

Adeolu Aderoju  
Oyelowo G. Bayowa  
Olatunbosun A. Alao

# Hydrocarbon Exploration Using Unconventional Interpretation Techniques

Reflection Seismology



Anchor Academic Publishing

*disseminate knowledge*

**Aderoju, Adeolu, Bayowa, Oyelowo G., Alao, Olatunbosun A.: Hydrocarbon Exploration Using Unconventional Interpretation Techniques: Reflection Seismology, Hamburg, Anchor Academic Publishing 2015**

Buch-ISBN: 978-3-95489-378-2

PDF-eBook-ISBN: 978-3-95489-872-5

Druck/Herstellung: Anchor Academic Publishing, Hamburg, 2015

**Bibliografische Information der Deutschen Nationalbibliothek:**

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <http://dnb.d-nb.de> abrufbar.

**Bibliographical Information of the German National Library:**

The German National Library lists this publication in the German National Bibliography. Detailed bibliographic data can be found at: <http://dnb.d-nb.de>

All rights reserved. This publication may not be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

---

Das Werk einschließlich aller seiner Teile ist urheberrechtlich geschützt. Jede Verwertung außerhalb der Grenzen des Urheberrechtsgesetzes ist ohne Zustimmung des Verlages unzulässig und strafbar. Dies gilt insbesondere für Vervielfältigungen, Übersetzungen, Mikroverfilmungen und die Einspeicherung und Bearbeitung in elektronischen Systemen.

Die Wiedergabe von Gebrauchsnamen, Handelsnamen, Warenbezeichnungen usw. in diesem Werk berechtigt auch ohne besondere Kennzeichnung nicht zu der Annahme, dass solche Namen im Sinne der Warenzeichen- und Markenschutz-Gesetzgebung als frei zu betrachten wären und daher von jedermann benutzt werden dürften.

Die Informationen in diesem Werk wurden mit Sorgfalt erarbeitet. Dennoch können Fehler nicht vollständig ausgeschlossen werden und die Diplomica Verlag GmbH, die Autoren oder Übersetzer übernehmen keine juristische Verantwortung oder irgendeine Haftung für evtl. verblichene fehlerhafte Angaben und deren Folgen.

Alle Rechte vorbehalten

© Anchor Academic Publishing, Imprint der Diplomica Verlag GmbH

Hermannstal 119k, 22119 Hamburg

<http://www.diplomica-verlag.de>, Hamburg 2015

Printed in Germany

## **DEDICATION**

This beautiful piece is strictly dedicated to my heavenly father; the owner of the universe, the author of my life, the one who knows my destination.

## **ACKNOWLEDGEMENT**

My greatest acknowledgement goes to Lord Almighty, the giver of knowledge, wisdom, talent, inspiration, ability, grace and ideas. Also, I acknowledge my good parents and siblings, their support are unending. Your scribes are so bold and deep, it is indelible. I appreciate you all.

My profound appreciation also goes to my Mentors; Dr. O. G. Bayowa, Dr. O. A. Alao and Dr. A. A. Adepelumi. Their impacts, love, trust and the hope they have awoken in me will forever remain. I am grateful.

My fat appreciation goes to the Earth Sciences Department, Ladoke Akintola University of Technology, Ogbomoso, the members of Staff and the students alike for a wonderful time shared together. I love you all.

Also, I want to acknowledge the Geology Department of Obafemi Awolowo University, Ile – Ife; from which I retrieved the Data that I worked with. Thank you so much, I am grateful.

I am also indebted to a great number of my friends; who have shown their support in diverse ways during the course of my stay in Ladoke Akintola University of Technology, Ogbomos, Nigeria; my appreciation is unending – Temitayo Alabi, Olaniyi Ayobami, Wole Olufunmilayo, Seun Olaniyi, Timothy Afonja, Wole Eesuola, Wale Egbuna, and many more that have escaped this list.

## TABLE OF CONTENT

|  |    |
|--|----|
| DEDICATION.....  | 5  |
| ACKNOWLEDGEMENT.....   | 6  |
| ABSTRACT .....   | 12 |
| <br>   |    |
| CHAPTER 1 .....  | 13 |
| 1.1    Introduction .....                                      | 13 |
| 1.2    Aim of Research .....                                   | 14 |
| 1.3    Specific Objectives of the Study .....                  | 14 |
| 1.4    Methodology.....  | 15 |
| 1.5    LOCATION AND DESCRIPTION OF THE STUDY AREA .....        | 16 |
| 1.6    LITERATURE REVIEW .....                                 | 19 |
| <br>   |    |
| CHAPTER 2 .....  | 22 |
| 2.1    GEOLOGY OF THE NIGER DELTA .....                        | 22 |
| 2.2    DEVELOPMENT OF THE DELTA.....                           | 25 |
| 2.3    THE PRESENT NIGER DELTA.....                            | 26 |
| 2.4    SUBSURFACE FORMATIONS OF THE TERTIARY NIGER DELTA ..... | 26 |
| 2.4.1    Akata Formation .....                                 | 26 |
| 2.4.2    Agbada Formation .....                                | 28 |
| 2.4.3    Benin Formation.....                                  | 29 |
| 2.5    BASIN ARCHITECTURE .....                                | 30 |
| 2.6    SUBSURFACE STRUCTURES OF THE NIGER DELTA.....           | 33 |
| 2.6.1    GROWTH FAULT .....                                    | 34 |
| 2.6.2    ROLLOVER ANTICLINES.....                              | 34 |
| 2.6.3    TRAPS AND SEALS .....                                 | 36 |
| 2.7    TECTONICS OF THE NIGER DELTA .....                      | 37 |
| <br>   |    |
| CHAPTER 3 .....  | 39 |
| 3.1    MATERIALS AND METHOD OF STUDY .....                     | 39 |
| 3.2    PHYSICAL BASIS OF REFLECTION SEISMOLOGY .....           | 39 |
| 3.2.1    P AND S WAVES .....                                   | 39 |
| 3.2.3    REFLECTION AND PHYSICAL PROPERTIES OF ROCKS .....     | 41 |
| 3.2.4    SEISMIC ACQUISITION .....                             | 43 |

|                     |   |     |
|---------------------|---|-----|
| 3.2.5               | SEISMIC DATA PROCESSING .....   | 44  |
| 3.2.6               | SEISMIC DATA INTERPRETATION.....  | 44  |
| 3.3                 | WELL LOGGING.....   | 48  |
| 3.3.1               | BOREHOLE ENVIRONMENT AND INVASION PROFILES .....                                    | 50  |
| 3.3.2               | LOG TYPES AND USES .....  | 50  |
| 3.3.3               | WELL LOG CORRELATION .....  | 57  |
| 3.4                 | SEISMIC ATTRIBUTES.....   | 57  |
| 3.4.1               | Introduction.....   | 57  |
| 3.4.2               | The Classification of Attributes.....   | 58  |
| 3.5                 | Spectral Decomposition: A Powerful Risk Reduction Tool .....                        | 61  |
| <br>CHAPTER 4       | .....   | 66  |
| 4.1                 | DISCUSSION AND RESULTS PRESENTATION. ....   | 66  |
| 4.2                 | Conventional Mapping .....  | 66  |
| 4.2.1               | FAULT MAPPING .....   | 67  |
| 4.2.2               | Horizon Tracking.....   | 69  |
| 4.3                 | Well to Seismic tying .....   | 71  |
| 4.4                 | WELL LOG INTERPRETATION .....   | 76  |
| 4.4.1               | Thin Sandstone Bed 1 (TB 01T):.....   | 77  |
| 4.4.2               | Thin Sandstone bed 2 (TB 03T):.....   | 82  |
| 4.5                 | SPECTRAL DECOMPOSITION.....   | 87  |
| 4.5.1               | Spectral Decomposition Analysis of TB 01T.....                                      | 89  |
| 4.5.2               | Trapping Mechanism in TB 01T .....  | 101 |
| 4.5.3               | Spectral Decomposition Analysis of TB 03T.....                                      | 101 |
| 4.5.4               | Hydrocarbon Potential in TB 03T.....  | 105 |
| 4.6                 | ISO - CHRON MAPS.....   | 106 |
| 4.6.1               | TB 01T ISOCHRON MAP: Time values to this horizon range 2437.4 ms to 2892.1 ms ..... | 107 |
| 4.6.2               | TB 03T ISOCHRON MAP: Time values to this horizon range 2163.3 ms to 2457.3 ms. .... | 107 |
| <br>CHAPTER 5       | .....   | 109 |
| 5.1                 | CONCLUSION .....  | 109 |
| 5. 2                | RECCOMENDATION .....  | 109 |
| <br>REFERENCES..... | .....   | 111 |

## **LIST OF TABLES**

|  |    |
|--|----|
| Table 1 The Properties of Sandstone bed TB 01T in relation to the wells it cuts across ..... | 80 |
| Table 2 The Properties of Sandstone bed TB 03T in relation to the wells it cuts across ..... | 83 |

## LIST OF FIGURES

|  |    |
|--|----|
| Figure 1.1: Schematic Diagram Showing the Research Methodology.....  | 16 |
| Figure 1.2: Basemap of the Study Area; Inset is the Map of Nigeria.....  | 17 |
| Figure 1.3: Description of the Study Area. ....  | 18 |
| Figure 2.1: Index Map of Nigeria and Cameroon .....  | 24 |
| Figure 2.2: Stratigraphic columns showing the three formations of the Niger Delta.....   | 27 |
| Figure 2.3: Stratigraphic Column Showing the Three Formation of the Niger Delta. ....  | 32 |
| Figure 3.1: Simple Schematic Diagram Illustrating the Underlying Principles of the Seismic Method. ....  | 41 |
| Figure 3.2: Definition of a Wavelet.....   | 42 |
| Figure 3.3: Reflected and Transmitted Rays Associated With a Ray Normally Incident on an Interface<br>of Acoustic Impedance Contrast.....  | 42 |
| Figure 3.4: Simplified Processing Flow (After Yilmaz 1987) .....   | 46 |
| Figure 3.5: Borehole Environments and Invasion Profiles ( <a href="http://www.petrolog.net/webhelp/logging_tools">www.petrolog.net/webhelp/logging_tools</a> ).....                              | 51 |
| Figure 3.6: Spectral decomposition is used to identify thin beds through analysis of the frequency spectrum<br>in a short window around the time of the bed. (Partyka <i>et al.</i> , 1999)..... | 63 |
| Figure 3.7: Comparison of Frequency Effects on thin Beds.....  | 64 |
| Figure 3.8: Spectral Decomposition Work Flow. ....   | 65 |
| Figure 4.1: Some of the picked faults on inline 5915 with Mapped pay sand reflectors (TB 01T and TB 3T).....   | 68 |
| Figure 4.3: Two tracked reflectors across the two markers; TB 03T and TB 01B.....  | 70 |
| Figure 4.4: Reflector Horizon for TB 03T tracked across the volume with the used wells.....  | 70 |
| Figure 4.5: Reflector TB 01T tracked across the volume with the used wells.....  | 71 |
| Figure 4.6: The Relationship between Sonic Log (DT), Computed Acoustic Impedance in Relation to<br>Depth and the Generated Synthetic Wave Form and Seismic Wave Form.....                        | 72 |
| Figure 4.7: Matching of the Synthetic Wave Form to the Seismic Wave Form.....  | 73 |
| Figure 4.8: An Excel Spread sheet, Showing the Generated Data for one of the Four Wells used for<br>tying and the Consequent Depth - Time Plot. ....   | 73 |
| Figure 4.9: The Depth – Time Graph of Well 3. ....   | 74 |
| Figure 4.10: The Depth – Time Graph of Well 4. ....  | 74 |
| Figure 4.11: The Depth – Time Graph of Well 5. ....  | 75 |
| Figure 4.12: The Depth – Time Graph of Well 6. ....  | 76 |
| Figure 4.13: Showing the Cross Section of TB 01T across the wells.....   | 78 |
| FIGURE 4.14: SHOWING THE CROSS SECTION OF TB 01T ACROSS THE WELLS AS IT MISSES OUT IN WELL 02. ....  | 78 |
| Figure 4.15: Using a Better Resolution Scale to View TB 01T.....   | 80 |
| Figure 4.16: TB 01T Sandwiched within a Thick Shale Unit.....  | 81 |
| Figure 4.17: Showing the cross section of TB 03T across the wells.....   | 84 |
| Figure 4.18: An improve scale enhance the viewing and mapping of the TB 03T. ....  | 85 |
| Figure 4.19: TB 03T Sandwiched within a Thick Shale Unit.....  | 85 |
| Figure 4.20: Seismic Data Showing the position of the Markers on Inline 5915- .....  | 88 |
| Figure 4.21: Amplitude Attribute- Inline 5915. ....  | 88 |
| Figure 4.22: Inline 5915- Energy Attribute .....   | 89 |
| Figure 4.23: Inline 5915- 25Hz FFT .....   | 90 |

|   |     |
|---|-----|
| Figure 4.24: Inline 5915- 30Hz FFT .....  | 91  |
| Figure 4.25: Inline 5915- 33Hz FFT .....  | 91  |
| Figure 4.26: Inline 5915- Color blended Image; Blue- 25Hz, Green- 30 Hz, and Red- 33Hz.....                                     | 93  |
| Figure 4.27: Inline 5915- Color blended of Amplitude Attribute, Blue- 25Hz, Green- 30 Hz, and Red- 33Hz.....                    | 93  |
| Figure 4.28: Inline 5915- Color blended of Energy Attribute, Blue- 25Hz, Green- 30 Hz, and Red- 33Hz.....                       | 94  |
| Figure 4.29: The seismic data of TB 01T .....   | 94  |
| Figure 4.30: The 15Hz FFT of TB 01T .....   | 96  |
| Figure 4.31: The 25Hz FFT of TB 01T .....   | 96  |
| Figure 4.32: Showing the 30Hz FFT of TB 01T .....   | 97  |
| Figure 4.33: Showing the 45Hz FFT of TB 01T .....   | 97  |
| Figure 4.34: Amplitude Attribute Map of TB 01T .....  | 98  |
| Figure 4.35: Energy Attribute Map of TB 01T.....  | 98  |
| Figure 4.36: Color Blended Map of TB 01T - 25Hz/Blue, 30Hz/Green, 33Hz/Red.....   | 99  |
| Figure 4.37: Color Blended Map of TB 01T - 25Hz/Blue, 30Hz/Green, 33Hz/Red, with Energy. ....                                   | 99  |
| Figure 4.38: Color Blended Map of TB 01T - 25Hz/Blue, 30Hz/Green, 33Hz/Red, with Amplitude.....                                 | 100 |
| Figure 4.39: Inline 5915 Instantaneous Amplitude Attribute, overlain on it is well 5 and its log and<br>Marker for TB 03T ..... | 102 |
| Figure 4.40: Showing Inline 5915 for 25Hz, overlain on it is well 5 and its log and Marker for TB 03T.....                      | 103 |
| Figure 4.41: Showing Inline 5915 for 30Hz, overlain on it is well 5 and its log and Marker for TB 03T.....                      | 103 |
| Figure 4.42: Instantaneous Amplitude Attribute on TB 03T. ....  | 104 |
| Figure 4.43: 25Hz Frequency display on TB 03T .....   | 105 |
| Figure 4.45: 33Hz Frequency display on TB 03T .....   | 106 |
| Figure 4.46: Iso – Chron Map for TB 01T .....   | 107 |
| Figure 4.47: Iso-Chron Map for TB 03T .....   | 108 |

## **ABSTRACT**

Technology has been predicted as the last card in combating the ever increasing demand of our commodity; oil and gas. Modern approach to Seismic acquisitions and interpretation is of prime essence. A powerful

Interpretation tool; Spectral decomposition, has been used to visualize (in 3 – D) a thin sandstone reservoir in “X – Field” Niger Delta, Nigeria. The study aimed at mapping thin sandstone beds which have been considered sub seismic or un-mapable.

Well log data were acquired and qualitatively and quantitatively interpreted using RocDok software and correlated across four wells; Tmb 01, 02, 04 and 05. The interpreted well logs were presented in Tables. Seismic data were also acquired. Thin sandstone bed markers were identified from well logs and consequently mapped on the seismic data. The data were interpreted using the OpendTect software for frequency analysis which was presented in form of maps.

Two thin sandstone beds were delineated from the well log these are; TB 01T and TB 03T. TB 01T had an average thickness of 4.16m and cuts across three wells (Tmb 01, 04 and 05) but was not delineated in Tmb 02. TB 03T was extremely thin. Its average thickness could not be estimated but cut across the four wells. Frequency analysis from seismic sectional view revealed the portion of the thin pay sandstone as the markers were engulfed by high amplitude. The plan view seismic analysis also showed high amplitude across the region of the thin sandstone.

The study concluded that the high amplitude represented on the seismic views characterize the thin sandstone pay. However, other regions on the seismic views with high amplitude could be new prospects.

# **CHAPTER 1**

## **1.1 Introduction**

Over time, beds of relative thicknesses between 10 - 30m or thin reservoirs have been deemed unmapable or probable to interpreters using conventional interpretation techniques. This is caused by various factors, such as: the reservoir's thinness, discontinuous occurrences, high degree of vertical and lateral variability in net sand thickness, weak impedance contrast at sand interfaces, high impedance of bounding overlying layers and the limited bandwidth of seismic data.

In geological settings where there are successive intercalations of rocks such as the Niger Delta basin of Nigeria, mapping of such thin reservoir may seem more challenging using the conventional Technology. This project is set to map such thin pay zones using a 3-D visualization and spectral decomposition attributes which in turn will help to define the thickness, heterogeneity, rock property changes, depth thickness and the lateral spread across oil wells in the selected locale of the Niger Delta, Nigeria.

### **The Research problem**

The term "All the easy oil has been found" is no more a novel term, it has grown popular. In the 1900s it was not uncommon to search for oil tucked beneath structurally simple anticlinal traps. However, geoscientists have to work much harder today to discover economic reservoirs. Searching for hard-to-find stratigraphic traps is common as we reexamine mature plays to uncover missed hydrocarbons. In modern times, simply relying on the full-stack amplitude response as a direct hydrocarbon indicator is not enough; typically, advanced reservoir characterization techniques and seismic attribute analyses are needed to evaluate a reservoir properly.

Most Seismic datasets contain higher frequencies near the surface; all frequencies attenuate as the wave front propagates deeper into the subsurface. Many of the Pays lie in depths where they are primarily imaged by frequencies as low as 10 to 20 Hz. This means that thin beds, beds that are 16 to 82 ft (5 to 25 m) thick are sub-seismic in nature (i.e., they cannot be resolved by the seismic wavelet and are considered to be below the tuning thickness). These are the type of thin stringer sands that are encountered on usual basis in seismic datasets. Given the low frequency content of these datasets, advanced attribute analyses techniques are required to properly evaluate these deposits. The processes helped to supplement the thin sandstone beds exploitation and to uncover the data that traditionally goes undetected.

## **1.2 Aim of Research**

To map thin pay zones using 3-D visualization and spectral decomposition attribute.

## **1.3 Specific Objectives of the Study**

The specific objectives of the study are to

1. Carry out interpretation of well data to determine possible thin reservoir sand, including the sand Reservoir in the study area.
2. Carry out conventional seismic interpretation over the study area, mapping faults and interpreting horizons
3. Overlay the well log data interpretation on the seismic interpretation to determine a lateral continuity of the thin sand.