Vertical and Lateral Hydraulic Connectivity of the Wilcox Formation for Tiber Field and the Outbound Structural Province of Keathley Canyon and Walker Ridge, Northern Gulf of Mexico

William F. Morrison
University of New Orleans, wfmorris@uno.edu

Follow this and additional works at: https://scholarworks.uno.edu/td

Recommended Citation
https://scholarworks.uno.edu/td/2569

This Thesis-Restricted is brought to you for free and open access by the Dissertations and Theses at ScholarWorks@UNO. It has been accepted for inclusion in University of New Orleans Theses and Dissertations by an authorized administrator of ScholarWorks@UNO. The author is solely responsible for ensuring compliance with copyright. For more information, please contact scholarworks@uno.edu.
Vertical and Lateral Hydraulic Connectivity of the Wilcox Formation for Tiber Field and the Outbound Structural Province of Keathley Canyon and Walker Ridge, Northern Gulf of Mexico

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

by

William F. Morrison

B.S. Tulane University, 2010

December, 2018
Acknowledgement

I wish to thank my advisor, Dr. Abu Mustafa Sarwar, for his support and patients with this work. I also wish to thank my graduate committee, Dr. Ioannis Geogeou and Mr. Brad Robison. I would like to especially thank Mr. Robison for his teaching and mentorship. Without which my knowledge of Petroleum Geology would be minimal and this project would not exist. I would also like to thank IHS inc. for donating the Kingdom Suite software package and Western Geco inc. for donating the seismic reflection survey used in this project. Both were instrumental in its completion.
Table of Contents

List of Figures ..................................................................................................................... iv

Abstract ................................................................................................................................. v

Chapter 1 ................................................................................................................................. 1
  Introduction ............................................................................................................................. 1
  Geologic History .................................................................................................................... 4
  Data ........................................................................................................................................ 10
  Methods ................................................................................................................................. 10
  Results and Discussion ......................................................................................................... 13

Chapter 2 ................................................................................................................................ 24
  Introduction ............................................................................................................................. 24
  Methods .................................................................................................................................. 25
  Results and Discussion ......................................................................................................... 27

Conclusion ............................................................................................................................... 32

References ............................................................................................................................... 34

Appendix A ............................................................................................................................... 36

Vita ........................................................................................................................................... 45
List of Figures

Figure 1: Depth Structure Map of Sub-Salt Siliciclastic Sediments ...........................................3
Figure 2: Generalized Gulf of Mexico Stratigraphic Column .........................................................4
Figure 3: Isopac and Depositional Model of the Wilcox Formation .............................................5
Figure 4: Stratigraphic Cross Section of Wilcox Units Across KC .............................................6
Figure 5: Stratigraphic Cross Section from Jack to Stones .............................................................8
Figure 6: Structural Dip Section From Shelf to Basin Floor Across Garden Banks and Keathley Canyon .................................................................................................................................9
Figure 7: Representation of an Oil Sand in Lateral Hydraulic Communication ............................11
Figure 8: Stratigraphic Cross Section Across Tiber Field .............................................................14
Figure 9: Pressure vs. Depth plot for KC 102 001 ........................................................................15
Figure 10: Structural Cross Section of Hydraulic Connectivity for Tiber Field ..........................17
Figure 11: Structure Map of Tiber Field ........................................................................................18
Figure 12: “Areas of Connectivity” for Keathley Canyon ..............................................................20
Figure 13: Temperature vs. Depth Comparison Between Connectivity Group B and WR ..........21
Figure 14: Lithostatic pressure plot for KC 102 001 .................................................................23
Figure 16: Comparison of Seismic Synthetics ..............................................................................26
Figure 17: Synthetic Seismogram to Determine Wx 2 Reflection ................................................28
Figure 18: Map of Wave Phase on Wx 2 ......................................................................................30
Figure 19: Map of Amplitude on Wx 2 .........................................................................................31
Abstract

Hydraulic connectivity for the Tiber field and 17 other Wilcox penetrations in Keathley Canyon (KC) and 5 fields in Walker Ridge (WR) protraction areas was assessed. All five chronostratigraphic Wilcox units are not in vertical communication across both protraction areas. Four of these units are in lateral communication across Tiber field except where faults isolate portions of the structure. Five “areas of connectivity,” where two or more fields are in communication, were found in KC. The fields in WR show no evidence of connectivity despite a relatively simpler structural environment than KC. I propose that the wells in WR are isolated due to a combination of diagenetic cementation and increased vertical effective stress acting to decrease permeability between structures. I also attempted to assess the possibility of hydrodynamic flow in the primary basin encompassing Tiber by geophysically identifying the field’s oil water contact and determining its orientation. This was unsuccessful.

Keywords:
Wilcox, Hydraulic, Connectivity, Keathley Canyon, Walker Ridge, Gulf of Mexico
Chapter 1

Introduction

The deep-water Wilcox formation is a Paleocene to Eocene turbidite deposit spanning over 32,000 miles^2 of the northern Gulf of Mexico (GOM). The term deep-water refers to the water depth during deposition of this portion of the Wilcox. This is to distinguish deep-water deposits from their time equivalent shelf deposits, which are currently onshore. Since the first deep-water oil discovery in the Wilcox, it has become a major exploration target in the GOM with a success rate of over 60% (Montgomery and Moore, 1997, Meyer et al., 2005, Zarra, 2007). Given the fined grained nature of the deposit, and local variations in fluid density, field scale permeability is a challenge for these discoveries (Lewis et al., 2007). Individual turbidite fan systems are small compared to the entire lateral extent of the formation. This leads to concerns about regional hydraulic connectivity. Structural deformation also limits connectivity at the field scale and regional scale for different structural provinces that contain Wilcox deposits (Meyer et al., 2005). Understanding regional hydraulic connectivity is important because it can affect past migration pathways and recover factors estimates. Understanding lateral connectivity is also important for accurately determining reservoir pore pressures for prospects in communication with existing wells.

This work gives a preliminary assessment of hydraulic connectivity of the Wilcox across Keathley Canyon (KC) and parts of Walker Ridge (WR) protraction areas using publically available formation pressure data collected using the modular formation dynamic tester tool (MDT). This assessment began by analyzing the vertical and lateral connectivity of wells in the Tiber field (KC 102, 57, and 147) and then increased the scale to include all wells in KC with
available data. Figure 1 shows the location of the study area and wells. Then wells in KC were compared with 5 fields in WR: Tucker (WR544), Stones (WR 508), St. Malo (WR 678), Jack (WR 758), and Das Bump (WR 724) were compared. Both the KC and WR wells are in the same structural province termed the amalgamated salt stock canopy province (ASSCP) by Pilcher et al. (2011). This province not only contains all of the Wilcox penetrations with available pressure data, but is also described as being more stratigraphically continuous than the more inbound structural province, termed the bucket weld province (BWP) (Pilcher et al., 2011 and Stokes et al. 2007). The differences between these 2 provinces in discussed in the next section. The WR wells are approximately twice the distance from the structural boundary as those wells in KC (Figure 1). I hypothesized that because greater stratigraphic continuity should exist farther from this boundary, WR wells were more likely to be laterally connected than KC wells. Conversely, evidence of the opposite was found. No evidence of hydraulic connectivity between the 5 fields in WR was found, and evidence of connectivity between certain wells in KC was found. These areas containing communicating wells were termed “areas of connectivity.”
Figure 1: Depth Structure Map of Sub-Salt Siliciclastic Sediments. This basemap shows the geographic location of the study area. It also includes the primary wells used in the study and the boundary between the structural provinces (red dashed line). The red box represents the extent of seismic reflection data used in this study. Modified from Pilcher et al. (2011).
Geologic History

The Wilcox formation was deposited during the late Paleocene to early Eocene. The Wilcox marks the transition of GOM basin fill from primarily carbonate to siliciclastic (Figure 2) (Mackey et al., 2012). The driving factor for this change and the main source for Wilcox sediments is the Laramide Orogeny (Mackey et al., 2012).

![Generalized Gulf of Mexico Stratigraphic Column](image)

**Figure 2:** Generalized Gulf of Mexico Stratigraphic Column. Wilcox deposition marks the transition from carbonate to siliciclastic basin fill in the GOM. The progradation of the second half of the Cenozoic is the driving factor for the structural context of the deep-water Wilcox, identified here with a star. From Galloway (2009)

Onshore, the Wilcox deposits are deltaic and near shore sands that have been prolific petroleum reservoirs since the 1920’s (Zarra, 2007). The deep-water Wilcox discussed here is the time equivalent, down dip deposit to the onshore Wilcox. The deep-water Wilcox consists of
amalgamated channel and basin floor fan deposits interbedded with background shale deposits (Meyer et al. 2005). The thicknesses of the turbidite and shale deposits vary across the Wilcox depending on the ever changing locations of paleo turbidite systems. The areal extent of the deep-water Wilcox is approximately 32,000 mil^2 (Meyer et al. 2005). The gross thickness across the areas of interest for this study is approximately 3000ft. The depositional model and regional isopach of the Wilcox is shown in Figure 3.

**Figure 3:** Isopac and Depositional Model of the Wilcox Formation. Note that the primary sediment source is from the northwest. Submarine canyons connecting the Wilcox shelf deltas to the deep-water deposits have been identified (Sweet and Blum, 2011). (From Zarra, 2007)

The deep-water Wilcox section is divided into five chronostratigraphic units: Wx 1A, Wx 1B, Wx 2, Wx 3, and Wx 4 (Zarra, 2007). Paleontological data is not available for wells in the
Tiber field. Age control for Tiber wells was achieved by correlating the shales that vertically separate the Wilcox units from KC 919 001 (Figure 4). These correlations are based on my interpretation of the log data. Formation tops for this well are published in Zarra (2007). Correlations were carried through KC 292 001 because it had limited paleontological data available. Figure 5 shows the Wilcox units in WR and how Wilcox stratigraphy compares between the two protraction areas.

**Figure 4:** Stratigraphic Cross Section of Wilcox Units Across KC. Age control for this study was achieved by correlating the Wilcox units from KC 919 001. The figure also shows the gamma ray log nature for the Wilcox. Note that there is variability in the thicknesses of bounding shales and individual sand bodies in the units. This leads to minor net thickness changes for the units across the area. Well logs are in the public domain and acquired from BOEM.
The structural deformation acting on the deep-water Wilcox also affects its hydraulic connectivity. The area of Wilcox deposition is located in the compressional regime of the GOM (Meyer et al., 2005). Compressional shortening in this regime accommodates extension from updip (Meyer et al., 2005). The up-dip loading has also mobilized the Jurassic Louann Salt formation (Hudec et al., 2013). In this study area, halokinetic features, such as salt walls, welds, and feeders, cross cut the Wilcox and are the primary structural isolators in terms of hydraulic connectivity (Pilcher et al., 2011). The trap styles in the study area are primarily four way dip closures (Montgomery and Moore, 1997). The Tiber structure is one of these. The fields in this study are not in an identified fold belt and are thus less likely to be isolated by regional reverse faults.

The complex interplay of post Wilcox halokinetics and up-dip deposition led Pilcher et al. (2001) to identify three structural provinces in the northern GOM (Figure 1). The primary concern for this study is the down dip transition between the Bucket Weld Province (BWP) and the Amalgamated Salt Stock Canopy Province (ASSCP). Figure 6 is a structural cross section across Keathley Canyon. It shows the typical nature of the two provinces in question. The BWP has more primary basins than the ASSCP. These primary basins are bounded by salt features that can act to isolate portions of the Wilcox (Pilcher et al., 2007). There are some salt features in the ASSCP near the boundary. The seismic data shows evidence for possible salt feeders around Tiber (Figure A 1). These salt features are less prevalent farther down dip from the structural boundary (Figure 6). Seismic stratigraphy of the Wilcox suggests increasing stratigraphic continuity farther distal from the boundary (Stokes et al., 2007 and Pilcher et al., 2011). This suggests that the hydraulic connectivity also increases down-dip from the boundary until the Wilcox pinches out. To test this hypothesis, I compared formation pressure data in KC with WR.
The WR wells are approximately twice the distance from the boundary as those in KC, thus greater connectivity between fields should be seen.

**Figure 5**: Stratigraphic Cross Section from Jack to Stones. Similar to KC, the Wilcox shows little thickness variation in WR. Note the lithologic differences between the Wilcox in WR vs. KC. WR Wilcox shows more interbedding of sands and shales. The shales dividing the units are also thinner in WR. This suggests a difference in fan deposition in WR vs. KC. From Zarra (2007).
Figure 6: Structural Dip Section From Shelf to Basin Floor Across Garden Banks and Keathley Canyon. The purpose of this cross section is to show the increased presence of halokinetic features in the BWP compared to the ASSCP. Also note how these features become less prevalent in the ASSCP further down dip of the boundary. Modified from Pilcher et al. (2011).
Data

I analyzed 37 wells, which penetrated the Wilcox Formation, for the hydraulic connectivity assessment. Well locations are shown in Figure 12. Of these, 26 had MDT pressure data publically available. I also used gamma ray and resistivity logs to correlate the different chronostratigraphic intervals of the Wilcox and interpret pore fluid types. I used the density log from KC 102 001 to create a lithostatic gradient as part of the hydraulic connectivity study. All well data used in this study are in the public domain. Data was acquired from the Bureau of Ocean Energy Management.

I also utilized a Kirchhoff Post Stack Depth Migrated seismic reflection survey covering 16 blocks of north-central KC. WesternGeco, a subsidiary of Schlumberger B.V., donated this survey. The location of the survey is shown in Figures 1 and 12. In the hydraulic connectivity assessment, the survey was used to understand the geometry of the Tiber structure as well as the stratigraphy above the structure. I was also able to use the seismic to develop a limited understanding of the surrounding structural geology.

Methods

The assessment began by determining the vertical connectivity of the Wilcox formation at the Tiber discovery well, KC 102 001. The scale of the assessment was broadened to include the three other wells with available data in the Tiber field. It was then further broadened to three dimensions by including all other wells in KC that penetrated the Wilcox and had MDT data available. I then compared the hydraulic connectivity results seen in KC with five wells in central WR.

Identifying hydraulic connectivity through analyzing formation pressures relies on the principle that fluid within a closed system will equally distribute forces acting on it and achieve
pressure equilibrium. In porous rocks where the pore space is filled with fluid, and enough porosity and permeability exists so that fluid in one pore can contact those in adjacent pores, fluid pressures will equalize despite differing overburden pressures over the extent of the formation (Zhang 2011). Realizing that pressure has equalized between two locations in a formation has a large impact on understanding stratigraphy and structural geology between those two locations (Beaumont and Fiedler, 1999). Simply put, if two locations within the same formation have fluid pressures that represent a single gradient equal to density of the fluid, it means there are likely no stratigraphic or structural barriers between wells to isolate fluids.

I determine pressure equalization, and thus assume hydraulic connectivity, using a simple method. Formation pressures taken at two locations within a hydraulically connected sand will plot along the same line on a formation pressure versus depth graph (Zhang 2011) (Figure 7). If the density of the fluid is the same at both locations, then their pressure vs. depth relationship will be the same (Zhang 2011).

**Figure 7:** Representation of an Oil Sand in Lateral Hydraulic Communication. Note how formation pressure points align on the pressure plot. This is due to pressure equalization across the connected sand. If fluid densities are the same in all wells then the pressure gradient will be the same. If a density change exists such as an OWC then pressure data from the denser fluid will vary from the line but the lines will intersect at the depth of the OWC. From Zhang (2011).
MDT logs report the accuracy of the formation pressure readings as +/- 2 psi. The formation pressures in the Wilcox range from approximately 22,000 psi to over 30,000 psi. At this scale, the error associated with pressure gauge accuracy is insignificant. Uncertainty in both depth and pressure values in the MDT data used here is unknown. For this reason, analysis of these data can only be a qualitative. Minor changes in MDT values can have large impacts on the calculated slope of the pressure data. For this reason I do not intend the assessment of the pressure vs. depth relationships to be quantitative, such as determining fluid densities. Instead, slopes on these graphs are used to reinforce the resistivity log interpretations about whether pore fluids are oil or water. Fluid samples taken during the MDT collection process often give a definitive answer to the question of pore fluid type, but sample data is sparse.

Since the relationship between pressure and depth is linear (Zhang 2011), I felt justified in visually identifying the linear trend in the data and then excluding data points which did not fit this trend. Off trend points could be the result of incorrect readings, minor sands that are stratigraphically isolated from the rest of the chronostratigraphic unit, or mud filtrate invasion. These points were deemed unnecessary for determining hydraulic communication. Data points that correspond to fluid sample depths were also discarded. There are often discrepancies between formation pressure recorded during the sampling and other pressure readings at the same depth. Again, the intent is not to quantitatively analyze these data, but simply identify instances where formation data from two wells lies along the same linear trend, suggesting pressure equalization and hydraulic connectivity between the wells.

For this study, pressure equalization assumes hydraulic connectivity. Having hydraulic connectivity does not necessarily mean fluids will freely flow from one point to another in the Wilcox. Wilcox oil reservoirs are known to have pockets of very dense oils with much higher
viscosity than surrounding reservoir fluids (Stokes et al., 2007 and Betancourt et al., 2016). These highly viscous oil pockets allow for pressure equalization, but often times not fluid flow (Betancourt et al., 2016). They can act as an agent of internal compartmentalization (Betancourt et al., 2016). The results of this study are not meant as a field development aid but as a tool for understanding regional stratigraphy of the Wilcox formation.
Results and Discussion

Tiber MDT Analysis:

All four chronostratigraphic units are present at Tiber. They show little thickness variation across the structure (Figure 8).

Figure 8: Stratigraphic Cross Section Across Tiber Field. This cross section is hung on the base of salt. There is little thickness variation of the Wilcox units across Tiber. The thickening of the Miocene section in KC 102 001 is explained in Brassieur (2016). Note the change in lithology of the top of Wx 2 from KC 57 to KC 102. Well logs are in the public domain and were acquired from BOEM.
The pressure assessment started with a one-dimensional assessment of vertical connectivity using the field’s discover well, KC 102 001. Each chronostratigraphic unit is vertically isolated from one another. The isolation is evident by positive magnitude pressure shifts, ranging from 10psi to 850psi, below the shale units that divide each sand unit (Figure 9). This circumstance is consistent across all Tiber wells and all wells in this study. There is of course variation in fluid and thus pressure gradients and magnitudes of pressure increase between different wells.

**Figure 9:** Pressure vs. Depth plot for KC 102 001. This plot shows the vertical isolation of the Wilcox units in Tiber. The isolation of the units is typical for all wells in the study. This well log is in the public domain and was acquired from BOEM
When comparing pressure vs. depth relationships for the other three wells in the field, the results suggest that Wx 1A, Wx 2, and Wx 3 are in lateral communication between the wells KC 102 001, KC 57 001 ST00, and KC 57 001 ST01 (Figure A 2). Lateral communication in Wx 1B is difficult to determine given scatter in the data. This interval shows the most stratigraphic variability. This likely accounts for the complex hydraulic communication and data scatter.

There is no pressure data for Wx 4 except in KC 102 001. No communication is seen between the wells above (KC 102 001, KC 57 001 ST00, and KC 57 001 ST01) and KC 147 001 for any Wilcox unit (Figure A 2). No pressure data is available for KC 102 002. I propose that faulting is isolating KC 147 001 from the main structure (Figures 10 and 11). These faults are presumed to be normal faults because following a contour across the fault trend results in an increase in depth. Fault compartmentalization is common for this type of Wilcox structure (Meyer et al., 2005). Given the low vertical resolution in the Wilcox, these normal faults are difficult to identify. I postulated their existence and location based on linear structural contour distortion (Figure 11). It should be noted that there exists a 300ft differential between the seismic depth of this horizon and its true vertical depth in well logs. More accurate depth conversion could change the interpretation of intra-field structural features. Figure 10 shows the distribution of vertical and lateral hydraulic connectivity for the Tiber field. The approximate depth of the OWCs for Wx 2 and Wx 3 was determined from a pressure data slope analysis and log analysis. This is used in the seismic OWC identification attempt in Chapter 2.
Figure 10: Structural Cross Section of Hydraulic Connectivity for Tiber Field. This cross section is a visual representation of pore fluid type and hydraulic connectivity for the Tiber field. OWC depths were determined from MDT data and are used for Chapter 2. Note the hypothesized graben, which I propose isolates KC 147 001 from the main structure. The cross section location can be seen Figure 11 by noting well locations. Wells logs are in the public domain and acquired from BOEM.
Figure 11: Structure Map of Tiber Field. This depth structure map was created on the top of Wx 2, the uppermost pay interval in the Wilcox. Well icon colors represent pore fluid type for the Wx 2. Green is oil, and blue is brine. Note the contour distortions that suggest the possible normal faults separating the main structure from the two smaller lobes. The presence of the Southwestern Lobe is hypothesized. Given that KC 147 001 is wet, it is likely that the eastern lobe is also wet.
Regional MDT Analysis:

After gaining a better understanding of lateral connectivity for Tiber, the pressure analysis was expanded to include all other wells in KC that penetrated the Wilcox formation and had publicly available formation pressure data. A comparison of the pressure vs. depth plots of these wells shows 5 pockets of possible hydraulic communication, termed “areas of connectivity.” These are labeled A-E on Figure 12. Figures A 3 - A 7 show the pressure vs. depth relationships that suggests these wells are in lateral communication.

Connectivity between Wilcox structures in KC can have significant implications for recovery factors. The dimensions for these areas of connectivity are likely controlled by salt structures, similar to those seen in the BWP. These areas are close to the Sigsbee Escarpment, the furthest basinward extent of allochthonous salt. Salt feeder structures are unlikely to extend to or past the edge of the salt sheet. This means that areas of connectivity could be unconfined on their basinward sides. If so, then the structures could be connected to the larger Wilcox aquifer. This introduces the possibility of water drive for these fields.

Next, these results from KC were compared with a similar analysis for five fields in central WR. The fields in WR do not show evidence of lateral hydraulic communication in the Wilcox despite being further from the boundary between the BWP and the ASSCP where I hypothesized greater stratigraphic continuity should be increasing (Figure A 8). Because of this, the fields assessed in WR do not show water drive potential. High temperatures, greater than 200 degrees F, in the Wilcox lead to an environment where diagenetic silica cementation is possible (Lewis et al., 2007 and Stokes et al., 2007). This can reduce porosity and permeability in the
synclines between structures and limit lateral hydraulic connectivity. Formation temperatures higher than 200 degrees F exist in the WR wells (Figure 13).

**Figure 12**: “Areas of Connectivity” for Keathley Canyon. This map identifies wells that are possibly in hydraulic communication based on having similar pressure vs. depth relationships. Labels “A”-“E” correspond with Figures A3 – A7. Solid green lines are given to those wells where formation pressures share a value at common depths, and dashed lines given to those whose pressures form a line but do not share common depths. The size and shape of these areas of connectivity are approximate because we do not have sufficient seismic data coverage to identify any structural boundaries. Wells labeled with a solid black dot have formation pressure data available for the Wilcox. Wells marked with an “X” did not have formation pressure data available. The red dashed line is the approximate transition between the BWP and ASSCP (Pilcher et al. 2011).
I also propose that higher VES in WR compared to KC is also contributing to a physical reduction in porosity and permeability in the intra-structural lows. Allochthonous salt thickness is less in WR compared to KC. The percentage of overburden consisting of salt for connectivity group B ranges from 50% to 75%. The percentage of salt as overburden for the five WR fields ranges from 10% - 40%. Despite the shallower top of Wilcox in WR, the overburden pressures could be greater than those seen in KC leading to greater VES. Less salt would also lead to less thermal conductivity and create better conditions for silica cementation in WR compared to KC.

Figure 13: Temperature vs. Depth Comparison Between Connectivity Group B and WR. Despite the Wilcox being deeper in KC, the temperatures seen in these two connected wells is at or below the temperature of the WR wells. This suggests that diagenetic cementation is more likely in WR vs. KC. Temperature data is from public MDT logs and was aquired from BOEM.
It is possible for formation pressures from two wells to align on a plot and the wells not be in hydraulic communication. The same formation in two different areas could coincidently have the same pressure if they have similar depths and overburden. To strengthen the assertion that KC 102 001 is connected to KC 292 001 I analyzed the lithostatic gradient of KC 102 001 to determine if lateral de-watering was possible for the Wilcox. I developed the lithostatic gradient using published numbers from Katahara (2003) for the supra-salt section. The lithostatic gradient was determined using density logs. An estimated fracture gradient of -1000 psi from the lithostatic gradient was used. Data from one leak off test was available. It showed that the estimated fracture gradient is a lower boundary of fracturing. When I compared the formation pressure from the Wilcox to the fracture gradient they are not close to equal at the depth of the Tiber structural crest (Figure 14). This suggests that the Tiber structure is not controlling its own pressure by vertically de-watering. This supports the theory that lateral connectivity with KC 192 001 is possible. Figure 14 shows that the top of each Wilcox unit has approximately the same VES. This suggests that all units are de-watering against the same surface, which is geographically removed from Tiber. The approximate depth of the Wx 1A against that surface is 25,000 ft (TVDSS). Any prospects that are in this depth range that are suspected to be in the communication with KC 102 001 and KC 292 001 are likely dry holes because of active or past de-watering.
Figure 14: Lithostatic pressure plot for KC 102 001. Note that the formation pressure at the depth of the top of structure does not approach that of the fracture gradient. This suggests that reservoir pressures for the Tiber structure have not equaled those of the top seal, thus the structure is not controlling its pressure and lateral connectivity of the Wilcox is possible. The pressure differential between the lithostatic gradient and the formation at the top of each chronostratigraphic unit is relatively equal. This suggests that all units of the Wilcox are de-watering against the same surface for this pocket of connectivity. The plot also suggests that the depth of this surface for the Wx 1A is approximately 25,000 ft (TVDSS). This is an important consideration when assessing prospects within this pocket of connectivity. Formation pressure data and density data is in the public domain and was acquired from BOEM.
Chapter 2

Introduction

The hydraulic connectivity assessment in the previous chapter shows evidence of possible hydraulic connectivity for portions of the Wilcox formation in the outer structural province of the Keathley Canyon protraction area (Figure 12). Hydraulic connectivity allows for the possibility of hydrodynamic flow in a reservoir (Green et al. 2014). I set out to test the claim of Green et al. (2014) that hydrodynamic flow is possible in the Wilcox. If evidence of hydrodynamics is found, it could have great impact on development of Wilcox fields. Green et al. (2014) identified a trend of systematic Wilcox overpressure decreasing towards the east. They suggests this is evidence of hydrodynamics in the Wilcox. In order for hydrodynamic to exist at this regional scale, there must be hydraulic communication between all Wilcox fields. The results of the previous chapter of this study show that regional connectivity in the Wilcox does not exist in the ASSCP. Given the level of structural deformation in the BWP, regional hydraulic connectivity is less likely than in the ASSCP. I hypothesize that sub-regional connectivity exists in portions of the ASSCP in KC. Because of this, I attempted to assess the possibility of hydrodynamic flow in the “area of connectivity” that includes Tiber field. I attempted to determine the presence of hydrodynamic flow by identifying the oil water contact (OWC) for Wx 2 in the Tiber field and determine its orientation. Given the relatively small size of this “area of connectivity” compared to the entire Wilcox formation, and that Tiber and KC 292 appear to share a common pressure vs. depth relationship, I do not expect to see evidence of hydrodynamics. Though, if evidence is found, it will greatly affect the fields’ reserves and
recovery amounts. Geophysical identification of OWCs in the Wilcox has never been successfully done. Doing so would be incredibly beneficial to the petroleum industry.

**Methods**

Green et al. (2014) identifies three characteristics of hydrodynamic reservoirs: systematic overpressure decline in the direction of flow, oil water contacts tilt in the direction of flow, and reservoir overpressures rarely match non-reservoir overpressures. Due to no pressure data available for non-reservoir intervals, the third criterion is currently untestable. I claim that the evidence for hydraulic connectivity is that formation pressures for the same interval at different structures share a common pressure vs. depth relationship. Because formation pressures line up on the graph, I cannot determine if pressures are systematically decreasing in the direction of flow. For the area of connectivity in question, there is only pressure data for two fields. Perhaps pressure decline in this situation is not evident because the two wells lie on the same pressure contour, meaning flow it perpendicular to their connecting line. Perpendicular to the connecting line is the direction of regional dip, so it is feasible that it could be the direction of flow. It is also possible that minor uncertainty in the data and the scale at which it is analyze masks minor pressure differences that are due to hydrodynamics. Because of this, and general lack of pressure data, assessing differential pressures with respect to flow direction is not feasible. For that reason I attempted to test the presence of a tilted OWC for KC 102 001.

The Wilcox shows few reflections in the study area. This is likely due to the amalgamated nature of the turbidite fan systems. Each fan system is not thick enough or has the aerial extent necessary to show a seismic reflection. The shale intervals that define the boundaries between Wilcox intervals should have greater thickness and extent and result in
reflections. I created a synthetic seismogram for each well in the Tiber field to show that reflections are possible and to identify which reflection represents the pay interval where a fluid change occurs (Figure 17). The pay interval is the top of Wx 2. To bolster confidence in the synthetic to real-trace correlation, we compared true to processing velocities for intervals that appear thinner or thicker in the seismic traces (Figure 17). I also created a seismic synthetic for KC 57 001 ST00. The Wx 2 is wet in this well. I compared the synthetics from these two wells to determine if a change in seismic signal would result from differences in pore fluid type (Figure 16). A significant change in seismic signal should exist between these two wells. It could be due to pore fluid type or differences in lithology towards the top of the Wx 2. Once I identified the Wx 2, I extracted various seismic attributes onto this horizon in an attempt to identify the OWC. The attributes used are listed in Table 1 (Appendix A).

**Figure 16:** Comparison of Seismic Synthetics. This is a comparison between seismic signals from a wet well, KC 57 001 ST00 and a well with pay in the Wilcox, KC 102 001. There is an obvious change in the Wx 2’s expected signature. This is likely caused by the lithology change in the upper Wx 2. Well data is in the public domain and was acquired from BOEM.
I also produced attribute maps for the large Cretaceous reflector below Tiber (Figure A1). This was to look for any disruption of the seismic signal caused by the oil cap on top of the structure, such as a frequency shadow. The expected pattern was not seen in this attempt. I then tried to manually assess the shape of the side-lobes of the wavelet above and below the Wx 2 reflector. I noticed certain areas of the survey where the wavelet shape was slightly different on different sides of the OWC. Mapping this change in wave shape did not lead to a discernable pattern.

**Results – Discussion**

The frequency of the seismic section for the Wilcox in this data is approximately 10hz. This low frequency means that the resolution of any attribute extractions will be very low. But, when looking at the field scale on seismic, the processing parameters for the relatively small depth range of the Wilcox interval would remain relatively constant compared to the whole depth interval. Given that the processing parameters are constant, two variables that could influence attribute values are pore fluid type and rock properties, such as mineralogy, porosity, and permeability. Since I identified the depth of the OWCs for Wx 2 and Wx 3 in the previous chapter and know that the OWC must pass between KC 57 001 ST00 and KC 57 001 ST01 (Figure 11), I know the approximate shape and location of the OWC in map view. The shape of the OWC would pass between KC 57 001 ST00 and KC 57 001 ST01 and follow structural contours if OWC is horizontal, and cross certain contours if it is tilted. Regardless, it would mimic that overall shape of the structure. I can then look for any attribute
Figure 17: Synthetic Seismogram to Determine Wx 2 Reflection. The purpose of this synthetic was to determine if bed thicknesses were great enough to produce true reflections in the Wilcox, which is the case. It was also used to determine which reflection represented the Wx 2. To give this interpretation more confidence I compared true velocities to processing velocities. Intervals that appear thinned in the seismic should show higher velocities used for processing than those with little thinning. Well data is in the public domain and was acquired from BOEM. The seismic data was donated from WesterGeco Inc.
changes that fit the expected shape. The change in attribute values that lead to that shape can then be likely attributed to changes in fluid type. Other differences in attribute values would then be likely caused by changes in rock properties.

The expected shape representing the OWC could not be identified with any attributes used. This is likely due to the similar density of Wilcox oil and formation brine seen from MDT data. However, a trend is seen across the attribute maps. Examples of this are shown in Figures 18 and 19. This does not fit the expected shape of the OWC. It possibly represents lithologic variability across the structure. This variability is seen when correlating the upper Wx 2 between wells KC 102 001 and KC 57 001 ST00 and KC 57 001 ST01 (Figure 10). If the attribute map is representing this lithologic variability in map view, it could have serious implications on lateral reservoir heterogeneity and thus volumetric calculations for the Tiber field. It is not advisable to use seismic attributes in deep, sub-salt Wilcox environments without well control. Given the limitation in processing parameters previously discussed, attribute values could change for many reasons. If some well control is present, like the case of Tiber, more confidence can be gained in why attribute values are changing, and what these changing values tell us about the rocks. In cases such as this, attribute studies in the Wilcox could still be useful despite the seismic imaging limitations. As the development of Tiber field continues, better well control will validate or refute the identification of permeability from attributes suggested here.
Figure 18: Map of Wave Phase on Wx 2. The pattern identified by the red oval is typical of patterns seen on several attribute maps including Wave Envelope, Wavelet Polarity, and Amplitude. This pattern does not fit the shape expected for the OWC, but may represent a lithology change in the Wx 2 shown in Figure 10. Seismic data was donated by WesterGeco inc.
Figure 19: Map of Amplitude on Wx 2. The pattern identified by the black oval is typical of patterns seen on several attribute maps including Wave Envelope, Wavelet Polarity, and Wave Phase. This pattern does not fit the shape expected for the OWC, but may represent a lithology change in the Wx 2 shown in Figure 10. Seismic data was donated by WesterGeco inc.


Conclusion

Wells in both KC and WR show vertical hydraulic isolation of the chronostratigraphic units of the Wilcox formation. Tiber field shows evidence of lateral connectivity of the Wilcox units across the main body of the structure. Similar to the St. Malo and Jack fields in WR, Tiber has a portion of the structure that is not in hydraulic communication with the rest of the field, and does not contain hydrocarbons. This is likely due to faulting. Given this result, the undrilled northeastern lobe of the structure is not likely to contain hydrocarbons.

Five “areas of connectivity,” where two or more wells show evidence of long distance lateral hydraulic communication were identified in KC. To reinforce this interpretation of connectivity I found that KC 102 001 is not controlling its own pressure, and thus lateral communication with nearby structures is possible. That same analysis suggests that the connected area containing KC 102 001 and KC 292 001 is dewatering at an approximate depth of 25,000 ft TVDSS. Prospects thought to be communicating with these wells and near that depth likely do not contain hydrocarbons. Identifying these “areas of connectivity” can lead to very accurate pre-drill formation pressure predictions for new prospects believed to be in hydraulic communication with existing wells.

Connectivity between Wilcox structures in KC could have significant implications for recovery factors. The dimensions for these areas of connectivity are likely controlled by salt structures, similar to those seen in the BWP. These areas are close to the Sigsbee Escarpment, the furthest basinward extent of allochthonous salt. Salt feeder structures are unlikely to extend to or past the edge of the salt sheet. This means that areas of connectivity could be unconfined on their basinward sides. If so, then the structures could be connected to the larger Wilcox aquifer.
This introduces the possibility of water drive for these fields. The fields assessed in WR do not show potential for water drive since they appear to be isolated from a larger aquifer.

Formation pressures for five fields in central WR were compared. They show evidence of being hydraulically isolated from one another. This refutes the original hypothesis that WR fields are more likely to be in hydraulic communication because they exist in a region of the Wilcox that shows greater stratigraphic continuity compared to the wells in KC. Temperature analysis between KC and WR wells supports the hypothesis that higher temperatures in the connecting synclines in WR compared to KC produce an environment that is more suitable to diagenetic cementation. I also propose that higher vertical effective stress in WR leads to physical reduction in syncline permeability furthering hydraulic isolation. Thinner allochthonous salt sheets in WR compared to KC could be the cause of higher VES in WR. This causes relatively higher overburden pressure in WR and decreases thermal conductivity leading to higher temperatures. It is also possible that stratigraphic changes between fields is responsible for the hydraulic isolation.

I was unable to geophysically identify the OWC for Wx 2 on the Tiber structure. Because of this, I was not able to determine its orientation and provide evidence for or against hydrodynamic flow in the Wilcox. A common pattern in various attribute maps was identified that could represent the lithologic change in the Wx 2 seen between KC 102 001 and KC 57 001 ST00 and KC 57 001 ST01. Mapping this lithology variation could have impacts on permeability distribution and volumetric calculations for the Tiber field.
References


Figure A 1: Seismic Cross Section Across Tiber Field. The location of the seismic survey, the base map in the upper corner, is shown in Figure 1. Note the ~20,000 ft section of allochthonous salt and potential salt feeder. The four corners of this survey show badly attenuated signals that may relate to active or past salt feeders. Note the Wilcox section is shown as Eocene-Paleocene. Also note the low relief of this structure, which supports the claim that halokinetics rather than compressional structural features play a larger roll in hydraulic isolation. Seismic data courtesy of WesterGeco Inc.
Figure A 2: Pressure vs. Depth Plots for Wilcox Units in Tiber Field. These plots suggest that the Wx 1A, Wx 2, and Wx 3 are in lateral communication across this field. It is difficult to make this determination for Wx 1B given the scatter of the data. This unit shows the most stratigraphic variability, which may account for the more complex hydraulic connectivity. Note that KC 147 001 is not in communication with the other wells. Pressure data is in the public domain and was acquired from BOEM.
Figure A 3: Pressure vs. Depth Plot for Connectivity Group A. This plot shows possible connectivity between two wells in the Wx 2 unit. Pressure data is in the public domain and was acquired from BOEM.
**Figure A 4:** Pressure vs. Depth Plot for Connectivity Group B. This plot shows possible connectivity between the Tiber structure and KC 292 001 BP01. It shows possible connectivity in the Wx 2 & Wx 3. Data for Wx 1A & Wx 1B are not available for KC 292. KC 414 001 is included to show how we define two wells that are not in lateral hydraulic connectivity. Pressure data is in the public domain and was acquired from BOEM.
Figure A 5: Pressure vs. Depth Plot for Connectivity Group C. This plot shows possible connectivity between two wells in the Wx 2 & Wx 3 units. Pressure data is in the public domain and was acquired from BOEM.
Figure A 6: Pressure vs. Depth Plot for Connectivity Group D. This plot shows possible connectivity between two wells in the Wx 2 & Wx 3 units. Pressure data is in the public domain and was acquired from BOEM.
Figure A 7: Pressure vs. Depth Plot for Connectivity Group E. This plot shows possible connectivity between two wells in the Wx 2 & Wx 3 units. Pressure data is in the public domain and was acquired from BOEM.
Figure A 8: Formation Pressure vs. Depth Plot for Fields Assessed in Walker Ridge. This plot shows formation pressures for various units of the Wilcox. Note that no pressure gradients share common values. I interpret this to mean that these five structures are not in hydraulic communication. Pressure data is in the public domain and was acquired from BOEM.
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Seismic Attribute</th>
<th>Geophysical Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band Width</td>
<td>Envelope Depth Derivative</td>
<td>Second Derivative of Phase</td>
</tr>
<tr>
<td>Chaotic Reflection</td>
<td>Envelope Modulated Phase</td>
<td>State Indicator</td>
</tr>
<tr>
<td>Curvature: Azimuth</td>
<td>Envelope Second Derivative</td>
<td>Similarity</td>
</tr>
<tr>
<td>Curvature: Curvedness</td>
<td>Event Continuity</td>
<td>Similarity Variance</td>
</tr>
<tr>
<td>Curvature: Gaussian</td>
<td>Imaginary Part</td>
<td>Smoothed Dip of Max Similarity</td>
</tr>
<tr>
<td>Curvature: in Dip Direction</td>
<td>Instantaneous Dip</td>
<td>Smoothed Similarity</td>
</tr>
<tr>
<td>Curvature: in Strike Direction</td>
<td>Instantaneous Lateral Continuity</td>
<td>Thin Bed Indicator</td>
</tr>
<tr>
<td>Curvature: Maximum</td>
<td>Instantaneous Phase</td>
<td>Trace Envelope</td>
</tr>
<tr>
<td>Curvature: Minimum</td>
<td>Instantaneous Wavenumber</td>
<td>Wavelet Band Width</td>
</tr>
<tr>
<td>Curvature: Most Negative</td>
<td>Instantaneous Wavenumber Envelope Weighted</td>
<td>Wavelet Dominant Wavenumber</td>
</tr>
<tr>
<td>Curvature: Most Positive</td>
<td>Normalized Amplitude</td>
<td>Wavelet Envelope</td>
</tr>
<tr>
<td>Curvature: Shape Index</td>
<td>Parallel Bedding Indicator</td>
<td>Wavelet Envelope Depth Derivative</td>
</tr>
<tr>
<td>Dip Azimuth</td>
<td>Real Part</td>
<td>Wavelet Envelope Second Derivative</td>
</tr>
<tr>
<td>Dip of Maximum Similarity</td>
<td>Relative Acoustic Impedance</td>
<td>Wavelet Phase</td>
</tr>
<tr>
<td>Dip Variance</td>
<td>SD Envelope Sub-band</td>
<td>Wavelet Q</td>
</tr>
<tr>
<td>Dominant Wavenumber</td>
<td>SD Trace Sub-band</td>
<td>Wavelet Second Derivative of Phase</td>
</tr>
<tr>
<td>Zones of Unconformity</td>
<td>Wavelet Wavenumber Envelope Weighted</td>
<td>Wavelet Wavenumber</td>
</tr>
</tbody>
</table>

**Table 1: Seismic Attributes Used to Determine OWC Orientation.**
Vita

The author was born in New Roads, Louisiana. He obtained his Bachelor’s degree in Geology from Tulane University in 2010. He joined the University of New Orleans Earth and Environmental Sciences graduate program in 2015. He is pursuing a Master’s degree focusing on petroleum Geology.