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RESERVOIR CHARACTERIZATION, MODELLING AND LATERAL PREDICTIONS USING MULTIVARIATE ANALYSIS: A CASE STUDY OF HEMS FIELD, BOHAI BAY, LIAOHE FIELD, CHINA

BY

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A THESIS SUBMITTED

TO

THE DEPARTMENT OF PETROLEUM ENGINEERING, SCHOOL OF ENGINEERING AND TECHNOLOGY, COLLEGE OF SCIENCE & TECHNOLOGY, COVENANT UNIVERSITY, OTA

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D) DEGREE IN PETROLEUM GEOPHYSICS

JULY, 2013

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CERTIFICATION

We certify that the thesis titled “Reservoir Characterization, Modelling and Lateral Predictions Using Multivariate Analysis: A Case Study of Hems field, Bohai bay, Liaohe field, China.” is an original work carried out by Mr. Rotimi Oluwatosin John (CUGP070197) in the Department of Petroleum Engineering, Covenant University, Ota, under the supervision of Prof. B. D. Ako and Dr. C. C. Uhuegbu. We have examined and found the work acceptable for the award of a degree of Doctor of Philosophy in Petroleum Geophysics.

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DEDICATION

This research work is dedicated to my Lord Jesus Christ, the wisdom and source of life. May His name be praised forever for his continual release of grace and mercies in divine revelations to conclude this study. I also dedicate this to my lovely family, especially to my adorable daughter - Delightful-Laughter for being the latest *Abidemi*.

.

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LIST OF ABBREVIATIONS

AI	Acoustic Impedance
SP	Spontaneous Potential
LLD	Deep Laterolog
EI	Elastic Impedance (EI 10, 20, 30)
V_p	P wave-velocity
V_s	S wave-velocity
V_p/V_s	P-velocity/ S-velocity Ratio
ϕ	Porosity (PHI)
CAL	Caliper log
AC	Acoustic/Sonic log
GR	Gamma Ray
S_w, S_{hc}	Water Saturation, Hydrocarbon Saturation
Temp	Temperature Log
BVW	Bulk Volume Water
CNL	Compensated Neutron Log
R_w	Water Resistivity
TST	True Stratigraphic Thickness
TVT	True Vertical Thickness
N/G	Net to Gross
K	Permeability
Electrofacies	L_facies
ρ	Rho (DENSITY)

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μ	Mu
λ	Lambda
μρ	Mu Rho
λρ	Lambda Rho
SMT	Seismic MicroTech Software (The Kingdom Suite)
IP	Interactive Petrophysics Software
HRS	Hampson Russell Suite (CGG Veritas)
SIS	Sequential Indicator Simulation
TGS	Truncated Gaussian Simulation
SGS	Sequential Gaussian Simulation
ROI	Region of Interest
RMS	Root Mean Square

Measuration and property Symbols

cm	Centimetre
m	Metre
^{o}C	Degree Celsius
g	Gramme
ms/gcc	Milliseconds per Gramme per Cubic Centimetre
μ	Shear Modulus
κ	Bulk Modulus
σ	Poisson Ratio

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ABSTRACT

Qualitative and quantitative predictions of reservoir properties and geometries beyond well control are vital to understanding the intrinsic characteristics of subsurface formations. Using well log data, 3D Seismic data, Geostatistical simulations, reservoir characterization, modeling via multivariate analysis was carried out for and lateral predictions on data set obtained from Liaohe field, western sag, Bohai Bay, Northern China. This sag is an intra-cratonic basin of Archean to Recent age.

Stratigraphic analysis, structural analysis, geomodel building and geostatistical methods were used. Well logs methods include conventional interpretation by picking sand units based on Self potential log (SP) and Resistivity logs (LLD) in addition to computation of volume of shale and other petrophysical properties. Unavailable logs like Density and Neutron were predicted from a cored well whilst missing logs sections were predicted using neural networks and fuzzy logic. Clustering technique was employed to predict facies (electrofacies) occurrences based on various log types. Sand tops earlier picked from well logs were laterally traced on seismic sections after well to seismic tie. Structural interpretation was done to map the architectural pattern of the rock units. The post-stack seismic inversion was done and calibrated with logs from 12 wells producing acoustic impedance and elastic impedance volumes. Multi-attribute analysis was used to predict rock properties like porosity from inversion results and vintage seismic data. Modeling of variogram and structural elements was done, after which suitable geostatistical simulation algorithms were used to populate cells and realize multiple equiprobable rock properties for the zone of interest after upscaling all needed rock properties into the earlier built non-partitioned simulation case. These were achieved using standard software such as Petrel®2008, CGGVeritas™ Hampson Russell suite (2008), Interactive Petrophysics v3.5, Kingdom Suite (SMT) 2008, GeoGraphix® 2008 and Surfer 9 (Golden Software).

Results show that clustering models converged to 2 classes namely sand and shale. Sand and shale sequences are fairly mixed and vertically inconsistent as a result of rapid deposition amidst unconsolidation on the toe of the sag structure. Petrophysical values viz hydrocarbon saturation is above 70%, porosity between 0.1 and 0.4, permeability between 0.6 and 3.0mD and volume of shale between 0.3 and 0.8. Structurally, 35 major and minor faults were mapped with 15 used for modeling. Prevailing fault orientation is northeast/southwest, dipping south-easterly and trending northwest-southeast direction. Bedforms are complex with gradual lateral changes in lithofacies. Sharp boundaries in horizontal direction define different depositional facies with a flexible non-partitioned model adopted. The lithofacies model result showed continuous lithological units with inconsistencies of stratigraphic and structural truncations which were also replicated on the rock properties model with clear heterogeneity seen in the observed values. Horizon cubes produced in regions of interest defined relationships that are clearly correlative with rock properties than with seismic attributes/properties. Majority, some of the properties predicted from multiattribute analysis of seismic data calibrated with computed logs correlated well with the simulated rock property volumes.

In conclusion, successful prediction has been done for rock properties at inter-well points and locations beyond well control. The heavy hydrocarbon in reservoir units of the field can be recovered by steam injection method (SAGD). The methodology and interpretation approach adopted in this work can be implemented initially with very few wells for multiattribute volume prediction, seismic inversion and on a larger scale with more wells for geostatistical simulations and modeling.