OBAFEMI AWOLOWO UNIVERSITY

INTEGRATED APPLICATION OF SEISMIC INVERSION AND ARTIFICIAL NEURAL NETWORKS FOR RESERVOIR CHARACTERIZATION AND PROSPECT DE-RISKING OF OA-FIELD

BY

Adedolapo Ayomide OGUNSADE

(B.Tech FUTA. M.Sc. IFP SCHOOL, FRANCE, M.Sc. O.A.U)

(SCP11/12/H/3280)

A THESIS SUBMITTED TO THE DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE OBAFEMI AWOLOWO UNIVERSITY, ILE-IFE IN PARTIAL FULFILLMENTOF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D) INAPPLIED GEOPHYSICS

2016

CERTIFICATION

This research work by Mr. OGUNSADE, Adedolapo Ayomide has been read and approved as meeting part of the requirement for the award of Ph.D. Applied Geophysics of Obafemi Awolowo University, Ile-Ife, Nigeria.

..	**..**
Dr. A.A. Adepelumi	**Dr. S.A. Adekola**
Supervisor	**Chief Examiner**

ACKNOWLEDGEMENTS

My sincere gratitude goes to God Almighty who has made this work possible and granted me the strength and perseverance to complete it. I also appreciate my parents for their wonderful contributions and support in ensuring that this dream is fulfilled.

My thanks go to my supervisor, Dr. A.A. Adepelumi for his support throughout the duration of the program and for giving me this splendid opportunity to contribute to the body of knowledge. I salute you sir. I won't fail to mention Dr. O.A. Alao for helping me sustain my drive towards completing this work. Thank you so much for your great kindness and encouragement through the years. My appreciation goes to all the academic and non-academic staff of the Department of Geology, Obafemi Awolowo, University, Ile-Ife.

Special thanks to my colleagues in the academia and the industry for their assistance in one way or the other during the course of this work. I also acknowledge the Department of Petroleum Resources (DPR) for the provision of the data used for this study.

To my lovely wife, Mrs. Temidayo Ogunsade, I say thank you, God will bless and lift you up for showing me the love that surpasses every challenge and for standing by me through it all. To my son Adedayo, in some years to come, I will remind you of how you always wanted to help daddy type on the computer anytime you were with me while working. These are sweet memories I will cherish forever.

And lastly, to the One who has made everything good in His own time, I give all glory, adoration and praise. Amen

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The study modified seismic inversion algorithm which incorporated artificial neural networks for reservoir characterization to pre-stack seismic data acquired in the "OA"-Field. The adopted workflow was used to transform the seismic data to acoustic impedance and petrophysical attribute "SoPhi"; considered to be a direct hydrocarbon indicator, in an integrated inversion scheme. This was with a view to characterizing "OA"-Field reservoirs, identifying the exploratory prospects and proposing possible development opportunities.

The data used for the study included pre-stack seismic substacks (near-, mid-, and far) and data for one well "OA" comprising gamma ray, resistivity, density, sonic, caliper, and neutron logs. Schlumberger's Petrel and CGG Veritas's Hampson Russell softwares were used for the analyses of the data. The hydrocarbon-bearing reservoirs were identified from the well logs using petrophysical parameters such as porosity, water saturation and the volume of shale. Well-to-Seismic calibration was used to tie the formation tops to seismic, thereafter, faults and horizons interpretation were carried out on the pre-stack seismic data. Wavelets were extracted from all the seismic substacks, while a priori impedance (Zp, Zs) and density models were generated from the P-impedance, computer S-impedance (using a modified form of Castagna's equation) and density logs, within a time window that covered the full extent of all observed hydrocarbon bearing intervals. The pre-stack seismic inversion workflow was run on the initial model for the selected time window and was progressively iterated over 100 runs to minimize the residual difference between the inverted model and the original seismic data. The inversion results with other seismic attributes were then fed as input into a back propagation neural network (BPNN) algorithm which learned the relationship between the desired output and the

training data. This was then used to convert the original seismic data into a hydrocarbon presence indicator.

Four hydrocarbon bearing reservoirs (A, B, C and D) were delineated from the OA well log. Reservoirs A and B were oil bearing, C was gas and oil bearing while reservoir D was gas-filled. Average porosity progressively decreased from Reservoir A (23%) to the deepest Reservoir D (at 16%). Hydrocarbon saturations of the reservoirs A, B, C and D were 55%, 66%, 58% and 68% respectively. Six faults (A, B, C, D, E and F) and seven horizons (HOR A, B, C, D, E, F and G) were interpreted in the "OA"-Field. Horizons E and F defined the upper and lower boundaries of the interval of the seismic inversion. The pre-stack seismic inversion data showed that in the reservoirs already found by the OA well, the impedance attribute could be directly correlated to hydrocarbon presence as was the case in Reservoirs A, B and C that had thicknesses in excess of 190 feet. Integration of the parameters from the inversion with six other seismic attributes in a back propagation neural networks (BPNN) scheme resulted in the identification of five exploration prospects (A, B, C, D and E) with different characters. Prospects A and C were identified as flat spots; with very good hydrocarbons presence. Prospect E was a possible anticlinal structure which extended beyond the limits of the study area and would require additional data to completely evaluate its potential. Prospects B and D were stratigraphic targets which would require two wells to be drilled to rest them.

The study concluded that the integration of pre-stack seismic inversion and artificial neural networks enhanced the exploration potentials of the "OA"-Field in terms of prospect delineation which could eventually lead to identification of additional hydrocarbon reserves and resources.

CHAPTER ONE

INTRODUCTION

Seismic exploration methods have developed a steadily increasing power and complexity during the past 50 years and the use of seismic data has advanced greatly with improvement in technology over these years. A typical interpretation workflow today goes beyond using maps and sections with computerized visualization and display techniques. It is now common to apply techniques such as rock physics, amplitude versus offset (AVO) and seismic inversion to reservoir characterization. The ultimate goal is to reduce exploration and production risks and optimize the recoverable hydrocarbon volumes from producing oil and gas fields.

Reservoir characterization, in spite of all these advances in interpretation techniques remain an onerous task due to the fact heterogeneity is an inherent property of most reservoirs. Recreating these heterogeneities in the reservoirs as accurately as possible is therefore, of utmost importance as the results impact the simulation processes and history matching carried out by reservoir engineers and also the hydrocarbon reserves estimated for prospects and of course the economic viability of any exploration or development projects.

Seismic inversion is a technique used to extract quantitative information about reservoir rocks and fluid parameters from seismic data. It involves integration of both seismic data and well data, where well data may serve to add the low frequency component below the

seismic band and to constrain the inversion. While seismic migration is aimed at imaging the reflectors or the interfaces at their correct subsurface locations, seismic inversion attempts to estimate elastic and flow properties of the layers bounded by these interfaces. Seismic data are sensitive essentially to seismic wave velocity and density contrasts in the subsurface rocks. Compared to seismic amplitudes, inversions show higher resolution and support for more accurate interpretations. This, in turn facilitates better estimations of reservoir properties such as porosity and net pay (Pendrel, 2006). However, there is significant overlap in elastic properties among different rock types, thus, mapping of these elastic properties to rock types and estimating porosity are not trivial.

Neural networks, on the other hand, are adaptive statistical models based on an analogy with the structure of the brain. They are adaptive because they can learn to estimate the parameters of some population using a small number of exemplars (one or a few) at a time. They do not differ essentially from standard statistical models. An artificial network consists of a pool of simple processing units which communicate by sending signals to each other over a large number of weighted connections (Krose and Smagt, 1996). The ability of neural networks to learn and generalize in addition to their wide range of applicability makes them very powerful tools.

1.1 STATEMENT OF THE PROBLEM

Hydrocarbon exploration and production is a risky and capital intensive venture. As a result of this, several techniques of data mining and analysis are employed to increase the value derived from very expensive field data sets. Seismic inversion is one of such

techniques and has been used by several analysts in conjunction with soft computing techniques such as artificial neural networks to enhance seismic data analysis with the aim of associating subsurface rock properties with seismic amplitude response. However, most of the current workflows for integrated seismic inversion and neural networks application has so far succeeded in transforming originally acquired seismic data into impedance and porosity cubes. None of these methodologies has attempted to relate inversion results particularly from known hydrocarbon bearing zones to other areas of the field where only seismic data is available with no information about rock properties and hydrocarbon presence. This research will develop and optimize workflows that will result in a robust reservoir characterization scheme that will use artificial neural networks to learn the relationship between subsurface rock properties, inversion amplitude response and hydrocarbon presence in the "OA"-Field.

1.2 OBJECTIVES OF THE RESEARCH

The specific objectives of this research were to:

i. **interpret pre-stack 3-D seismic data to obtain two-way travel times for major horizons;**
ii. **analyze well data for petrophysical properties and establish relationships between these subsurface rock properties and the seismic data;**
iii. **carry out seismic inversion analysis for the "OA"-Field; and**
iv. **integrate results from (iii), with an artificial neural networks scheme to characterize hydrocarbon bearing reservoirs and prospects in the "OA"-Field.**

1.3 CONTRIBUTION TO KNOWLEDGE

This research takes to a new frontier, the level to which pre-stack seismic data and well logs can be used. Likewise, it establishes the important use of integrating seismic inversion with artificial neural networks in correlating known hydrocarbon response in already discovered hydrocarbon bearing reservoirs with other possible exploratory and infill targets. Finally, this work shows that it is feasible to identify transform a raw seismic data into a volume that can indicate hydrocarbon presence, even though well information might be sparse. Thus new prospects can be identified in areas where it otherwise would have been impossible, and the possibility of targeting multiple prospects with a single well helps to reduce the risks associated with drilling such multi-million dollar wells for exploration, appraisal and hydrocarbon field development purposes.

1.4 RESEARCH MATERIALS AND LOCATION OF THE FIELD

The data used to carry out this research comprised three–dimensional (3D) digital Pre-stack seismic volumes (Near-, Mid- and Far- substacks), a suite of well data comprising of gamma ray, resistivity, density, neutron, sonic logs and checkshot data for one well. Data for the study was sourced through my supervisor from the Department of Petroleum Resources. Data analysis was carried out by using Petrel (a Schlumberger software) for interpretation and Hampson-Russell software (provided to the Department of Geology Obafemi Awolowo University by CGG Veritas) for the inversion and neural network analysis. The field is an onshore oil acreage located in the Niger Delta Basin and has been renamed as the "OA"- Field for proprietary reasons (Figure 1.1). It covers an area of 318 sq.km.

1.5 RESEARCH METHODOLOGY

In order to achieve the objectives of this study, the following workflow was adopted:

i. **Petrophysical analysis of the well logs was done to determine the reservoir targets, and parameters such as volume of shale (V_{sh}), porosity (ϕ) and water saturation (S_w) were determined.**

ii. **Well-to-Seismic calibration was done using the checkshot data to tie to formation tops to the seismic data.**

The pre-stack 3D seismic data volume was interpreted for faults and horizon using the workstation based interpretation software, Petrel by Schlumberger. 3D subsurface