Application of geostatistical seismic inversion in reservoir characterization of Igloo Field, Niger Delta, Nigeria.

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Summary

A stochastic approach to seismic inversion was used in characterization of R3 reservoir of Igloo Field, Niger Delta. This study utilizes Stratigraphic Modified Lorenz (SML) plot as major framework on which inversion was carried out thus reducing vertical upscaling problems and improving the estimation of reservoir properties between wells. The calibration of acoustic impedance using sonic and density logs porosity showed a 0.88 correlation co-efficient; this formed the basis for geostatistical seismic inversion process. The transformation of acoustic impedance into reservoir parameters using Sequential Gaussian Simulation (SGS) and collocated cokriging algorithm resulted in ten equiprobable acoustic impedance models. These models were converted to porosity using cloud transform; permeability was modeled with a single transform of core porosity with correlation coefficient of 0.86. The property maps generated imaged typical fluvial to deltaic environment without precondition to facies model. Comparison with conventional model of porosity showed similarities in their histogram distribution; however there were differences in their spatial distribution which is a major control to fluid flow.

Introduction

The Igloo field is located within the Northern Depobelt of the Niger Delta, Nigeria (Fig. 1). The Niger Delta clastic wedge spans a 75, 000 km^2 area in southern Nigeria and the Gulf of Guinea offshore Nigeria (Evamy *et al.*, 1978). This clastic wedge contains the world's 12^{th} largest known accumulation of recoverable hydrocarbons, with reserves exceeding 34 billion barrels of oil and 170 trillion cubic feet of gas (Tuttle *et al.*, 1999; Obaje *et al.*, 2004; Anakwuba *et al*, 2010).

The qualitative determination of inter well properties of a reservoir is one of the most challenging activities in the understanding of reservoir heterogeneity for optimal management. Well data have higher vertical resolution than seismic data. However, only very few wells are drilled due to economic reasons; wells of course have poor lateral coverage. Seismic at its poor resolution can cover the extent of the reservoir; this gives it a quantitative advantage.

Different seismic inversion methods have been introduced for the incorporation of seismic data as a secondary variable in the prediction of inter-well reservoir properties. The methods can be broadly classified as either deterministic (one globally optimized acoustic impedance result) or stochastic (multiple equiprobable results). Deterministic approaches are generally cheaper in terms of computation time and disk space, with the vertical resolution of the results (typically tens of meters) being constrained by the seismic bandwidth (Deutsch *et al*, 2001).

Stochastic acoustic impedance inversion approaches, such as geostatistical inversion (Haas & Dubrule 1994), combine seismic, well and geostatistical data to produce multiple 3D acoustic impedance blocks at higher resolution than the seismic data. Outside the seismic bandwidth, the acoustic impedances are constrained with log data and geological stratigraphic concepts.

This study integrates the Stratigraphic Modified Lorenz (SML) plot (Gunter *et al.*, 1997) and Collocated Co-Kriging approach of geostatistical seismic inversion (Haas and Dubrule, 1997) in the characterization of R3 Reservoir in Igloo Field of Niger Delta. The study is expected to establish a clear workflow for the implementation of these practices and serve as model for usage in the local industry.

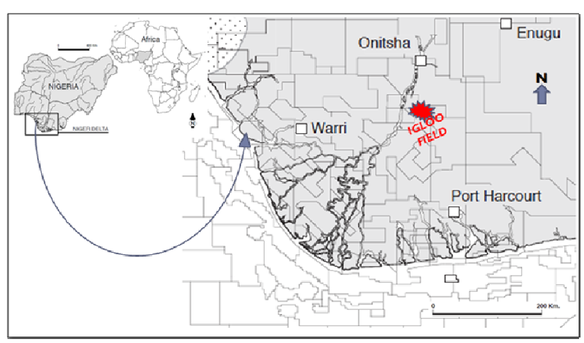

Fig. 1: Map of Niger Delta showing the study area (Modified from Haack *et al.*, 2000)

NSGAPC Beijing 2013: First Near Surface Geophysics Asia Pacific Conference.
Beijing, China. 17-19 July, 2013

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Data and Methodology

The set of data available for this study includes processed Igloo 3D seismic volume, well log suites of 19 wells (Caliper, gamma ray, spontaneous potential, resistivity, density, neutron and sonic logs), velocity check shot data and core petrophysical data (porosity, water saturation, permeability and oil saturation).

The workflow used is illustrated in Fig. 2. The items highlighted on red are major emphasis of the project while item on green is not part of the project. The execution of these steps was done with the aid of Schlumberger Petrel©. The overview target of the workflow is to generate all necessary interpretations and input for geological modeling from seismic and well data interpretations. The techniques have been discussed by many authors (Wenlong *et al*., 1992; Haas and Dubrule, 1994; Asnul and Mohan,1998; Alvaro *et al*., 2000; Udofia *et al*., 2004; Questiaux, 2008; etc). The input data set of interest here include the field fault geometry, the structural map of the R3 hydrocarbon interval, the seismic attributes for control on petrophysical distribution and the generation of stratigraphic divisions using SML-Plot.

Geostatistical inversion was performed on acoustic impedance using collocated co-kriging method (Haas and Dubrule, 1994). This was transformed into porosity using bivariate method.

Fig. 2: The Project workflow

Results and Discussion

Geostatistical seismic inversion approach involves the re-sampling of the original seismic acoustic impedance into the geological model constructed. This process ensures that each cell in the 3D grid gets a seismic impedance value. The seismic acoustic impedance was then calibrated with porosity. The porosity values used for this analysis were calculated from all the wells using the average of sonic and density log porosities. The linear relationship and correlation coefficient obtained improved the confidence for the usage of cloud transform to classify porosity against acoustic impedance (Fig. 3). Ten equiprobable realizations were generated using Collocated Co-kriging approach (Fig. 4). By running ten equiprobable impedance simulations, one assumes that a large degree of the possible local variations will be captured (Fig. 5). This helps in defining the uncertainty in the reservoir model work and they have the same distribution and statistics.

A stochastic approach known as Cloud transform, was used to convert impedance to porosity using Petrel© SGS algorithm. This process depends on the bivariate relationship between porosity and acoustic impedance and it reduces uncertainty in the relationship between porosity and acoustic impedance by capturing the distribution histograms of both parameters with smaller intervals. The data is divided into ten classes labeled from 1 to 10 (Fig. 6).

Permeability model was also generated using the core porosity vs. core permeability transform. The function was taken from a single regression line through the crossplot. The advantage of this method is that it keeps simple relationship between the porosity and permeability models in the absence of defined geologic facies. This ensures that the petrofacies of each individual cell is consistent with theoretical relationship between porosity and horizontal permeability (Fig.7). Here we expect a cell with high porosity to also have a corresponding high permeability.

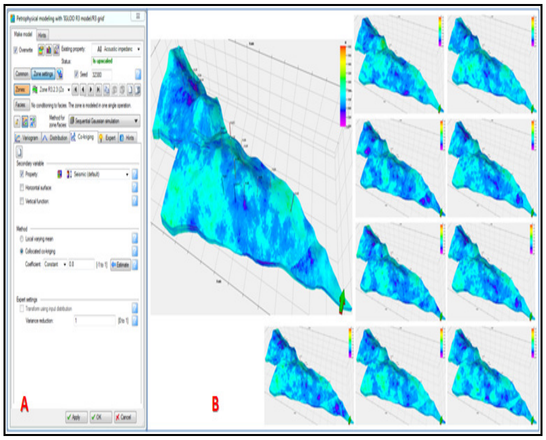

Fig. 3: Geostatistical inversion of acoustic impedance using Collocated Co-kriging approach.

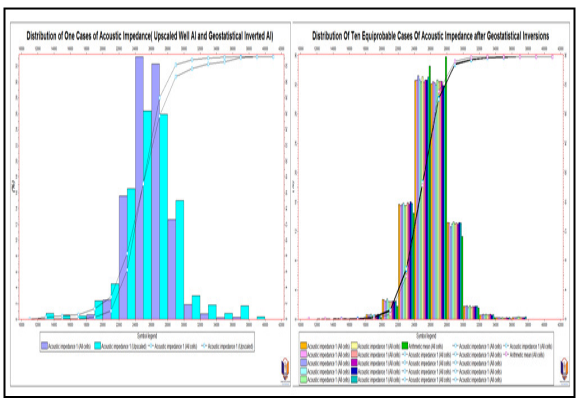

Fig. 4: The relationship of the ten realizations of the generated acoustic impedance.

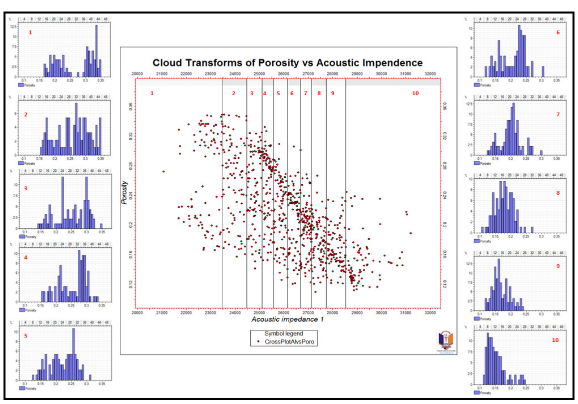

Fig. 5: Cloud transform of porosity and acoustic impedance

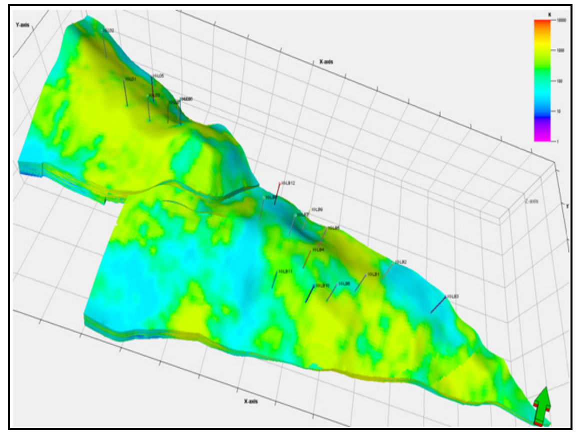

Fig. 6: Permeability model of level R3 **Igloo** Field

Comparing the workflow result with conventional approach

A conventional model of porosity was developed using the same variogram model, input porosity data and SGS with normal scores transform only. The inter-well porosity was simulated without seismic attribute constants; within the already developed Permeability model of level R3 Igloo Field structural and stratigraphic frame work of R3 reservoir. This conventional model was then compared with the porosity models developed using the integration of geostatistical inverted acoustic impedance. This was done to validate the contribution of the workflow in reducing inter-well uncertainties in property modeling. The result of this comparison showed that both models were similar in their descriptive statistics, (probability and cumulative distribution functions).

However, major differences were observed in the spatial distribution of porosity values in the grid. Cross sections across the models revealed that the conventional method captures the well data very effectively and assumes trend relationships between the wells. The implication is that geologic heterogeneities in-between well positions will be missed. Example will be modeling; braided river system or delta front environments with sand lobes of different sizes.

The model with seismic inversion reduced the uncertainties associated with these kinds of environment by mimicking the distribution of seismic impendence at positions of low well influence. Fig. 7 shows the difference between the two models; one can easily notice the spatial relationship between seismic, acoustic impedance and porosity in the inverted model, whereas for the conventional model, the porosity takes correlation relationship across points of variegation.

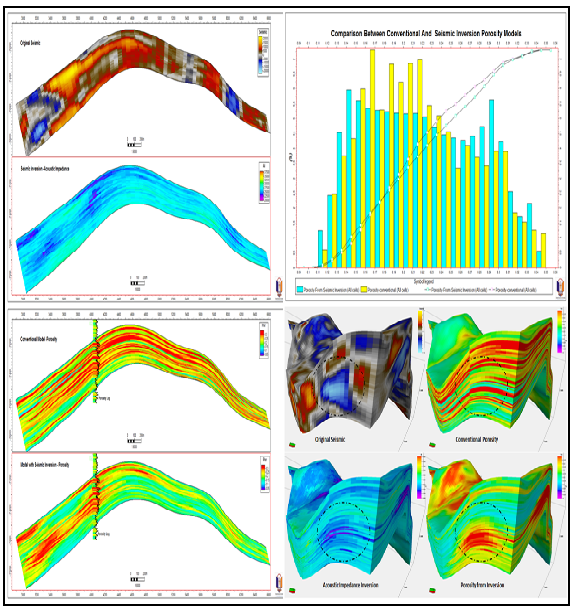

Fig. 7: Comparing the workflow result with conventional approach

To illustrate the effectiveness of the process; a permeability map of R3 reservoir generated using the volume weighted average value of one of the equiprobable models probabilistically predicted channel fill trend and distribution of the sand (High permeability). The general geometry predicted looks much of meandering channel bodies flowing in the SE-NW direction (Fig. 8).

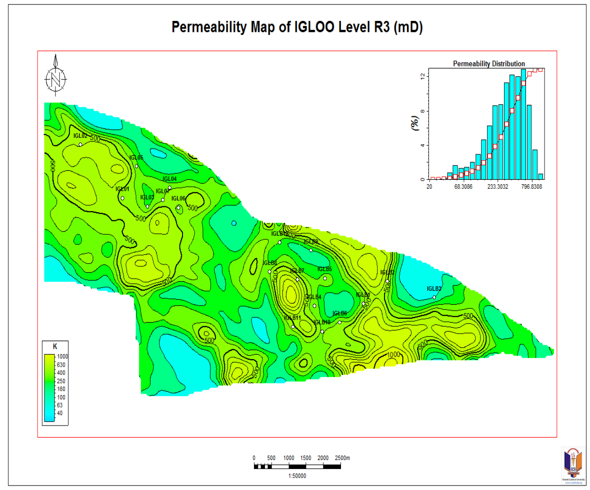

Fig. 8: Permeability map of level R3 Igloo reservoir

Conclusions

R3 hydrocarbon level in Igloo Field, Niger Delta has been characterized and modeled by integrating 3-D seismic volume, geophysical well logs and core petrophysical data. The main conclusions are as follows:

1. The R3 reservoir is structurally characterized by footwall/hanging wall trapping system, interpreted to be fluvial to deltaic channelized shallow marine environment with average properties of 250ft thickness, 21% porosity, 34% volume of shale and 680 mD permeability.
2. Incorporation of acoustic impedance yielded a credible estimation of porosity away from well point.
3. Geostatistical inversion ensured that the hard data at well points were retained over the secondary data.
4. SGS with cloud transform reduced uncertainty in the porosity model by constraining the model to retain similar probability distribution function as the sample data.

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