H3 and H4 represents mostly sandstones (Figure 1.5B). These sandstones are interpreted as showing an E-W trending channel complex. At the northern side of the trend a lobe-complex is visible, which indicates the eastern end of the channel (i.e. eastward paleocurrent flow). The interpretation of this channel-lobe complex is also supported in a total amplitude map slicing through the middle (and parallel to H4) of the package between H3 and H4 (Figure 1.6). This amplitude map shows a meandering to straight channel and a lobe-complex, which are also discernable in seismic section. To further correlate this channel in the amplitude map a crossline was run through the channel its self. Crossline 1270 (Fig. 1.6) distinctly show the channel and lobe in the crossline seismic display.



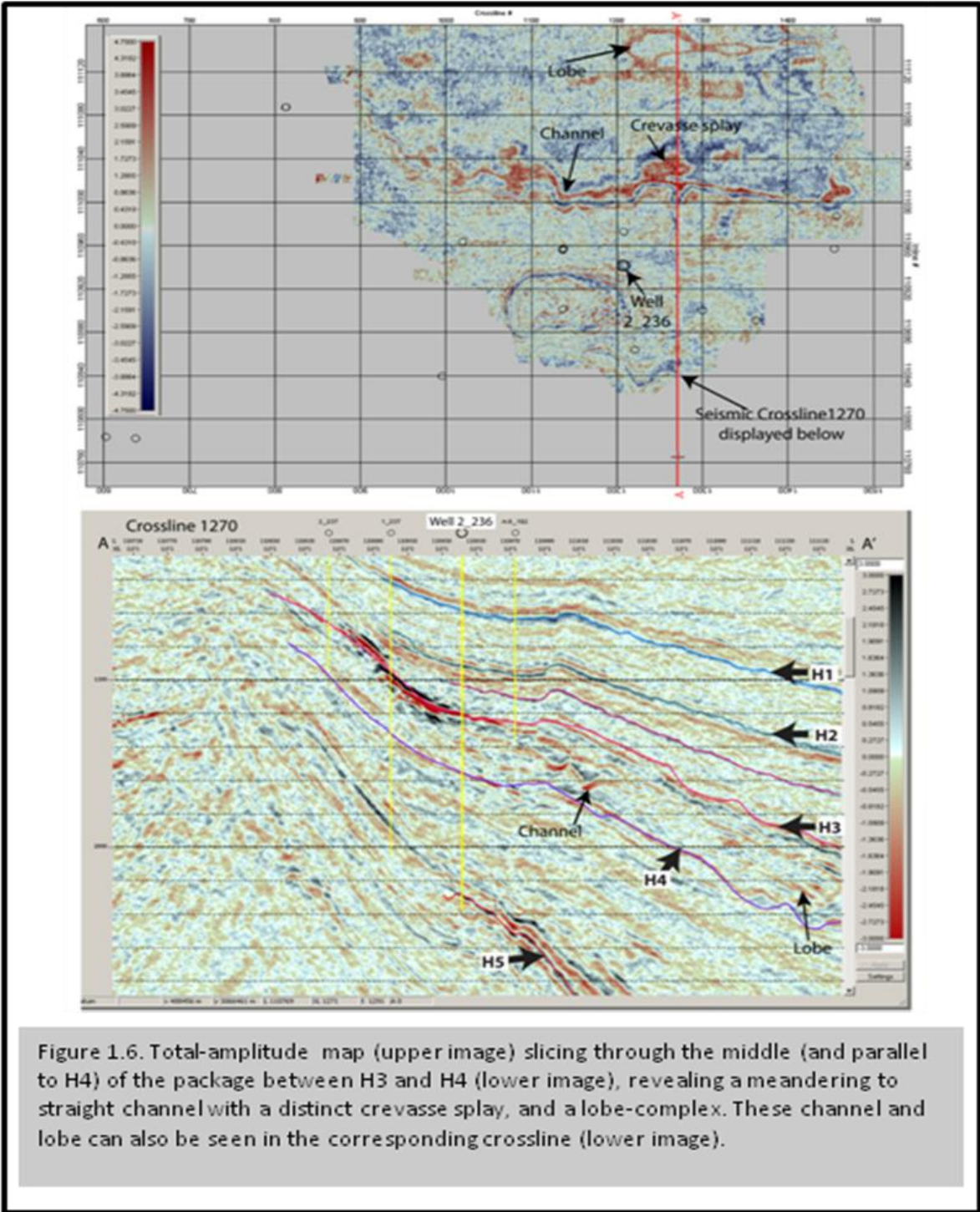


Figure 1.6. Total-amplitude map (upper image) slicing through the middle (and parallel to H4) of the package between H3 and H4 (lower image), revealing a meandering to straight channel with a distinct crevasse splay, and a lobe-complex. These channel and lobe can also be seen in the corresponding crossline (lower image).

Discussion and Conclusion

Although the Garden Banks 236 field has been in production since the late seventies, there has not been any published data on the nature of the reservoir sand. The field is mentioned in the Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs Volume 2, where the depositional center is identified as an Upper Pleistocene Submarine Fan Sandstone (Hentz et. al. 1995). The channel-lobe complex identified in this study is known as the “4500 foot sand”, which is a producing sand, in the geologic report for well 2_236. According to this report, the 4500 foot sand is an Upper Pleistocene sand-package found with the *Trimosina A* fauna. In well 2_236, the top of the 4500 foot sand is at 5152 feet (1570 m) measured depth and the bottom is at 5430 feet (1655 m) measured depth.

Using public data and proprietary 3D seismic data I was able to map and investigate the producing 4500 foot sand channel-lobe in the Garden Banks 236 field. We feel that our approach in using 3D seismic data and public information obtained from Minerals Management Service’s web site is a user friendly, inexpensive and quick method of mapping and verifying depositional environments in producing fields. With recent advances in 3D seismic acquisition and processing, the cost of these data has decreased substantially and the availability has increased in the past few years (Posamentier 2003).

This method has also revealed a potential target to the northeast of the study area in block 193. As shown in Figure 1.5B, a thick channel-lobe sand body lies in an area which has not been tested by drilling activity. Future study could provide more definitive information on the extent and nature of this channel-lobe sand and could rank drilling targets simply by using the public data that is available and 3D seismic. We also feel that this method, if applied to a basin wide study, could at the very least reveal depositional environments if not new potential targets in the basin search.

This study also reveals a potential exploration/drilling target to the northeast of the study area in block 193. As shown in Figure 1.5B, a thick channel-lobe sand body in this area has not been tested by drilling activity. A future extension of this study in block 193 could provide more definitive information on the extent and nature of this channel-lobe sand body and could rank drilling targets.

**SECOND PAPER:
COMPREHENSIVE STUDY OF THE RESERVOIR SAND AND
DEPOSITIONAL SETTING OF GARDEN BANKS FIELD 236, NORTH
CENTRAL GULF OF MEXICO**

Abstract

Garden Banks Field 236, also known as Pimento Field, is part of the lower middle Pleistocene submarine-fan deposits in the Northern Gulf of Mexico.

Hydrocarbon exploration and production of these deposits has yielded one of the largest gas producing trends in the Gulf of Mexico continental shelf-slope break filling and spilling minibasins along the way. Channel complexes cut through these deposits as depositional systems migrate over the shelf-slope break to the basin floor.

Pimento Field is composed of seven Outer Continental Shelf blocks (OCS). We have data for six of these blocks. The study area encompasses 54 sq miles (140 sq km). Public domain data, downloaded from Minerals Management Service, and donated proprietary 3D seismic data were used to explore and map the depositional setting of the producing reservoir rock in the field. Additionally, the overall depositional setting of the field was investigated. Mapped horizons revealed overall structural elements of the field including fill and spill facies of the minibasin that directly influence the framework of the field. This study further investigates the reservoir sand in the field using side-wall core data, well log data, and seismic interpolations. The investigation indicates a channel- levee complex

along the edge of a minibasin. A potential exploration target that is located in block 193 was also identified and mapped. Though to this date we have no supportive data that it has been drilled, this target is a substantial bright spot.

Introduction

Objective of the study

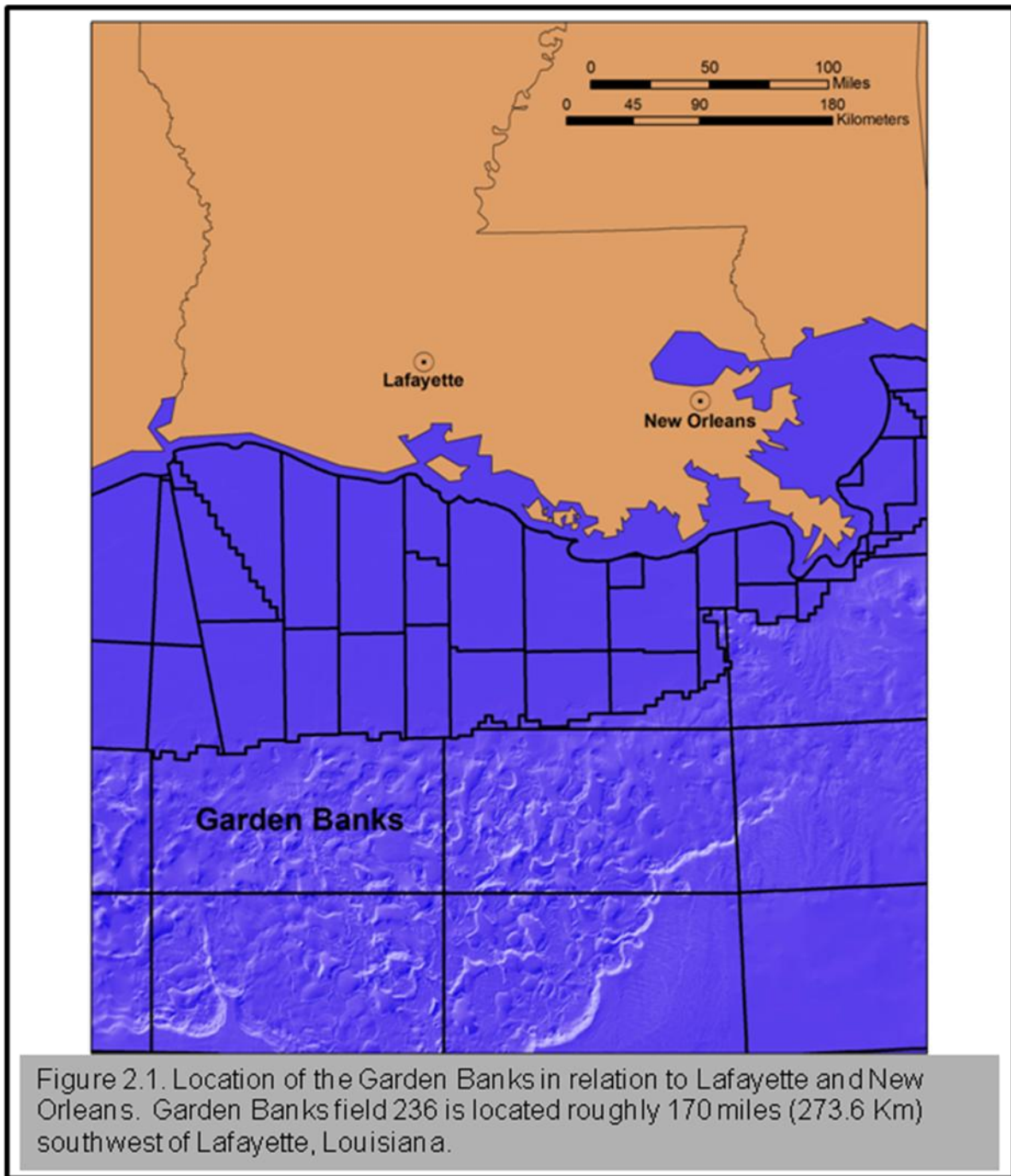
This study focuses on a single minibasin in the Gulf of Mexico slope break. Earlier studies, such as Galloway et al. (1998) and Prather et al. (1998), have focused on the slope break as a depositional system and how it fits into the hydrocarbon plays in the Gulf of Mexico. This study narrows that depositional system down to a single minibasin to investigate how that system influences the minibasin fill and spill.

The objective of this study is to develop a comprehensive interpolation of the 4500 ft. reservoir sand in the Garden Banks Field 236. By using 3 dimensional (3D) seismic data and well data, this study investigates the depositional setting of the 4500 ft. reservoir sand and the minibasin in the field.

The main focuses are to: 1) explore the depositional setting of the field, 2) map the 4500 ft. reservoir sand, 3) interpolate the depositional style of the 4500 ft. sand reservoir using seismic attributes and seismic interpolation techniques, 4) produce cross sections showing the 4500 ft. sand across the field, and 5) map a potential prospect in the field.

Location

The Garden Banks Field 236 is a proven gas play that is located roughly 170 miles (273 kilometers) southwest of Lafayette, Louisiana in the Garden Banks Area. The average water depth of the field is 700 feet (213 meters) (Figure 2.1). The Garden Banks Field 236 consists of seven blocks. This study covers six of those blocks which include: blocks 191, 192, 193, 235, 236, and 237 (Figure 2.2). Block 141 is excluded because it wasn't part of the donated 3-D seismic data. Each block in the field is nine square miles (24 square kilometers) for a total of 54 square miles (140 sq kilometers) include in the entire study area. The known hydrocarbon reservoir of this field is part of a lower middle Pleistocene progradational delta-fed apron sandstone deposit (Galloway et. al., 2000). The reservoir sand has the foraminiferal maker *Trimosina "A"* associated with it. According to the Minerals Management Service Biostratographic Chart (Whitrock et al., 2003) the sand is in the lower middle Pleistocene around 640,000 years B.P. (Figure 2.3).



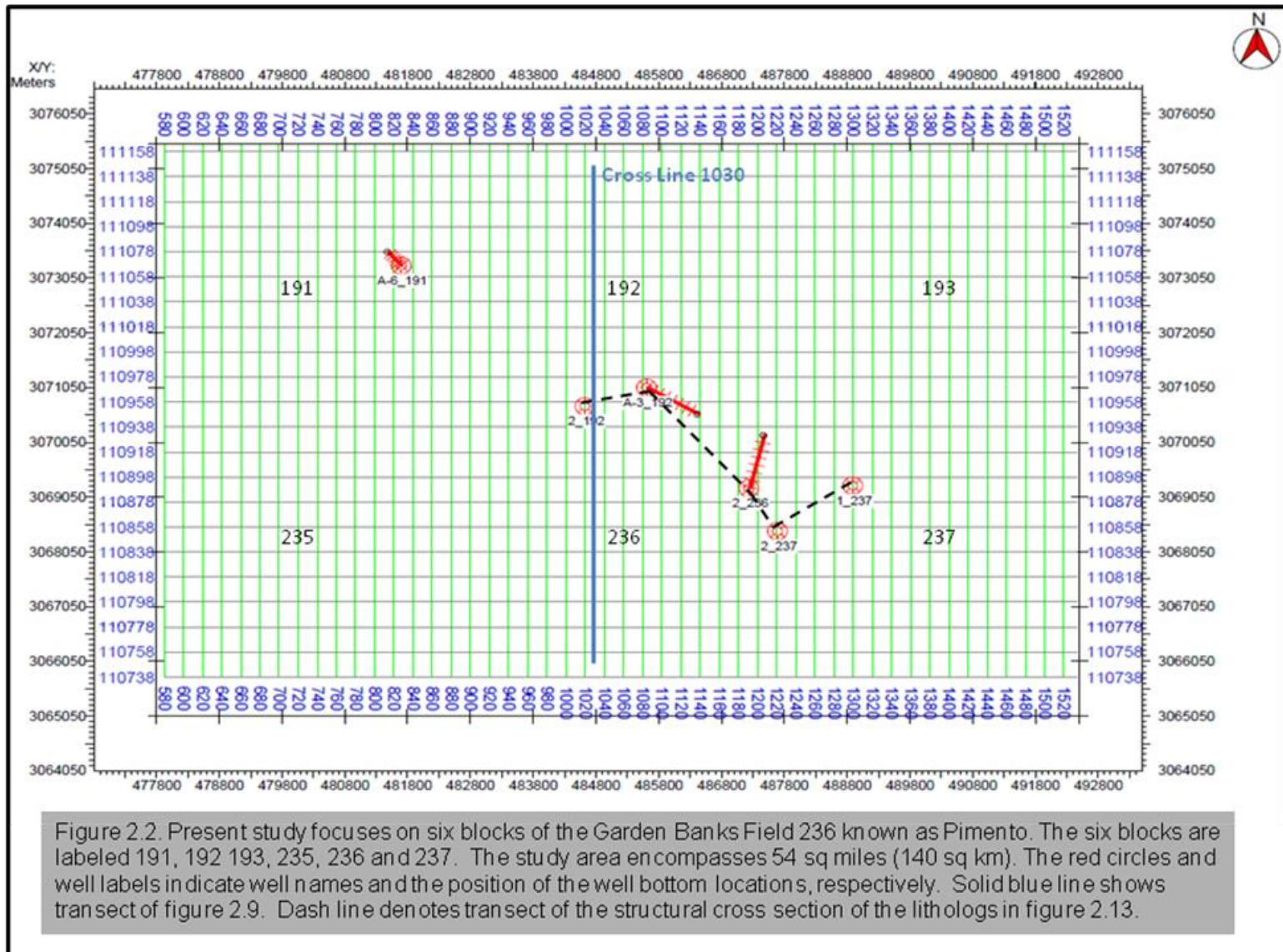


Figure 2.2. Present study focuses on six blocks of the Garden Banks Field 236 known as Pimento. The six blocks are labeled 191, 192, 193, 235, 236 and 237. The study area encompasses 54 sq miles (140 sq km). The red circles and well labels indicate well names and the position of the well bottom locations, respectively. Solid blue line shows transect of figure 2.9. Dash line denotes transect of the structural cross section of the lithologs in figure 2.13.

MMS

United States Interior Department
Minerals Management Service

Biostratigraphic Chart of the Gulf of Mexico Offshore Region, Jurassic to Quaternary

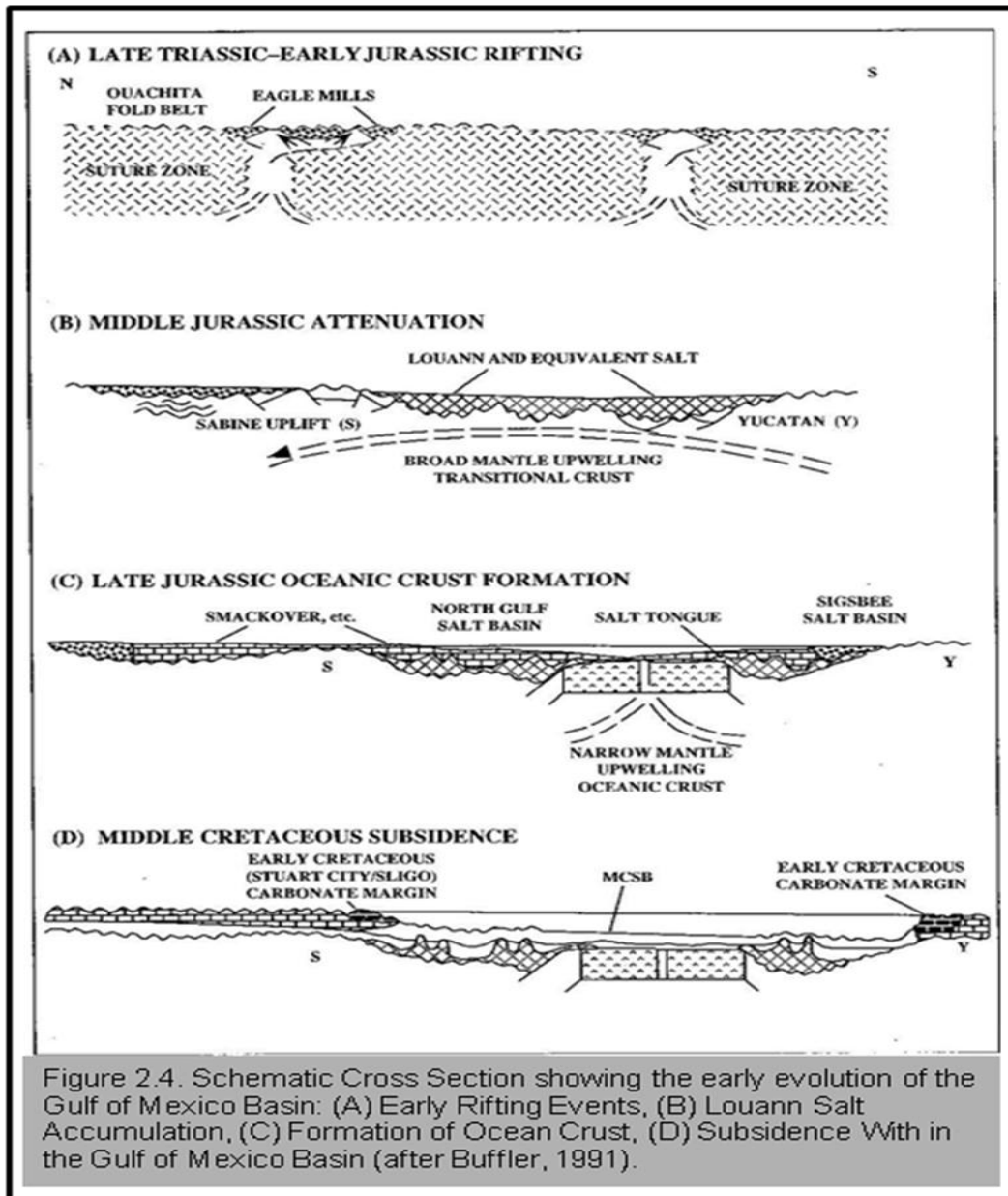


Time (mya) (not to scale)	CHRONOSTRATIGRAPHY				BIOSTRATIGRAPHY		MMS CHRONOZONE		
	System	Subsystem	Series	Stage	Foraminiferal planktic and benthic regional and local markers	Calcareous nannoplanktic regional and local markers	Proposed	Current	
	Q u a t e r n a r y		Holocene		Globorotalia inflata				
			P l e i s t o c e n e	M i d d l e	U p p e r	Globorotalia flexuosa	Emiliana huxleyi (base of acme) Pontosphaera indoceanica Gephyrocapsa oceanica flood Gephyrocapsa caribbeanica flood	P L U	U p p e r
-0.20						Globorotalia truncatulinoides coiling change, right-to-left	Helicosphaera inversa Pseudoemiliana lacunosa "A" Pseudoemiliana lacunosa "B" Gephyrocapsa caribbeanica increase Gephyrocapsa omega Gephyrocapsa parallela Pseudoemiliana ovata		
			P l e i s t o c e n e	L o w e r	C a l l a b r i a n	Trimosina "A"		P L L	P l l o w e r
-0.78						Stilostomella antillea Globorotalia incisa Sphaeroidinella dehiscens acme "A"	Pseudoemiliana lacunosa "C" acme Gephyrocapsa aperta acme Scyphosphaera pulcherima, Gephyrocapsa sp. (large variety)		
	Trimosina "A" acme Angulogerina magna Hyalinea balthica / Trimosina "B" Globorotalia tosaensis tosaensis								
-1.77	Sphaeroidinella dehiscens acme "B" Angulogerina "B" Uvigerina hispida	Helicosphaera sellii Lithostromation perdurum Calcidiscus macintyreii							

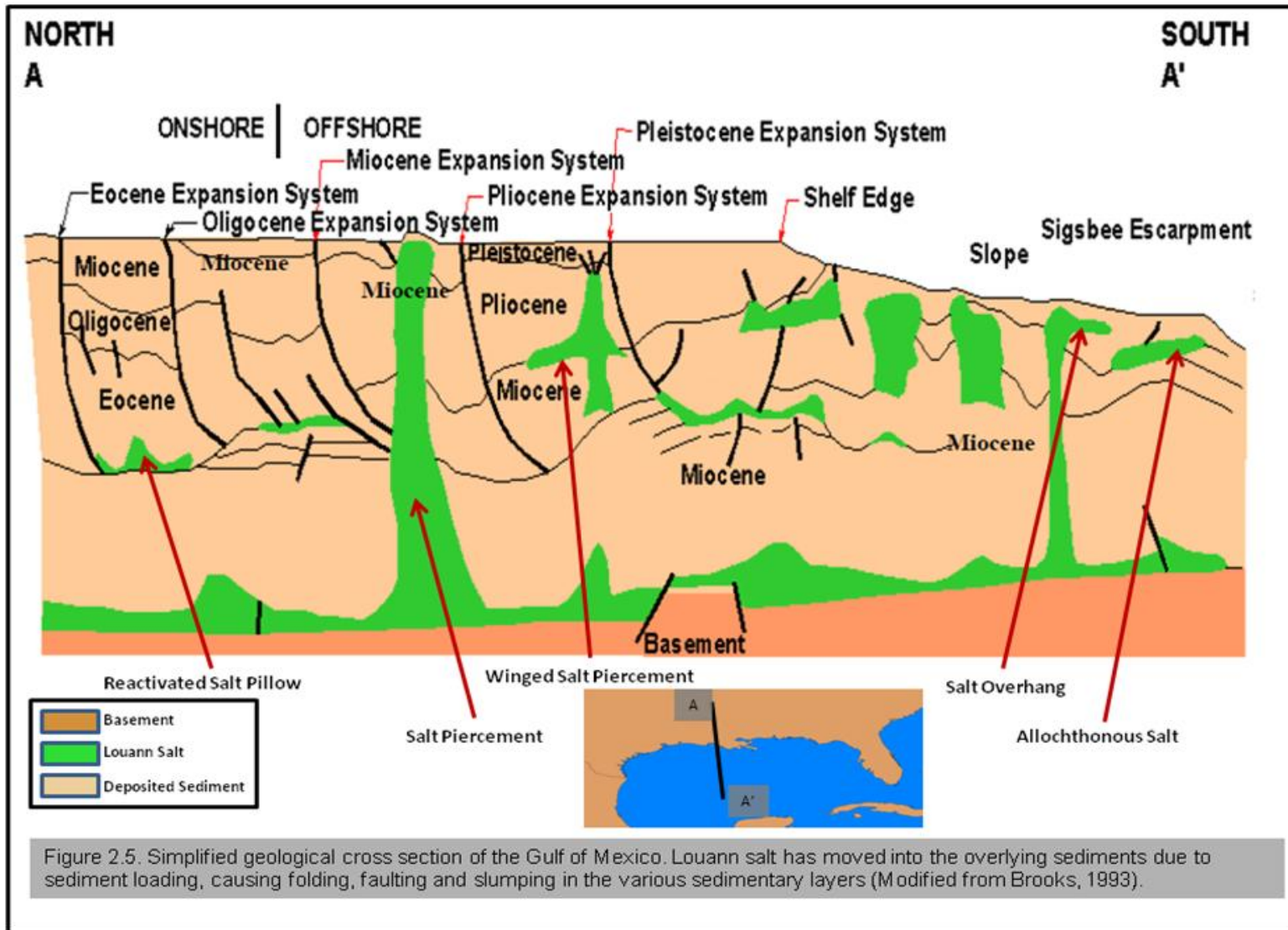
Figure 2.3. Biostratigraphic Chart published by the Minerals Management Service in 2003. The new chronozone is Lower Middle Pleistocene for Trimosina "A". The older chronozone placed this in the Upper Pleistocene. (After Witrock et al., 2003)

Geology of the Gulf of Mexico

Currently the Northern Gulf of Mexico is a passive margin basin. Formation of this basin is a result of two rifting events. One occurred in the Late Triassic and the other in the Middle Jurassic (Buffler, 1991, Figure 2.4).



During the Middle Jurassic rifting episode, deposition of the Callovian (Louann) salt took place across the basin. When remobilized later, due to the overburden pressure of thick Cenozoic strata, this Louann salt played a critical role in the maturation, migration, and entrapment of hydrocarbons in the northern Gulf of Mexico (Weimer, 1998). This remobilization caused salt-withdrawal which formed intraslope minibasins within large salt massifs that were emplaced into the upper to middle slope during the Oligocene and Miocene (Diegel et al., 1995). Figure 2.5 illustrates the movement of the Louann Salt through younger strata that caused deformational features such as folding, faulting and slumping.

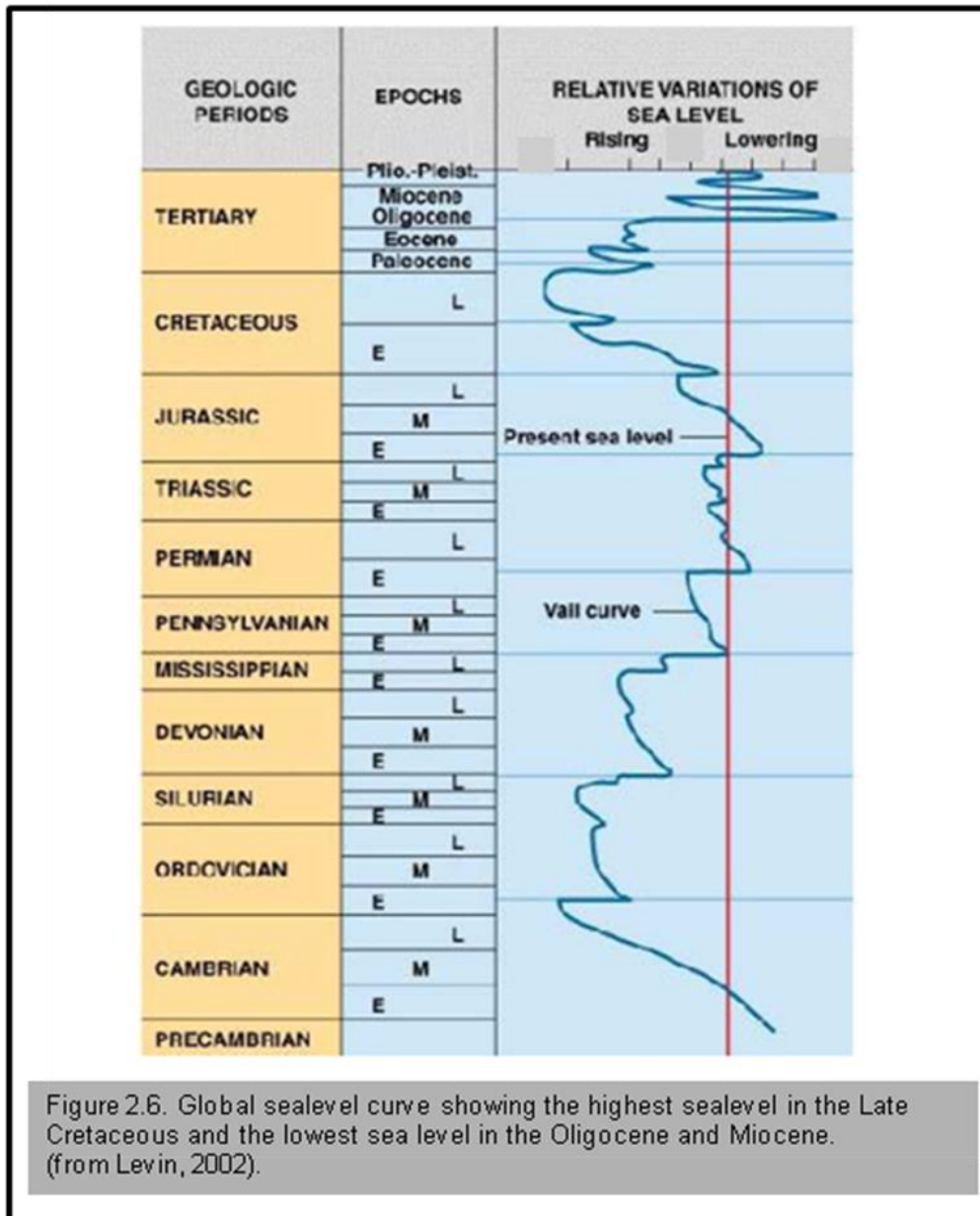


Cenozoic

By early Cenozoic, regionally-extensive continental to shallow water siliciclastic depocenters developed in the northwestern Gulf Basin (Weimer, 1998; Martin, 1978). During the Cenozoic a relatively low sea level enhanced the amount of material removed from the continent and inner shelf by river erosion. The sediments deposited during this time have formed important reservoirs in both offshore and onshore basins. During the Miocene the depocenters switched in such a way that central North America was draining through Louisiana into the north central Gulf of Mexico. In the Miocene the northern Gulf of Mexico experienced transgression and regression, intense structural and diapiric activity, and shifting depocenters. These variables have all contributed to an extensive Miocene aged sediment body under the continental shelf of the Gulf of Mexico (Galloway et al., 1991).

Plio-Pleistocene

The Plio-Pleistocene was a period of eustatic sea-level fluctuations due to the Northern Hemisphere glacial cycles (Figure 2.6).



It is widely believed that these glacial cycles began in the Pliocene with the Nebraskan 3.45 million years ago (Ma). This period was then followed by the Kansan 2.42 (Ma), Illinoian 0.61 (Ma), and the Wisconsinian 0.19 (Ma). Less significant glacial cycles have also been recorded within these intervals as well. These include the Yarmouthian 2.14 (Ma), Sangamonian 0.48 (Ma), and the

Peorian 0.12 (Ma) (Prather et al. 1998). These glacial cycles generated eight depositional cycles in the Gulf of Mexico Basin (Berggren, 1972; Shackleton and Opdyke, 1977; Beard et al., 1982; Prather et al. 1998).

The coeval bathyal sediments were deposited in a series of minibasins on top of and between allochthonous salt bodies. Structural hydrocarbon traps have formed due to salt tectonics. Studies show that continuous diapirism cannot occur in a tectonically passive environment until the sediment immediately above the salt has a density that is greater than the density of salt (Nelson, 1989). This salt is common in the northern deepwater Gulf subprovince and forms many of the hydrocarbon reservoirs (Weimer, 1998; Weimer et al., 1994).

Delta lobes and interdeltic facies developed rapidly beyond the exposed continental shelf during the eight depositional cycles. As sediment supply increased, progradation was enhanced across the continental shelf to the slope. This influx of sediment was increased from previously northward flowing rivers in the Great Plains and eastern United States. Continental ice sheets caused the rivers to become dammed, which triggered the rivers to switch their flow to the Mississippi River drainage Basin (Bluemle, 1972; Teller, 1973; Swadley, 1980; Bloom, 1991; Prather et al., 1998). During low stand sea levels, the incised valleys of the ancient Mississippi River and small coastal rivers provided routes to the deepwater intraslope basin (Suter and Berryhill, 1985; Steffens, 1986, 1993; Winker, 1993;

Prather et al., 1998). Additional sediments were introduced to the intraslope basins from mass wasting events on the upper continental slope (Woodbury et al., 1976; Booth, 1979; Colman et al., 1983; Prather et al., 1998).

Interglacial periods allowed for sediment influxes as melt waters made their way through the drainage basins to the continental shelf and shelf slope. This occurrence was especially prevalent early in the interglacial phases (Perlmütter, 1985; Steffens, 1986; Kolla and Perlmütter, 1993; Prather et al., 1998). Eustatic low stands and initial high stands caused sediments to fill interslope basins and move in a southerly direction (Prather et al. 1998). Salt domes and diapirs also provided excellent traps during the same time as they pierced through the layers of strata.

As sea levels rose southward flowing rivers in the drainage basins became dammed causing these tributaries to flow in a northward direction (Teller, 1973; Prather et al. 1998). This event decreased the amount of sediment load in the distributaries. The decrease in the amount of sediment led to the deposition of clay rich shale and marls on the slope and basin floor (Prather et al. 1998).

At the beginning of the Pleistocene, the Mississippi River permanently captured the Ohio River and Upper Missouri River (Swadley, 1980; Prather et al., 1998). Permanent capture of the Missouri River system is believed to have occurred in the late Yarmouthian glaciations (Prather et al., 1998). These glacial

cycles and the capturing of these river systems have been the main mechanisms for sediment deposition in the Gulf of Mexico.

Plio-Pleistocene Submarine Fan

A major depositional feature during the Plio-Pleistocene in the Central Gulf of Mexico includes submarine fan deposits. Garden Banks field 236 is part of an extensive submarine fan complex. This fan sandstone is part of eleven discontinuous groups of proven fields ranging from the Ewing Banks in the west to the South Timbilier area in the east (Heinz, 1995). River fed delta fans prograded out onto the continental shelf. As the system moved across the shelf sediment was then deposited on the slope. This sediment was deposited in low areas dominated by salt domes and salt diapirs (Figure 2.7). The down-dip limits between the paleo shelf-break salt features were filled with predominantly fan-lobe, channel-fill, levee deposits and fringe sheet sands (Heinz, 1995). These sandstones can range from a few meters to more than a hundred meters thick. Overlapping fan-lobe deposits can be more than 1000 feet thick in some areas (Heinz, 1995).

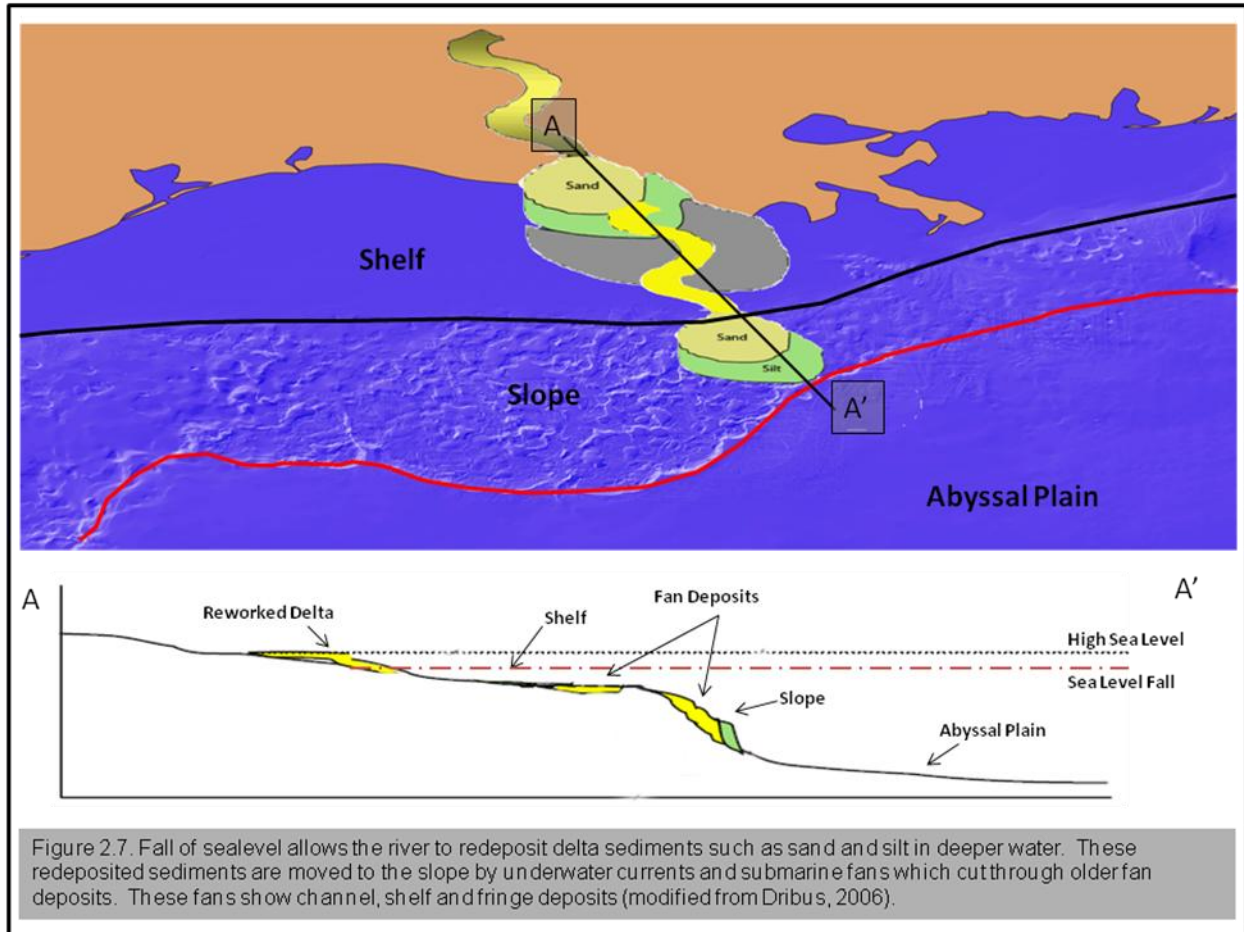
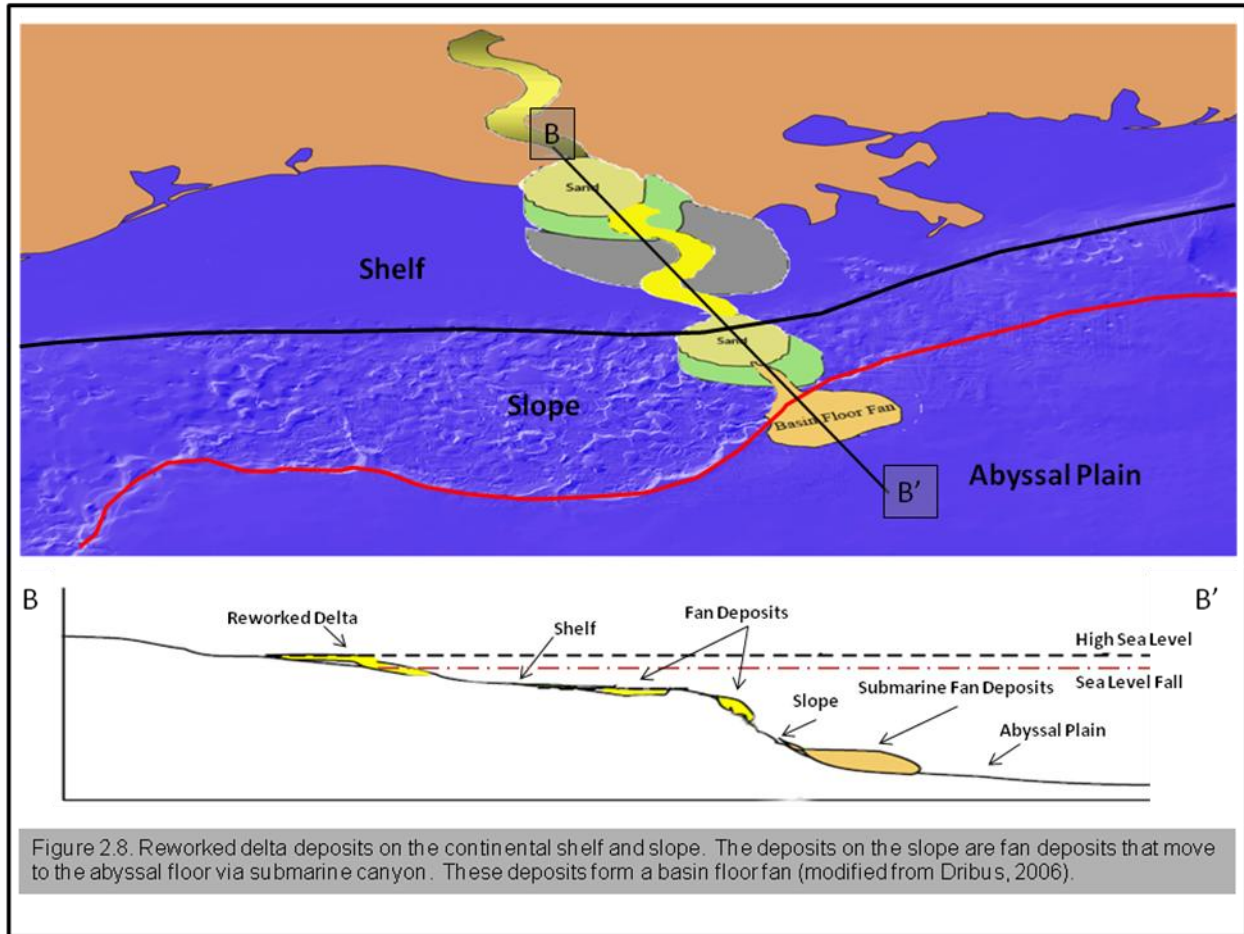


Figure 2.7. Fall of sealevel allows the river to redeposit delta sediments such as sand and silt in deeper water. These redeposited sediments are moved to the slope by underwater currents and submarine fans which cut through older fan deposits. These fans show channel, shelf and fringe deposits (modified from Dribus, 2006).

Sand bodies deposited on the shelf and slope were eroded through submarine canyons during low sea levels, and redeposited on the basin floor (Figure 2.8). As sediments continued to build on the slope, mass wasting events and channel formations took place on the slope. These sediment gravity flows slide down the slope to the basin floor. These events are common on the flanks of submarine canyons and can resemble submarine fans.



Bryant Submarine Canyon

The Bryant Submarine Canyon is a Pleistocene aged canyon that is located in the southern reaches of the Garden Banks Area. This canyon cuts across the once delta-fed Central Gulf Apron (Galloway et al., 2000). Canyons during the Pleistocene show evidence of extending as much as 100 miles (160 Km) landward from the shelf edge (Galloway et al., 2000). The continental margin provided deltaic and coastal plain deposits to these large canyons. The Bryant Fan is a point source fan featuring channel, overbank, and sediment gravity flow deposits in channel-lobe facies (Saucier, 1994).

Dataset and Methodology

The dataset used in this study was a combination of public and proprietary data. The public data was acquired from Minerals Management Service's (MMS) website. MMS's data consists of wireline logs (gamma, resistivity and conductivity), check-shot velocity surveys, directional surveys, geology reports, side-wall core descriptions, some biostratigraphic reports, and well activity reports. The proprietary 3D seismic data was provided by Diamond Service Corporation. The seismic data covers the entire six blocks in the study area. The data acquisition parameters are as follows: Acquisition bin: 25 ft x 150 ft (8 m x 46 m); Record length: 9.6 seconds; Nominal fold: 34; and Frequency: 23 Hertz.

This study used six wells, spread throughout the six blocks, to investigate the 4500 ft. sand. All wells had wireline logs, velocity data, geologic reports including sand interval tops and bottoms, and all but one had side-wall core data. The six wells include: A-6_191, 2_192, A-3_192, 2_236, 2_237, and 1_237. The first number represents the well name and the second number is the block it is located in. These wells are spread throughout the six blocks to display the overall trend of the 4500 ft. sand. Cross sections were made connecting all six of the wells to show the trend of the 4500 ft. sand.

The 3D Seismic and well data were loaded into the seismic interpretation software package KINGDOM Suit 8.2. Several horizons were mapped and

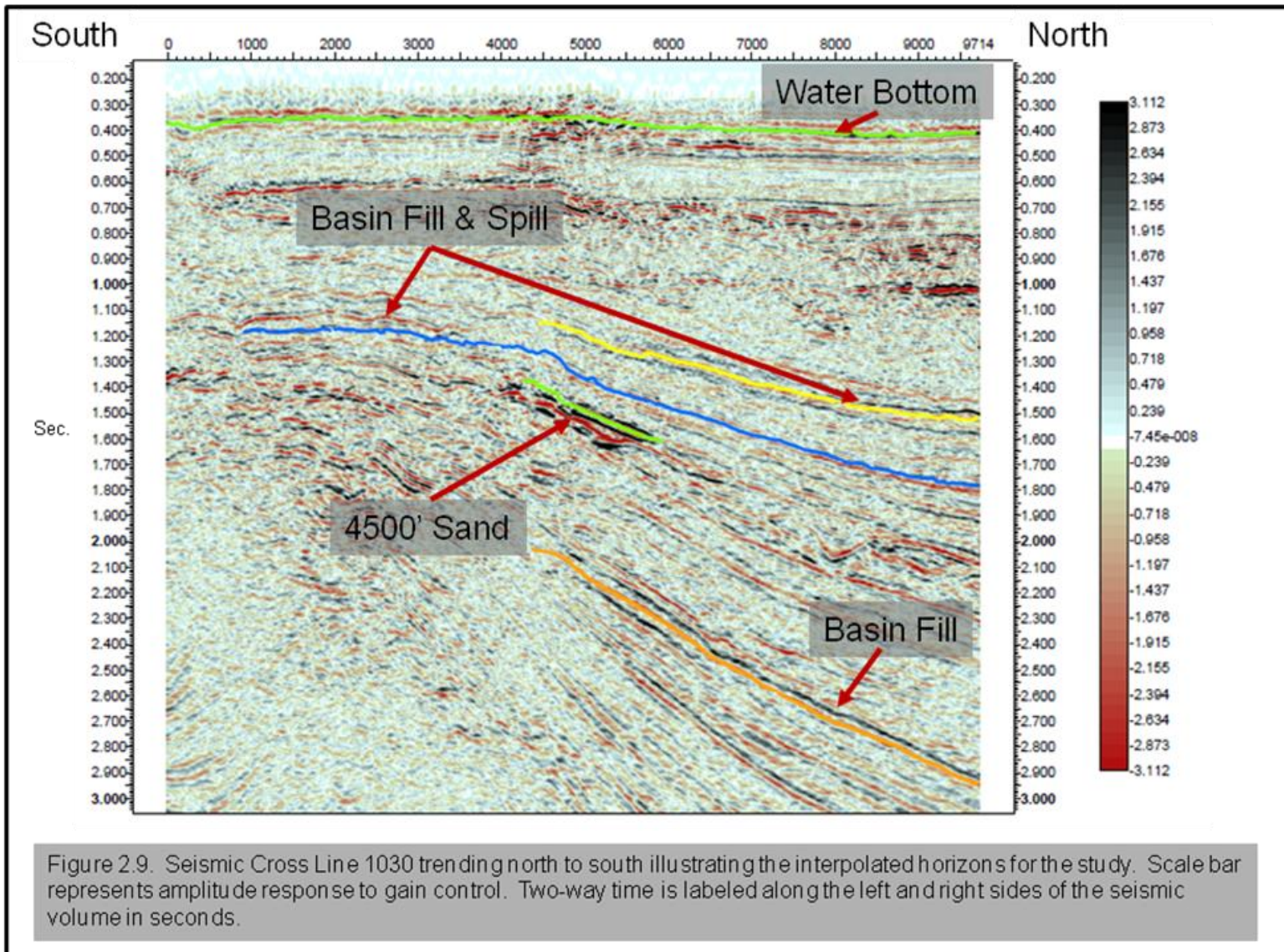
associated time, depth and amplitude maps. For potential prospect identification both amplitude and isopach maps were produced. Well logs were correlated to seismic and side wall core data. Velocity surveys were used to place accurate depths within the seismic allowing for placement of wells and side core lithologs. These velocity surveys also allowed us to place formation top-markers and bottom-markers. Paleogeomorphic features were identified by using seismic geomorphology techniques.

The seismic technique of flattening was used to pull out the geomorphology of the reservoir sand. Using the mapped 4500 ft. sand horizon we flattened the entire 3D volume down to 3 seconds. The volume was then displayed in the base map and a cross-line was taken through the flattened seismic volume. A time slice was taken at 27 milli-seconds above the flattened horizon, revealing the geomorphology. The flattened volume was also loaded into the 3D viewer called Vue-PAK. The viewer gave us the ability to pan through the flatten volume showing the channel's path around the minibasin.

Results

Multiple horizons were picked in the 3D seismic data representing different depositional phases (Figure 2.9). The top horizon is the water bottom and the lowest horizon is part of the minibasin sediment. Additional horizons include the basin spill point, and the 4500 ft. reservoir sand. The salt dome and diapirs were

also mapped to show the structure of the basin and depositional trends in the basin. These salt features form the western and southern boundaries of the minibasin's structure and have a direct impact on the deposition in the minibasin (Figure 2.10). The thickest deposits are in the center of the basin and the thinnest deposits are around the edges of the basin. The mapped spill point for the basin is situated between the two salt diapirs. Seismic time slices and the spill horizon show the migration of the sheet sands between the salt diapirs (Figure 2.11). The initial spill begins at 3.316 seconds or 10,714 ft. (3,265 m) true vertical depth. The spill ends around 1.1 seconds or 3,554 ft. (1,083 m) true vertical depth. Above this depth the sediment moved through the area continuously with no constraints.



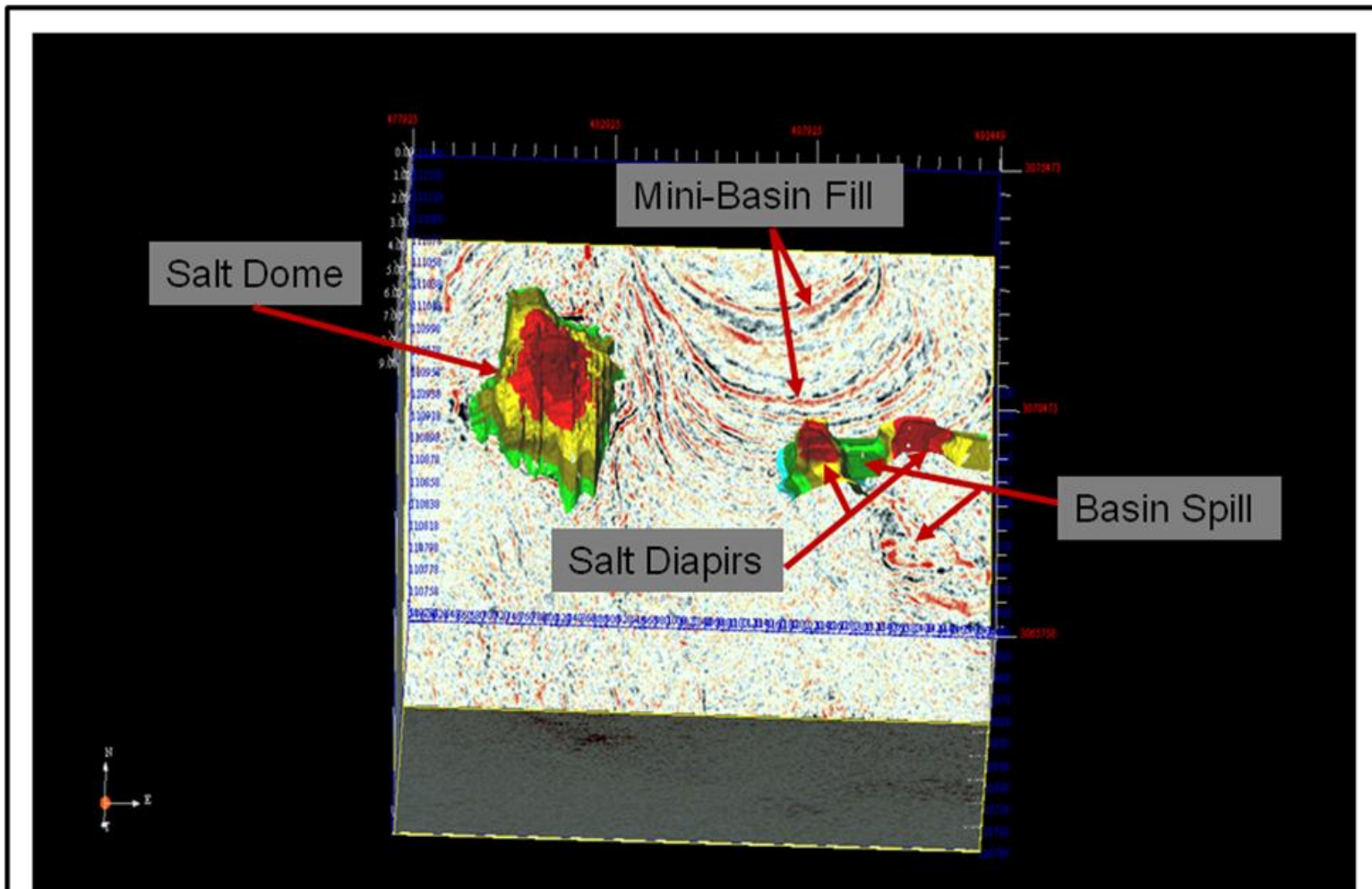


Figure 2.10. 3D volume displaying the 3.2 second time slice. The salt dome to the west and the salt diapirs in the south are shown to have direct influence over the deposition of the sediment in the area. This is evident by the identification of the basin spill point.

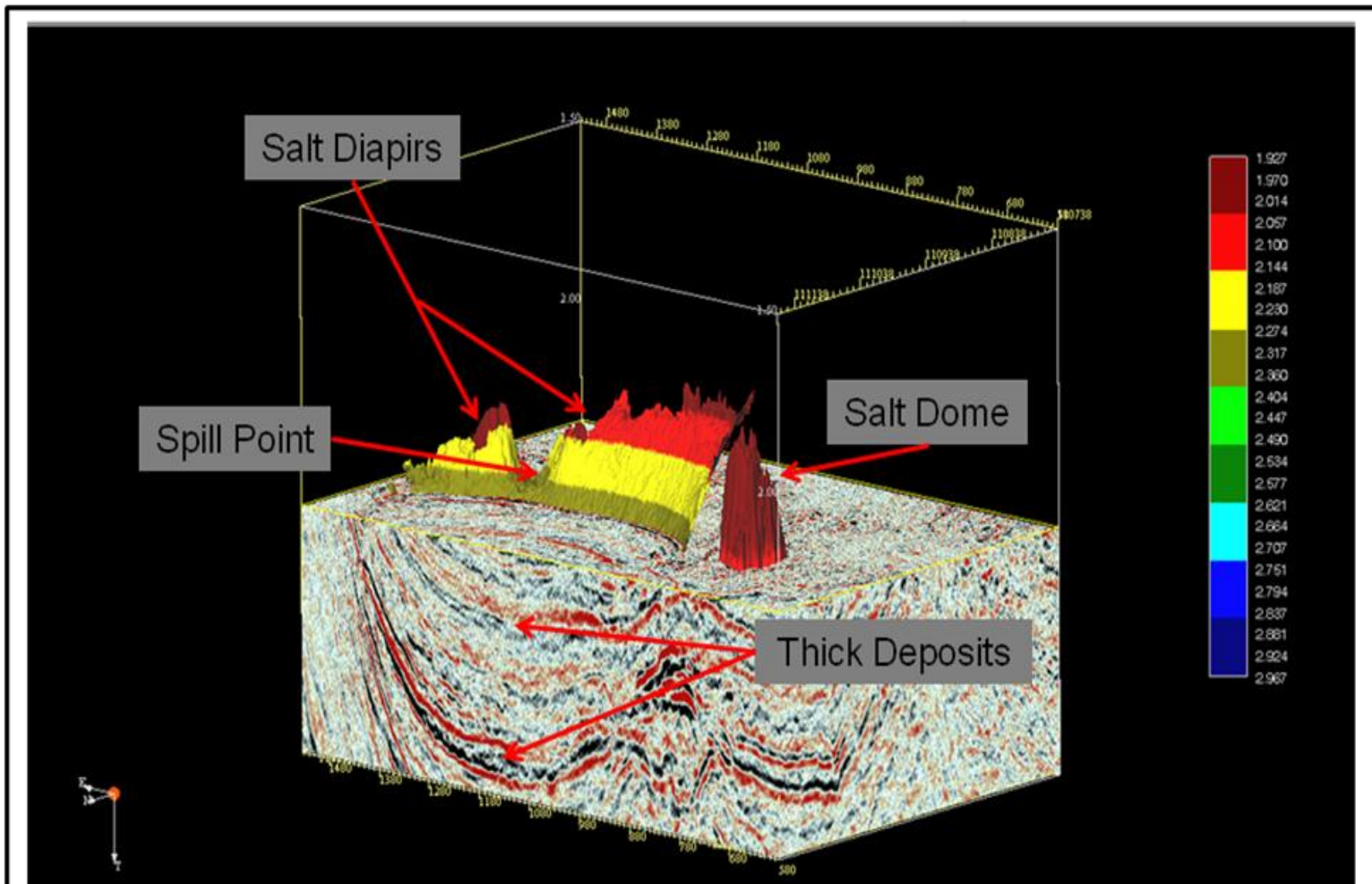


Figure 2.11. 3D volume displaying the salt dome and two salt diapirs. The basin spill point lies between the two salt diapirs. The scale on the right indicates the two-way time in seconds of the sediment spilling between the salt. The numbers in yellow denote the in-lines and cross-lines.

The 4500 ft. sand was mapped for the entire study area. The sand is found in all of the studied blocks trending from northwest to southeast. The thickest portion of the studied 4500 ft. sand is found in block 191 above the salt dome. The sand found in well A-6_191 has a gross sand interval of more than 700 ft. (213 m) thick. The thinnest gross sand interval is found in well 2_192 to the southeast of well A-6_191. The sand in 2_192 has a gross sand thickness of 107 ft. (32 m). An amplitude map shows the distribution of high amplitudes throughout the picked interval (Figure 2.12). These high amplitudes represent potential hydrocarbon accumulations, especially related to gas sands.

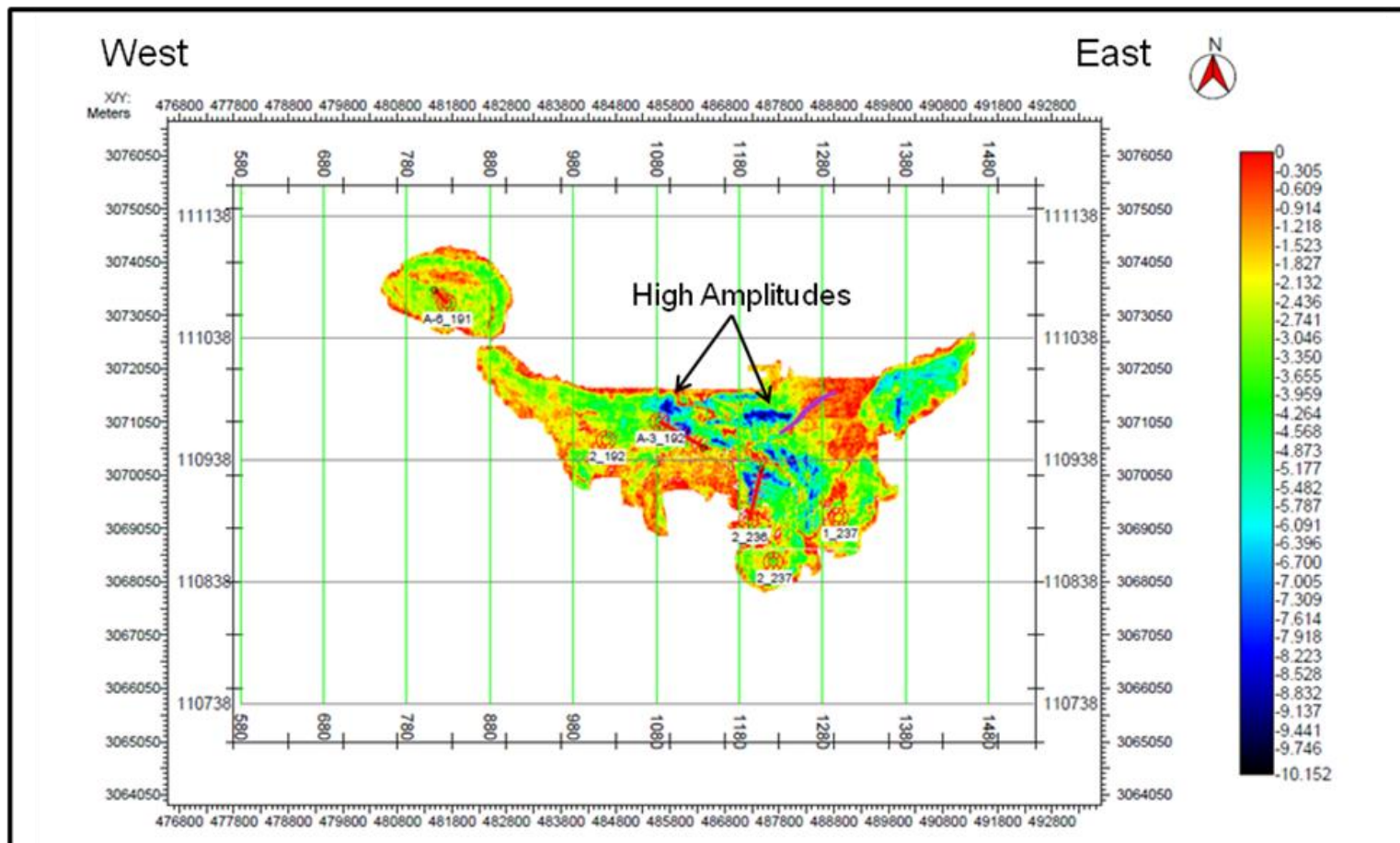


Figure 2.12. Amplitude map of the 4500 ft. sand. The dark blue represents high negative amplitude and the red represents a low negative amplitude. High negative amplitudes are associated with hydrocarbon sands. The blue and green amplitudes also indicate sand deposits. The red and yellow amplitudes indicate shale deposits.

Six wells, which penetrated the 4500 ft. sand reservoir, were used to further investigate the sandbody distribution. Sand-shale lithologs were created for five wells using side-core descriptions available for those wells. These sand-shale lithologs show a general correlation to the gamma logs when matched to the formation tops for each well. The lithologs were hung in a structural cross section for the five wells with side-core data. The blue lines in each of the wells denote the top of the 4500 ft. sand and the gold line below denotes the bottom of the sand (Figure 2.13). A stratigraphic cross section was produced for all six wells by flattening on the 4500 ft. sand top. The correlated gamma and resistivity logs show thickening and thinning trends of the section, possibly linked to the change in accommodation from a migrating salt dome and diapirs (Figure 2.14). In addition, a structural cross section was made for the six wells, showing the correlation between the seismic, gamma, and resistivity logs (Figure 2.15).

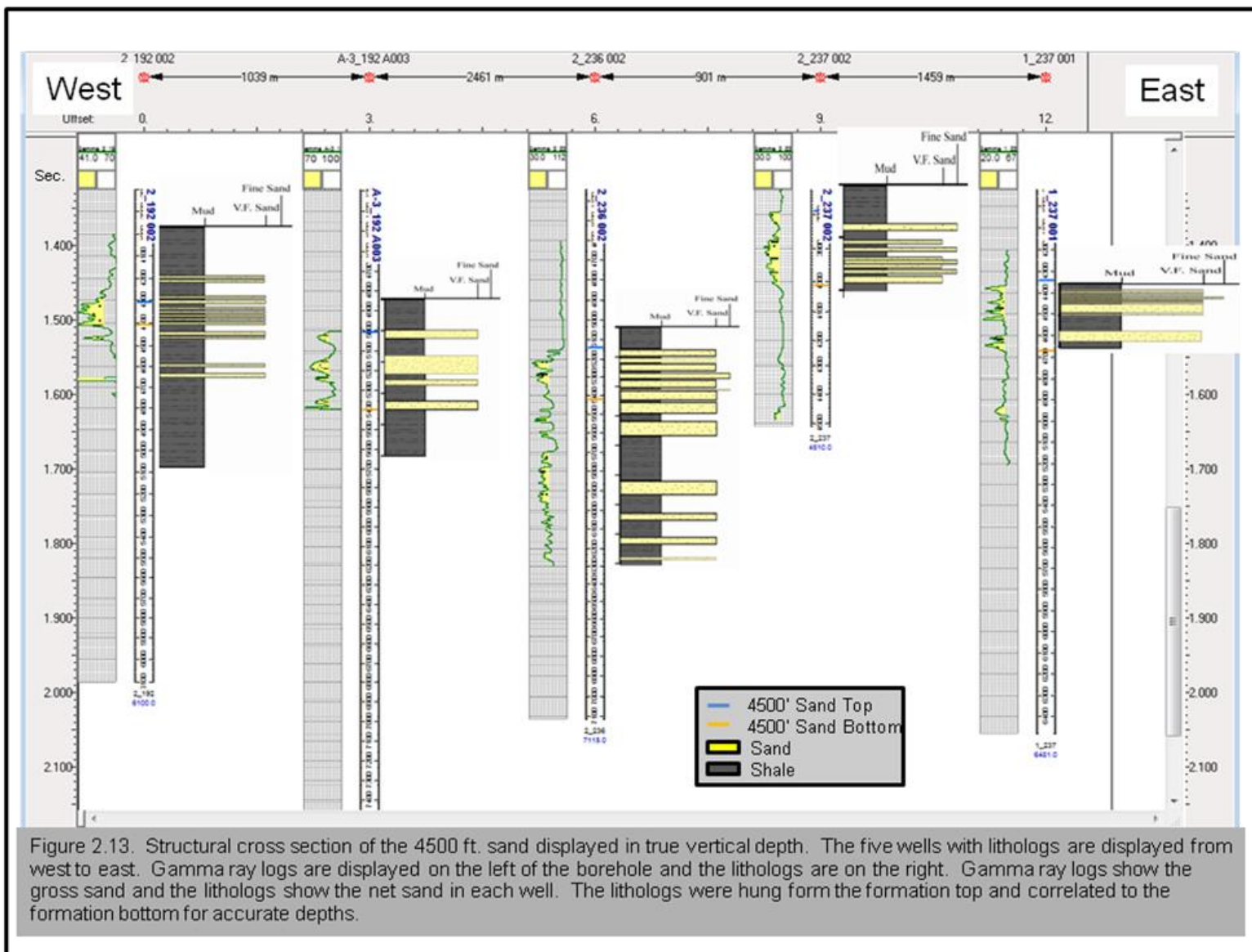


Figure 2.13. Structural cross section of the 4500 ft. sand displayed in true vertical depth. The five wells with lithologs are displayed from west to east. Gamma ray logs are displayed on the left of the borehole and the lithologs are on the right. Gamma ray logs show the gross sand and the lithologs show the net sand in each well. The lithologs were hung from the formation top and correlated to the formation bottom for accurate depths.

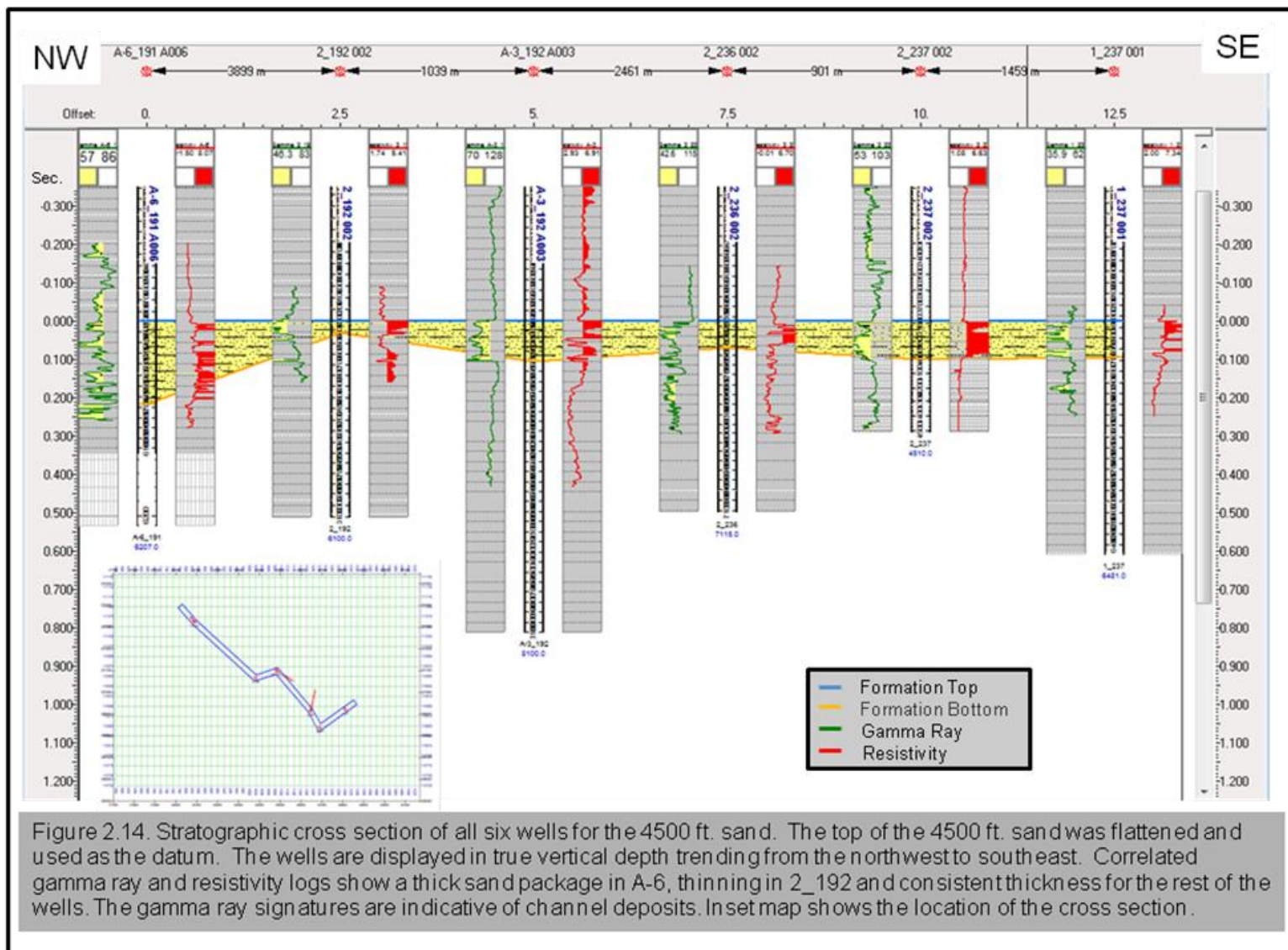


Figure 2.14. Stratigraphic cross section of all six wells for the 4500 ft. sand. The top of the 4500 ft. sand was flattened and used as the datum. The wells are displayed in true vertical depth trending from the northwest to southeast. Correlated gamma ray and resistivity logs show a thick sand package in A-6, thinning in 2_192 and consistent thickness for the rest of the wells. The gamma ray signatures are indicative of channel deposits. Inset map shows the location of the cross section.

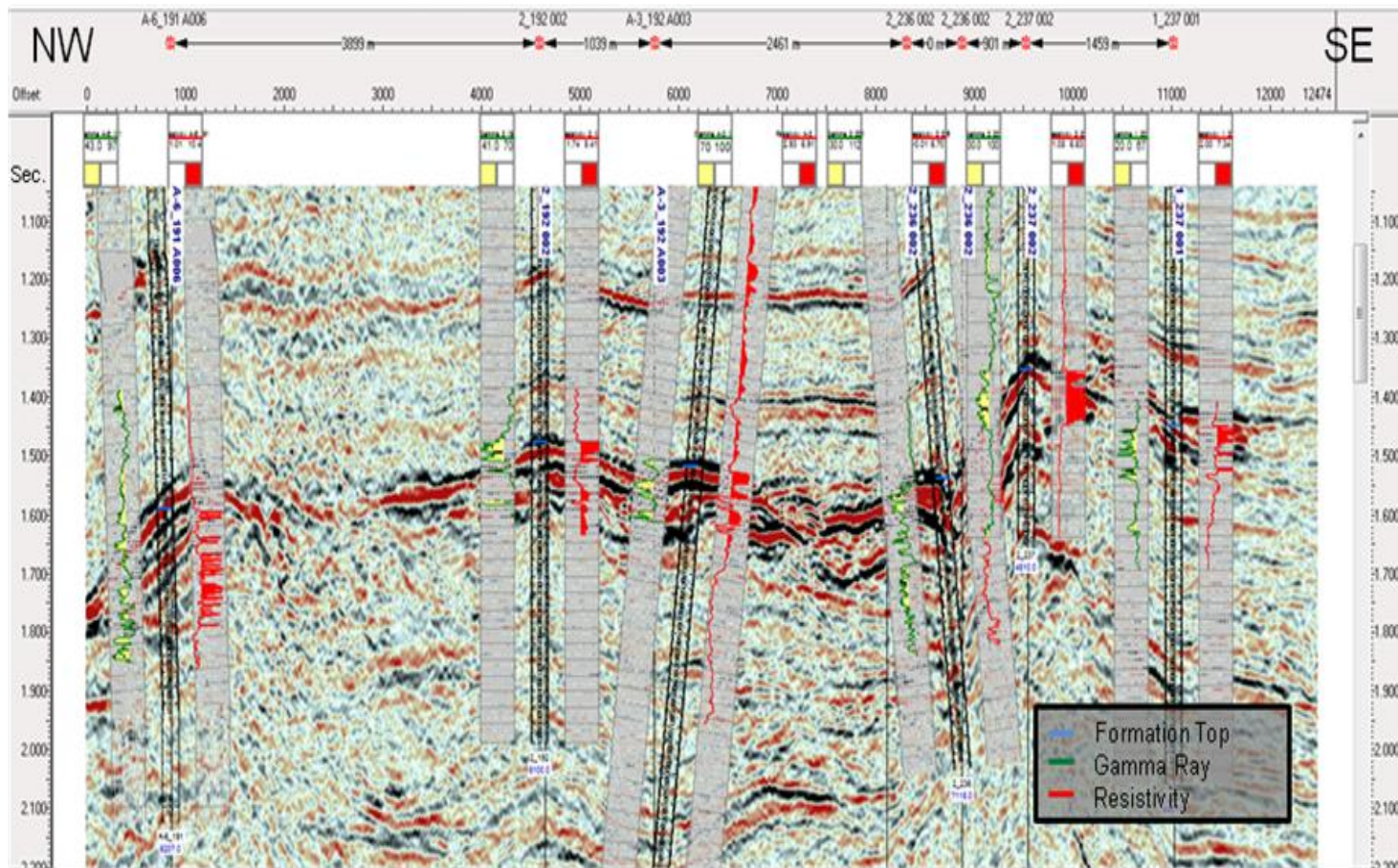
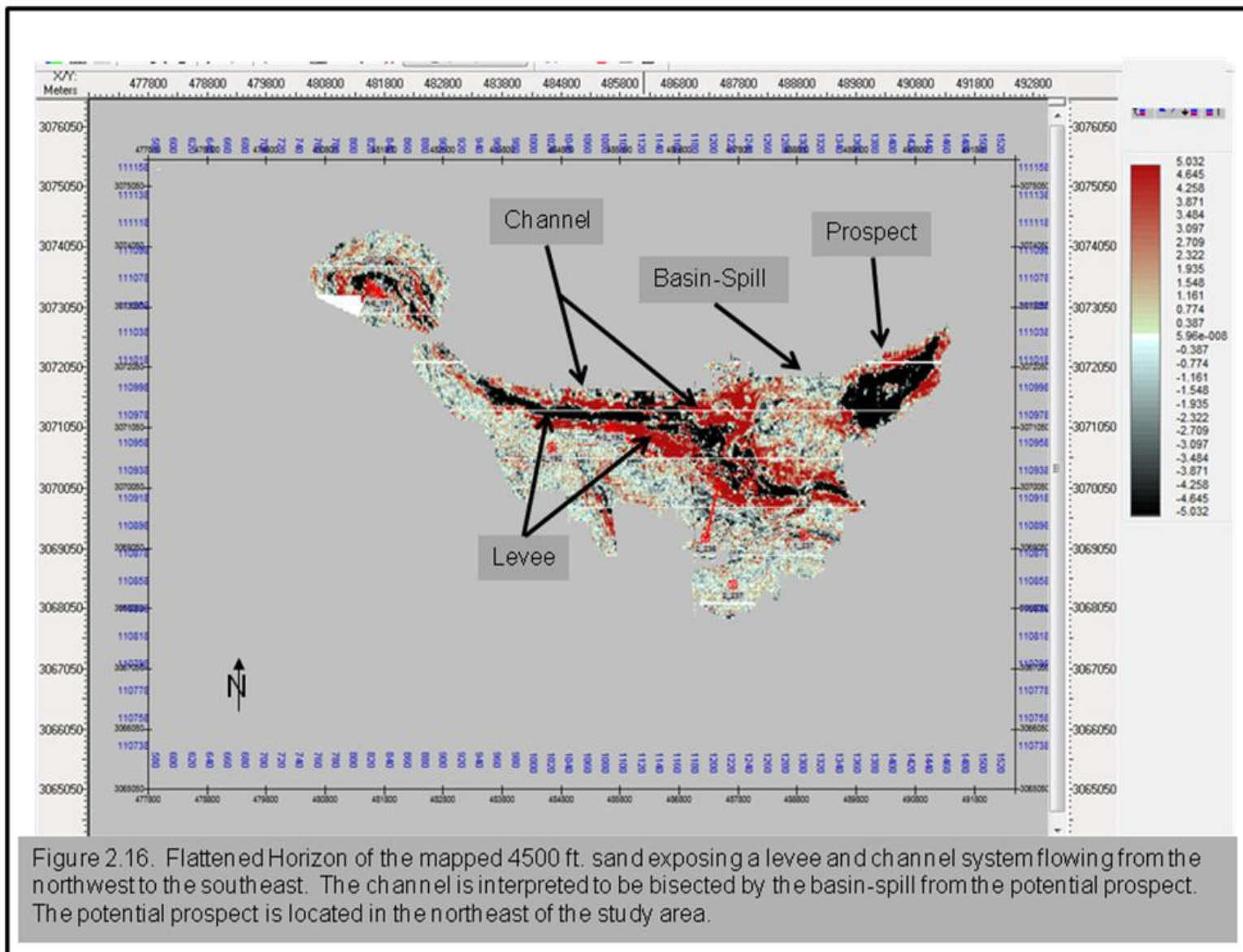


Figure 2.15. Structural cross section of the 4500 ft. sand displayed within the 3D seismic volume. An arbitrary line was drawn through each well from northwest to southeast. Well tops and bottoms were taken from geologic reports and entered into the KINGDOM Suite.

In the Garden Banks 236 Field, O'Brien et al. (2009) documented a meandering to straight channel with crevasse splays at the sides and an attached lobe at the end. Our investigation of the gamma ray logs indicate stacked channel and levee deposits among the six wells. To correlate this in seismic data, the 4500 ft. sand horizon was flattened and displayed in a time slice revealing a channel complex (Figure 2.16). The channel is interpreted as a levee-channel system that was flowing from the northwest to southeast. The channel followed the edge of the minibasin and turns southward. The basin-spill is cutting through the 4500 ft deposit separating it from a potential prospect to the northeast.



A potential prospect was identified in the 193 block to the northeast. All of the data used in this study supports that this area has not been drilled. Isopach, amplitude, and structure maps were generated for the prospect. The prospect is a bright spot located on the up thrown side of a fault to the east of the 4500 ft. sand (Figure 2.17). This prospect, with very high amplitudes toward the south, is interpreted to be part of the 4500 ft. sand to the west separated by the basin-spill (Figure 2.18).

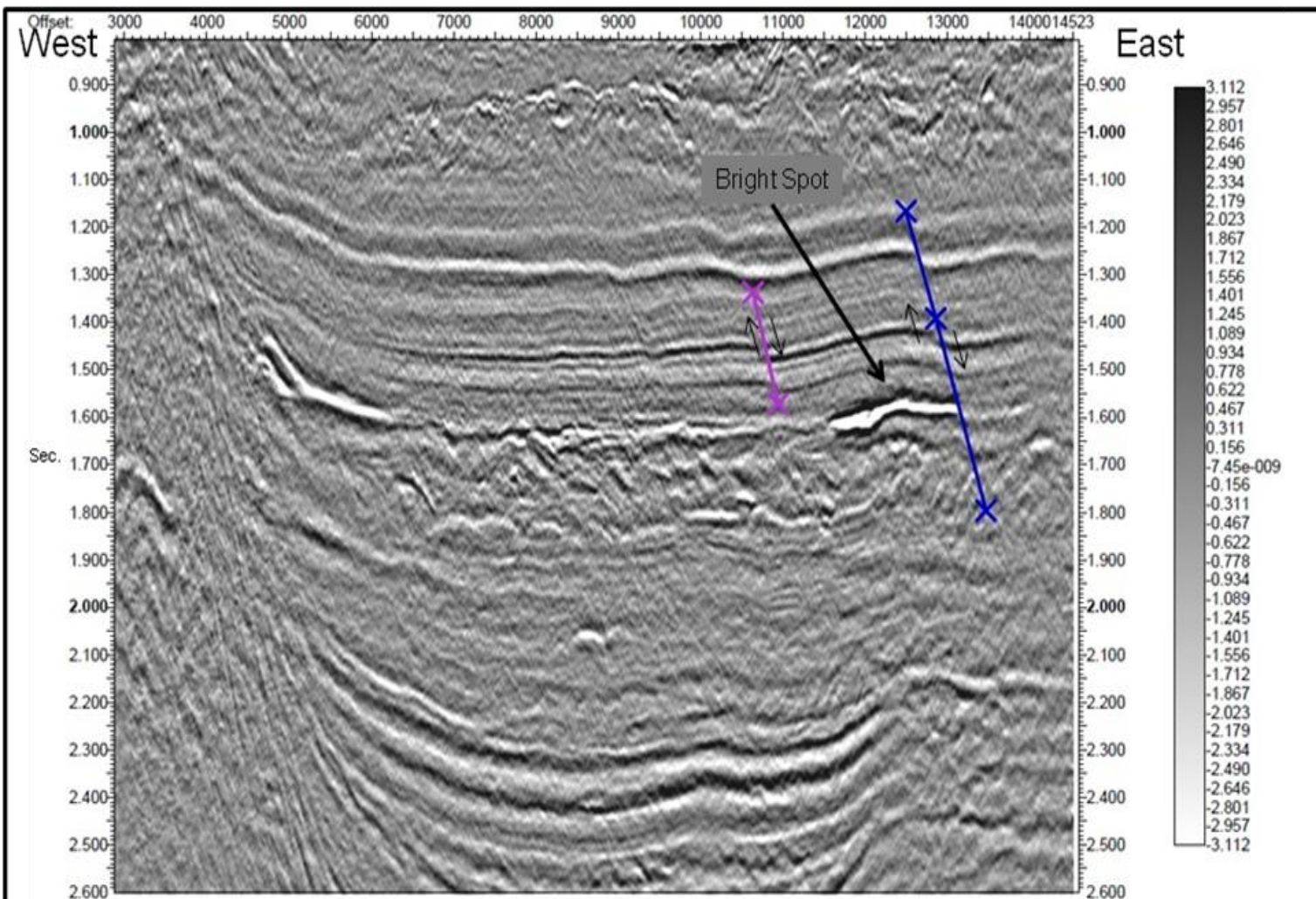


Figure 2.17. Inline 110997 running east to west displaying the bright spot and associated normal faults that were investigated as a potential prospect. The bright spot is between the 1.5 second and 1.7 second time interval which is the same as the 4500 ft. sand

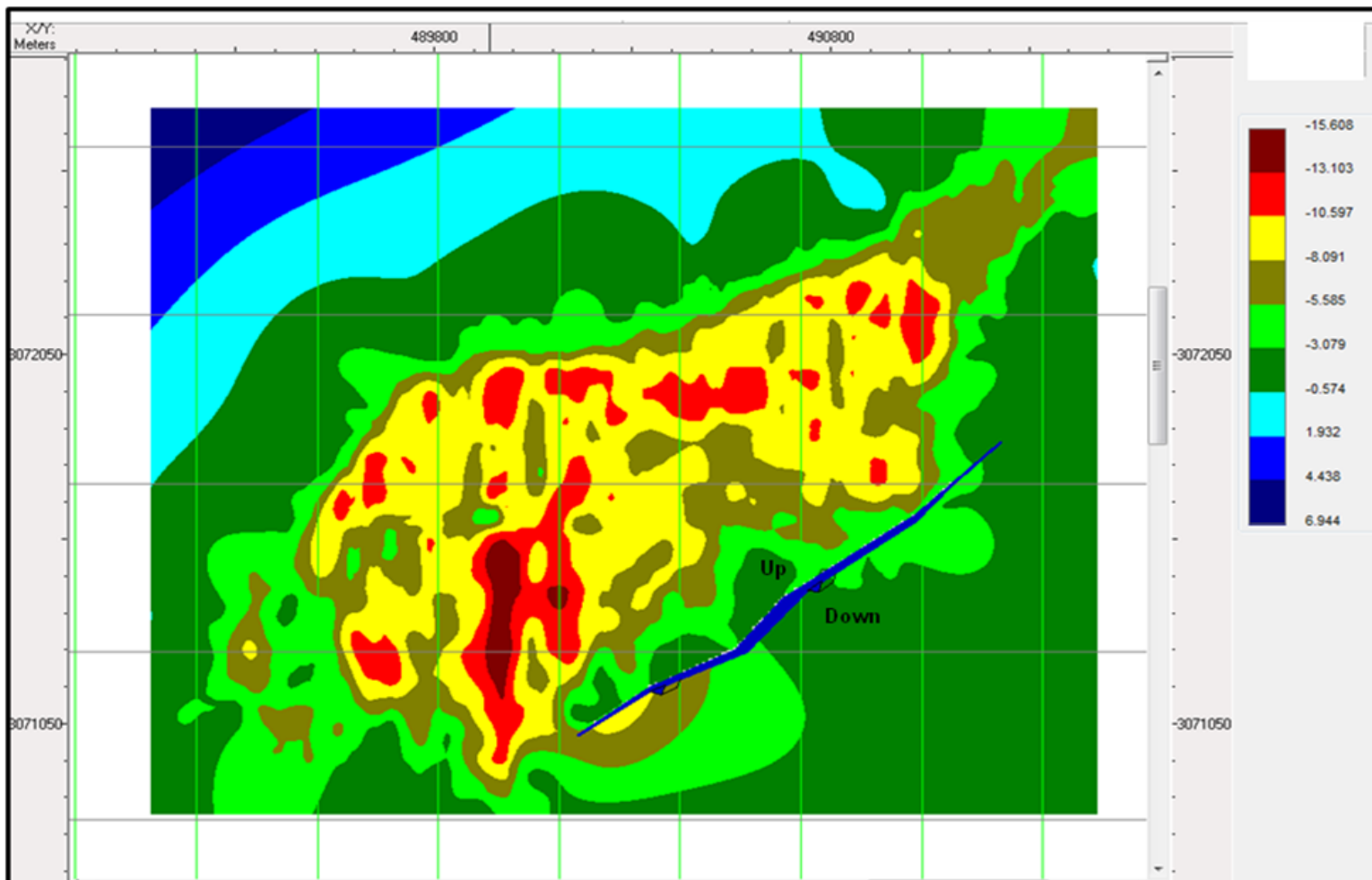


Figure 2.18. Amplitude map of the potential prospect in block 193. The high negative amplitudes displayed in yellow, red, and dark brown are strong hydrocarbon indicators trending from the northeast to the southwest. The prospect is on the up thrown side of the fault (blue line).

Deposition is interpreted to have taken place from the west. An isopach map illustrates that as much as 130 ft (39.6 m) of sand was deposited in some portions of the prospect (Figure 2.19). Trapping mechanisms are thought to be stratigraphic, or combined structural and stratigraphic. The prospect is sitting on the up-thrown side of a fault to the east. In the 3D viewer, a proposed test well has been digitized for the wildcat prospect. The well would penetrate a structural high that has high amplitude (Figure 2.20). Though further investigation of the prospect is needed, the initial structure and amplitudes show good promise.

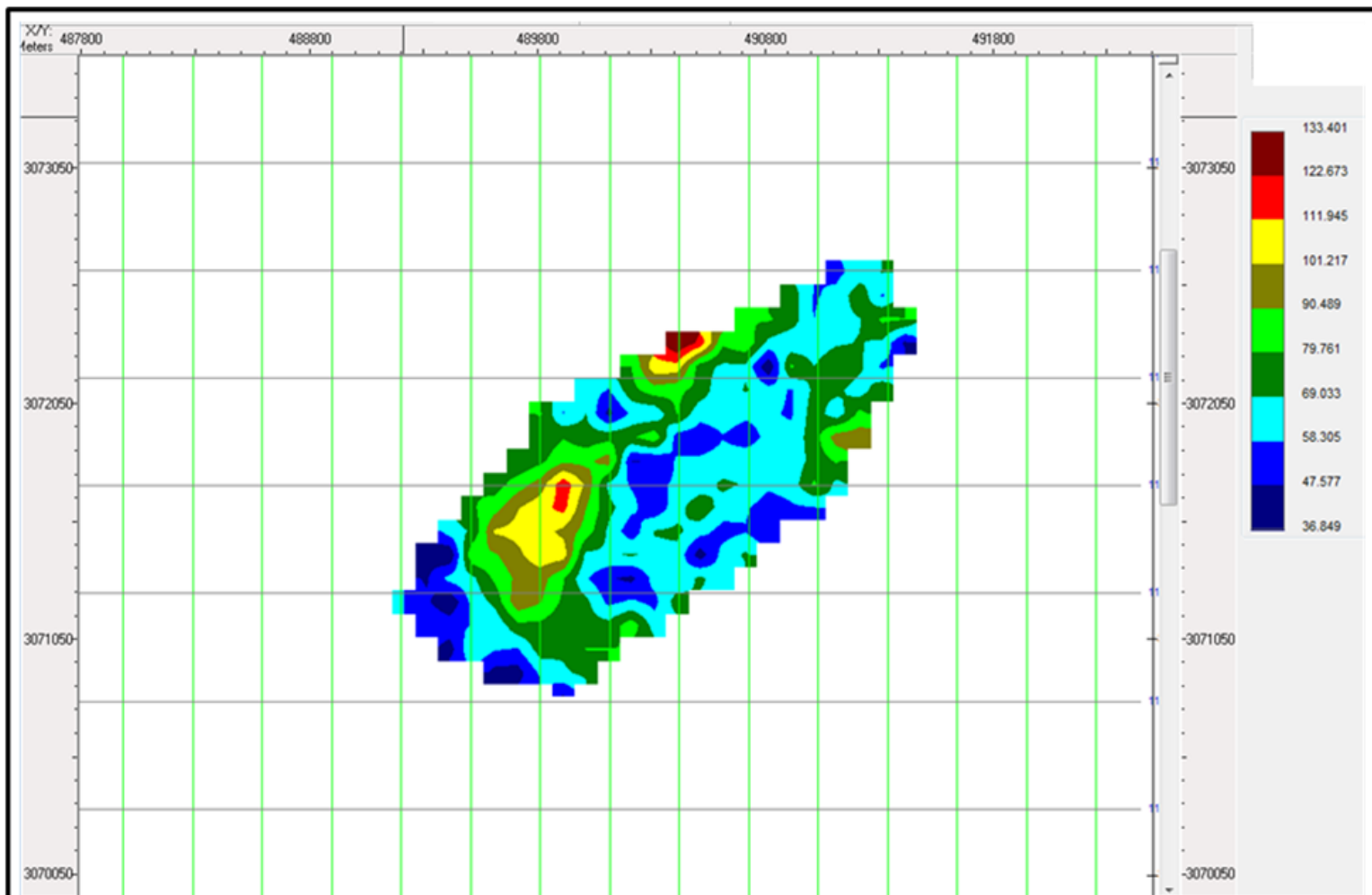


Figure 2.19. Isopach map of the prospect. Thickness scale is in feet.

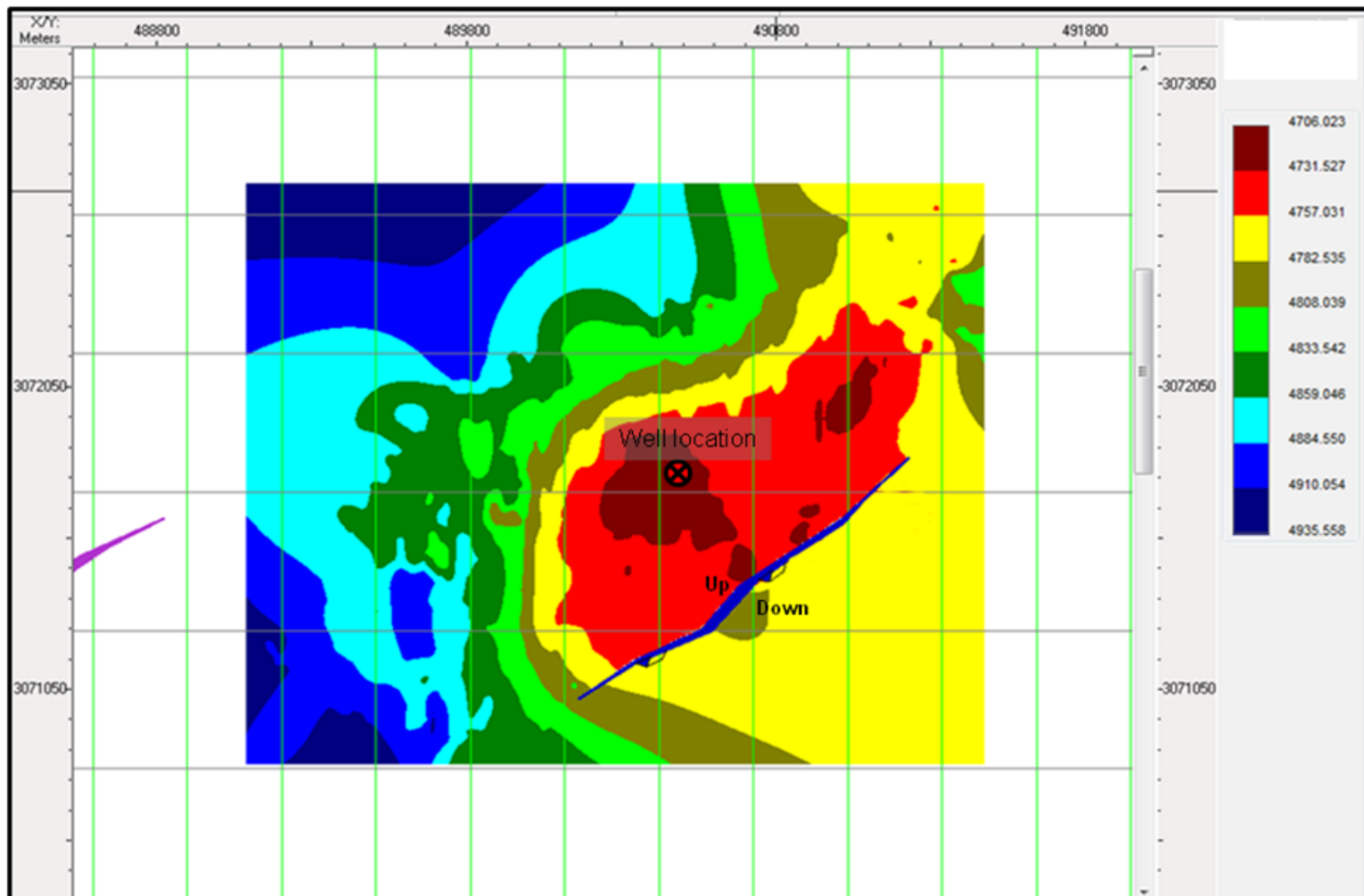


Figure 2.20. Structure map illustrating the highs and lows of the prospect. The dark brown represents the structural highs and the dark blue is the structural low. A drilling target is shown which correlates with the amplitudes in the prospect. The depth scale is in feet.

Discussion

The depositional features found in the Pimento Field are common on the continental slope environments in the Gulf of Mexico. The slope, in the Gulf of Mexico, is complicated by salt withdrawal and rapid subsidence. Minibasins on the slope are filled to spill by channel and fan deposits making their way to the basin floor. This relatively simple concept has led to one of the most productive hydrocarbon provinces in the world known as the Gulf of Mexico slope break.

The slope break and its minibasin geology have been studied extensively throughout the Gulf of Mexico. Steffens in (1993) defined two types of deep marine clastic systems on the Gulf of Mexico slope. The first is the ponded, confined system and the second is the large sourced river system. Pimento Field's minibasin is an example of a ponded confined system. Lee et al. (1996) defines the ponded confined system as situated in a partitioned network of salt-withdrawal minibasins.

This study does not focus on the slope system as a whole but on an individual minibasin. The characteristics of the minibasin and the depositional mechanisms that fill it are linked to the slope break system as a whole. This study mapped the strata that filled these basins and showed how sediments moved further down the slope via spill. This study also identified how sediment gravity flows are trapped in the basin resulting in sheet sands and channel-levee complexes such

as the 4500' reservoir sand. This study serves as a case study of a single minibasin and how the depositional mechanisms influence a single minibasin on the Gulf of Mexico slope break. This investigation shows the potential of minibasin formation in the upper slope region and the nature of the associated possible hydrocarbon plays. This case study should help others to reexamine other minibasins on the slope for potential hydrocarbon plays due to its fill and spill geomorphology on the slope.

Conclusion

Garden Banks Field 236 was in production for almost two decades and was part of one of the largest gas producing deposits in the Gulf of Mexico. The overall deposition of the area is a lower middle Pleistocene submarine fan complex that filled a minibasin and spilled over. As the basin was filled the 4500 ft. sand was deposited in a channel- levee system around the edge of the minibasin. The channel can be tracked from northwest to southeast and eventually shales out in the south. The reservoir sand was divided by the minibasin spill leaving a thick sand deposit in the east.

In this study we incorporated six wells for the investigating the 4500 ft. sand. We also documented the minibasin's overall structure and depositional style in the study area. The basin was filled to spill allowing the submarine fan to continue to prograde further down the shelf. Continued deposition of these

sediments formed channels on the sea floor leading to the 4500 ft. sand body. The overall depositional trend of the 4500 ft. sand is further documented by rendering of a channel in seismic time slices and 3D volume.

In this study, we were able to pick a potential prospect and conduct a preliminary investigation of it. The initial investigation shows a bright spot with high amplitudes and over 100 ft. (30.48 m) of sand. A potential well location was digitized using structure and amplitude for the target. Further investigation would be needed before serious consideration could be given to the target. Overall it does have promise of being a hydrocarbon producing reservoir.

COMPREHENSIVE CONCLUSION

The two papers presented in this thesis focused on the depositional elements of the Pimento Field. The Garden Banks area, in which the field resides, is known for the intrusion of salt bodies. The Jurassic salt in the area has caused major deformation of younger units within the Garden Banks area, which has acted as a sediment trap throughout the Cenozoic. The mini-basin in the field is a perfect example of how salt tectonics influences the styles of sedimentation.

First paper

The purpose of the first paper was to describe the depositional mechanism in the field using a single well and all corresponding data. The data included picked horizons, 3D seismic data, side-cores, well logs and velocity surveys. The paper indicates that there is a direct relationship between the well data and seismic data. The litholog of the side-core data matches the well log signature of a channel. When both were hung at a common datum in the seismic, the logs matched with amplitude reflections associated with sand. To further justify the interpolation of a channel, a flattened horizon displayed a straight to meandering channel-lobe complex. A secondary objective of the paper was to find a potential prospect. The prospect was found in an isopach map that showed a channel-lobe in block 193.

Second paper

The second paper is an in-depth investigation into Pimento Field's overall deposition and a broader investigation into the 4500 ft. sand reservoir. In this paper I used the KINGDOM seismic interpolation software package to interpolate the data, produce cross-sections and maps. This paper utilized 3D seismic, well logs, side-core data, geologic reports, velocity surveys and directional surveys. The second paper helped to further solidify the results of the first paper that identified channelized reservoir sand.

Cross-sections were used to show the stratigraphic and structural elements of the sand as well as how the well data matched the seismic data. The mapped salt bodies in the field were shown to influence the mini-basin up to the spill point which is situated between the two southern salt diapirs. This paper was able to show two channels for the 4500 ft. sand using similar geomorphological techniques used in the first paper. Another new addition was the use of the 3D seismic viewer for panning through the flattened section to show the meandering nature of the channel.

Final Summary

Paper one was confined to one well and the associated data with that well in conjunction with 3D seismic. The second paper expanded on paper one by including surrounding wells and their well data plus tying these wells together

through cross-sections. Both papers did arrive to the same conclusion. The reservoir sand in the field is a channel complex deposited in a mini-basin dominated field. The same data sets and methods were used, but the use of two different seismic interpolation packages show the versatility in the methods. Both papers show a potential prospect, but the second prospect was studied in-depth and provided a potential drilling target. Further investigation needs to be conducted but the target shows promise.

Other regional scale studies have shown the depositional elements for the Northern Gulf of Mexico, where as localized studies, such as this one, will aid in the overall understanding of how sediment behaves in specific areas of the Gulf. This understanding can help further our knowledge of sediment transport and depositional mechanisms, aiding in better explanation and exploitation strategies.

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APPENDIX

2000 Lakeshore Drive
New Orleans, LA 70148

February 23, 2010

Dr. Royhan Gani
University of New Orleans
2000 Lakeshore Drive
New Orleans, LA 70148

Dear Dr. Gani,

I am completing my thesis at the University of New Orleans entitled "Sedimentology of a Lower Middle Pleistocene Reservoir in Garden Banks Area, Northern Gulf of Mexico: Integration of 3D Seismic Data, Cores, and Well Logs". I would like your permission to use the two journal articles that we worked on as chapters in my thesis. The two articles are entitled: "Integrated 3D Seismic Data, Cores, and Well Log Study of Upper Pleistocene Submarine Fan Reservoir in Garden Banks Area, Northern Gulf of Mexico" and "Integrated Study of the Reservoir Sand and Depositional Setting of the Garden Banks Field 236, North Central Gulf of Mexico". As you recall the first paper was published in Gulf Coast Association of Geological Societies' Transaction volume 59, and the second is out for review to the GCACS currently.

The requested permission extends to any future revisions and edits of my thesis, including non-exclusive world rights in all languages, and to the prospective publication of my thesis by UMI Company. These rights will in no way restrict republication of the material in any other form by you or by others authorized by you. Your signing of this letter will also confirm your co-ownership of the above described material.

If these arrangements meet with your approval, please sign this letter where indicated below. Thank you very much.

Sincerely,



Sean O'Brien

PERMISSION GRANTED FOR THE USE REQUESTED ABOVE:



Dr. Royhan Gani

Date: 2-24-2010

VITA

Sean O'Brien was raised in New Orleans, LA. He received a B.S. in Marketing from Louisiana State University and a B.S. in Earth and Environmental Science from the University of New Orleans.