An Integrated Approach to Dealing with Fluid Type and Contact Uncertainty – A Case Study for Egu Field Offshore Niger Delta

Obinna Chudi, Chukwunweike Awa, Olalekan Balogun, Tamunotonye Biambo, Milan Stevanovic, Kakayor Omagbemi, Magnus Kanu, Chima Emelle, Mora Glukstad Miguel and Ejiuwa Nworie
Shell Petroleum Development Company

ABSTRACT

Knowing the primary fluid type(s), and their distribution are fundamental in making right field development decisions. Hence, oil and gas companies invest millions of dollars in the early phase of field development planning in acquiring relevant data to address fluid type/contact uncertainties. Egu field lies in the shallow offshore of the Niger Delta within a water depth of 13-30 m and is structurally complex with series of crestal faults resulting in compartmentalized reservoirs. The C8000 and C9000 reservoirs were studied as part of the Egu Field feasibility assessment. For both reservoirs, an improved understanding of the pore fill type, fluid distribution and contacts was key to reaching a final development decision. Available well data was unable to resolve the underlying fluid uncertainties, hence seismic data and other petroleum engineering information were integrated in this study. Amplitude from seismic integrated with well data was utilized to generate an improved understanding of the fluid fill and distribution leading to the prediction of an oil rim with thickness of 44ft and a gas-oil-contact (GOC) at 7251 ft for the C9000 reservoir. As a prove of concept, these techniques predicted similar hydrocarbon type and fluid contacts across adjacent reservoir blocks where pore fill and contacts were previously known from well logs. This therefore served as a means of calibrating the results across the area of interest hence improving confidence in the predictions. Semblance map revealed a multi-channelized fan system with varying degree of channel incision for the C8000 reservoir. The varying degree of channel incision is observed to be responsible for the contrasting fluid contacts logged in the different compartments and hence defines the C8000 reservoir to be stratigraphically compartmentalized which hitherto was interpreted as a structurally segmented reservoir. Therefore, multiple geological scenarios were defined to manage the compartmentalized nature of the reservoir. The outcome of this study for the C8000 and C9000 reservoirs have influenced the reservoir modelling approach and therefore the development philosophy, particularly with respect to the initial proposed appraisal scope, well count, and completion strategy with a cost saving of close to $50M.

Keywords: Niger Delta, Fluid, Uncertainty, Seismic Reservoir, Channel, Faulting, Impedance, Semblance.

INTRODUCTION

Fluid type and contact uncertainties are common place in shallow offshore fields mainly due to structural complexity (dense faulting), complex reservoir architecture, limited well data and occasionally sub-optimal seismic data quality. Despite Egu field being one of the most developed shallow offshore fields, this challenge still exists. Finding an approach to dealing with fluid type and contact issues is considered critical in realizing the huge potential in Nigeria's shallow offshore fields.

The C8000 and C9000 reservoirs were studied as part of the feasibility assessment for Egu Later Oil and Gas Development (LOGD) project. During the initial data analysis phase, fluid fill and contacts were identified as major uncertainties for these reservoirs. Further development of both reservoirs hinged on developing an improved understating of the pore fill type, fluid distribution and fluid contacts which made it important for an in-depth interrogation into all available data. Due to insufficient well data (pressure, density-neutron logs etc.), the approach adopted in resolving the underlying fluid uncertainties was heavily dependent on seismic data. This paper therefore showcases the detailed seismic technique integrated with other subsurface information in resolving the fluid uncertainties in Egu field.

GEOLOGICAL SETTING AND FIELD OVERVIEW

Geological Setting

Egu field is situated 100 km southwest of Warri (Figure 1). The field lies shallow offshore of the Niger Delta in 13 to 30 meters of water depth. The fields comprise of a large, elongate, NW-SE trending rollover, collapsed-crest structure, bounded to the North by a regional growth fault with an SW hade (Figure 2). This fault flattens with depth

We are grateful to the Shell Petroleum Development Company for granting the permission to publish this work.

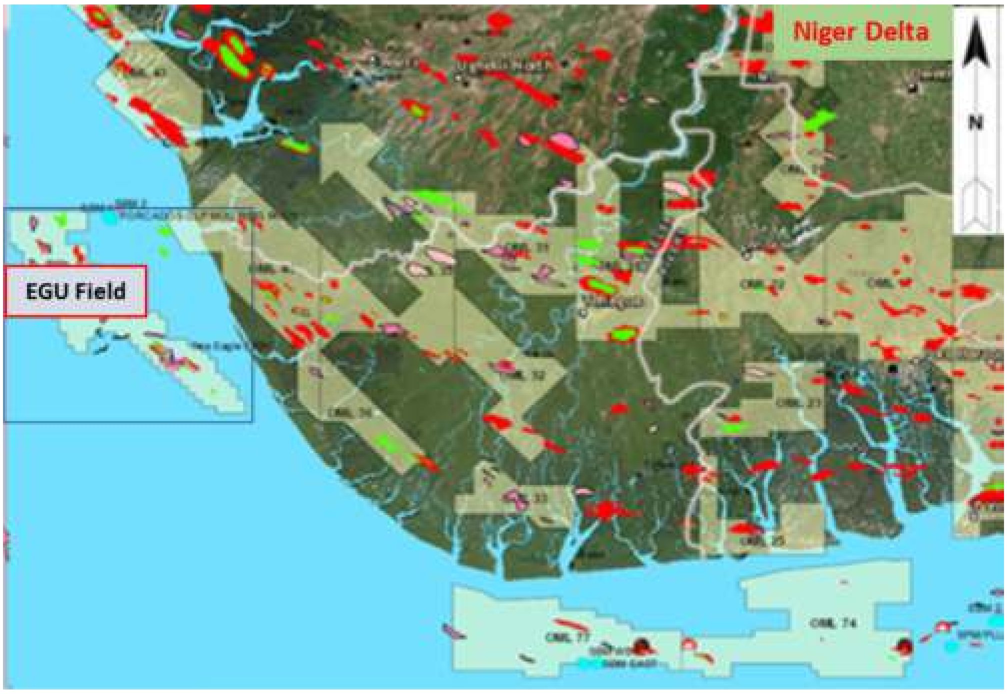

Figure 1: Map showing the location of Egu field.

into the bedding plane below the field, at about 12500ft TVDSS.

The structure is dissected by a system of semi-parallel NW-SE trending antithetic and synthetic faults into thin semi-parallel fault blocks, resulting in several fault-dip closures and collapsed crest. The faults form fault blocks that are some 0.5 to 1.5 km in width, partially closed-off to the West and North-West by boundary faults. However, the faults open out to the SE, as far as the currently interpreted seismic data delineates, creating a potential for good aquifer support to the SE directions for all Egu Field's blocks. Estimated fault blocks lengths are in the order of some 5 to 10+ km. Hydrocarbon accumulations have been proven in all the fault-blocks (A, B, C, D, E, G, H, K, N, P &Y). However, only A, B and C blocks are been studied in the Egu-LOGD Project. Hydrocarbon accumulations in these blocks are typically elongate, parallel to structural and depositional strike and are bounded by antithetic normal faults within the collapsed-

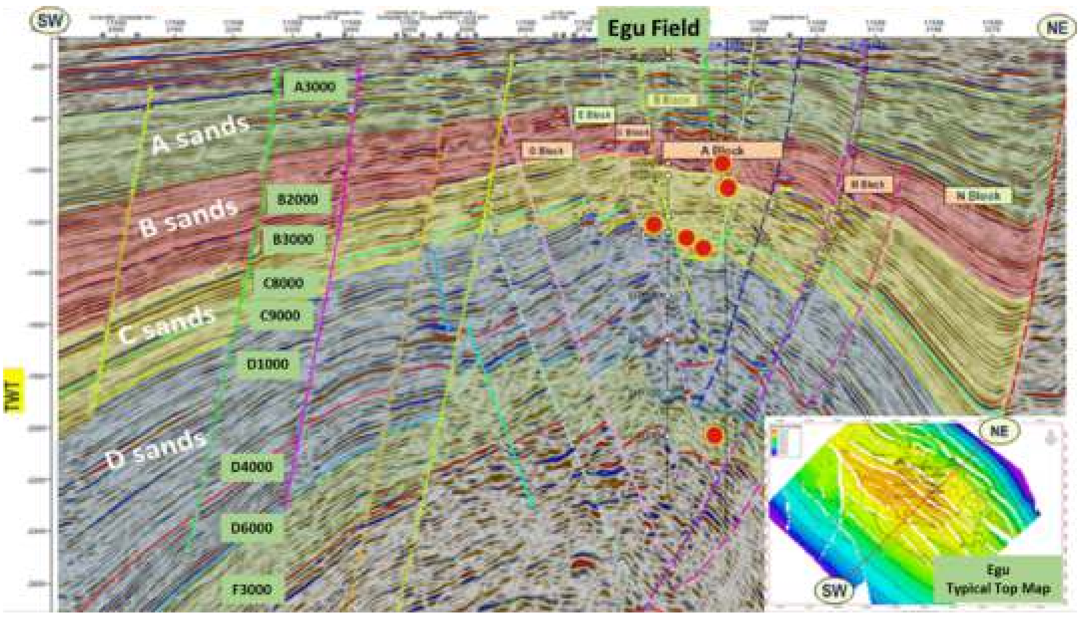

Figure 2: Dip-orientated seismic line revealing structural pattern in Egu field

crest rollovers structure.

The basic sedimentary system in Egu field is interpreted as a wave-dominated delta. The stratigraphic column consists of stacked marine shales, shoreface, and estuarine channel deposits. The sands of the 'Shelf-Shallow Offshore Belt' have been deposited during the progradation process, which became progressively younger in seawards direction. The C8000 and C9000 reservoir sands are relatively thick (ca. 100 m gross thickness) deltaic sequence. Figure 3 is an example of a correlation panel showing the near consistent thickness of the C9000 reservoir. Overall, the sedimentary pile and the structural framework of the Egu field is linked to the evolution of the Niger Delta controlled by pre- and syn-sedimentary tectonics described by Evamy et al. (1978), Ejedawe (1981) and Doust & Omatsola (1990). Wells drilled in Egu field encountered stratigraphic units recognized in other fields of the Niger Delta shallow-water system, and consistent with the Niger Delta tripartite lithostratigrahic units - the Akata, Agbada and the Benin Formations as described by Doust & Omatsola (1990).

FIELD OVERVIEW

Sixty wells have been drilled in the Egu field, more than a third of these wells were exploration/appraisal wells – this is due to the compartmentalized nature of the field. Production from the field started in 2002 via an FPSO. The key challenge in the field is how to arrest production decline (Figure 4) which has led to the substantial under-utilization of the FPSO. The C8000 and C9000 reservoir are two of the reservoirs that were planned for late development due to their size and relatively more complex nature compared to the currently producing reservoirs. A project to develop both reservoirs along with 5 others is currently in the feasibility stage. The key uncertainties for the C8000 and C9000 reservoirs are pore fill type, fluid distribution and contact. Managing or reducing these uncertainties is crucial to reaching a final development decision for both reservoirs.

DATA AVAILABILITY

Well Logs

Fifteen wells have penetrated the C8000 reservoir so far, open hole logging was conducted in all the wells. The

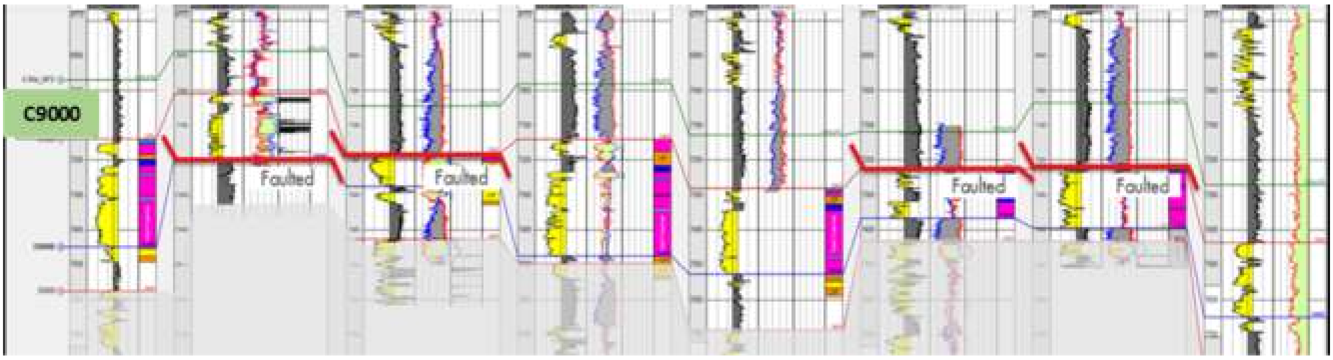

Figure 3: Well correlation panel for C8000 reservoir.

Figure 4: Egu historical production and deferment. Plot shows a steady production decline through time.

acquired logs are of different vintages spanning a period from 1965 to 2002. In summary, there's good coverage of gamma ray and resistivity logs for C8000 but only a limited number of wells have density/neutron logs. Formation pressure data was acquired in Well A12 both in the oil and gas leg. Also, PVT data is available in A9 well.

Nine wells have been drilled into the C9000 reservoir with two wells (B1 and B2) penetrating the block of interest (Block C). Gamma ray and resistivity logs were acquired in both wells but only Well B2 had density/neutron logs.

Sidewall core sample data is available in about a third of the wells drilled in Egu field. The summary fluorescence for these wells was used to support the definition of reservoir pore fill where the data was available. Full bore cores were not cut in any of the reservoirs of interest. The table below illustrates the well data coverage across C8000 and C9000 reservoirs.

Log quality control (QC), depth matching, and environmental corrections were applied on all the logs using the standard techniques prior to utilizing them for the petrophysical study. Generally, the logs and data available for the study were of satisfactory quality. However, the presence of most of the well data requisite for fluid typing and contact definition is not evenly distributed across the Egu structure with most of the data acquired in wells located in some fault blocks or across shallower reservoir levels leaving an uncertainty across the reservoirs and blocks of interest.

3D Seismic

Information derived from seismic data is constrained by its vertical resolution. In general it is not possible to resolve formation thickness to less than 10m , although this resolution varies as a function of the seismic

Table1: Well data coverage in C8000 and C9000 reservoir.

RESERVOIR	LOG	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
C8000	GR	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	RES	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	DEN	N	N	Y	N	N	N	Y	Y	Y	N	N	Y	N	N	N
	NEU	N	N	N	N	N	N	Y	Y	Y	N	N	Y	N	N	N
	DTC	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N
	RFT	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N

RESERVOIR	LOG	B1	B2
C9000 Block C	GR	Y	Y
	RES	Y	Y
	DEN	N	Y
	NEU	N	Y
	DTC	N	N
	RFT	N	N

Y Available N Not Available Y Available but low quality

Figure 5: Hydrocarbon fluid distribution stick plot for C8000 reservoir showing varying OWC contact and deeper than expected ODT logged in A2 well. Well distribution on stick plot is aligned with their location on structure.

frequency and the velocity of the rock being investigated. The 3D seismic data utilized in this study was acquired using the streamer technique across the study area. A Kirchhoff Pre-stack Depth Migration (PSDM) was the processing algorithm applied to the seismic data. The data showcases the structure and stratigraphy within a 6s window, sampled at 4 ms and processed at a bin grid of 25m x 25m. The dominant frequency of this survey is 20Hz although the overall frequency ranges from 5-70Hz. The data has been processed as a zero-phase wavelet with a negative polarity displayed as a trough that characterizes an increase in acoustic impedance. The seismic data is of reasonable quality with a signal to noise crossover frequency of 25hz. The C8000 and C9000 surfaces representing the top of these reservoirs are strong continuous seismic reflectors and were mapped across the 3D seismic data.

METHODOLOGY

Petrophysical Evaluation

Fluid type interpretation was done using a combination of log data, sidewall core sample descriptions and formation pressure data were available. Integration between the Petrophysicist, Production Geologist and Seismologist ensured that the structural framework was consistent with the fluid distribution as interpreted from well data.

C8000 Reservoir

Majority of the wells that penetrated C8000 reservoir do not have density/neutron logs which makes gas/oil differentiation across the reservoir challenging. The original gas-oil contact (OGOC) interpretation is based mainly on density/neutron data from Well A12, supported by RFT data in the same well. A 4 ft deeper OGOC was picked for Well A3 using a combination of sidewall sample shows and density log data but this data was considered less reliable than the Well A12 data. Varying oil-water contacts (OWCs) were penetrated by different wells with a 6 ft difference between the shallowest logged OWC at 2953 ftss (Well A9) and the deepest logged OWC at 2959 ftss (Well A7). Well A2 encountered an ODT at 2962 ftss, 13 ft deeper than the deepest logged OWC. This is considered a major uncertainty for the C8000 reservoir. What could be responsible for the varying OWC encountered by these wells particularly Well A2 that penetrated an ODT deeper than the fluid contacts logged by other wells? Investigations into possible depth errors with Well A2 were made but no systematic depth error was established. A stick plot showing the fluid distribution for the C8000 reservoir is shown below (Figure 5). A major part of this study was geared towards deepening our understanding of geological controls on varied fluid contacts.

C9000 Reservoir

Two wells (B1 and B2) penetrated the C9000 reservoir in the block C- the main block of interest. Full suite of logs was acquired in Well B2 while only resistivity and GR logs were acquired in Well B1. Well B2 is an up-dip penetration and encountered the reservoir fully gas bearing with a GDT at 7191 ftss while for Well B1, due to the absence of density/neutron logs, gas/oil differentiation could not be done. However, using the resistivity log a HCWC of 7294 ftss was interpreted leaving a 103ft unknown hydrocarbon column between the GDT of 7191 ftss (logged by Well B2) and the logged HCWC in B1. The Figure below shows the fluid distribution interpretation for C9000 reservoir across three blocks.

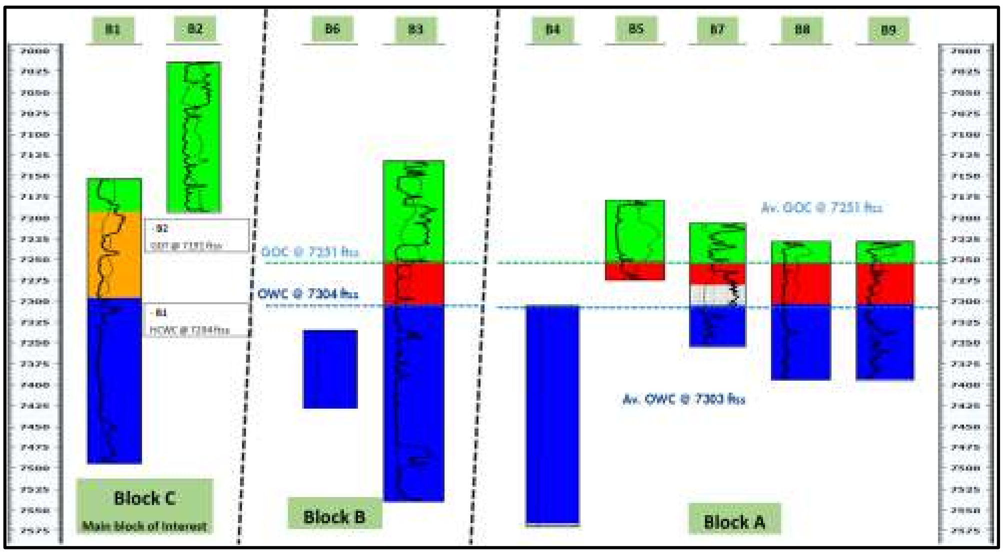

Figure 6: Hydrocarbon fluid distribution stick plot for C9000 reservoir showing varying pore fill and contact uncertainty in Block C. Beige color in B1 represent unknown fluid column. Well distribution on stick plot is aligned with their location on structure.

Reservoir Geophysics

Three primary seismic attributes were utilized in resolving pore fill and fluid contacts in the C8000 and C9000 reservoirs: (1) Root mean Square (RMS) amplitude; (2) Semblance and (3) Seismic acoustic impedance. Results from these attributes were calibrated with petrophysical log evaluation to ensure consistency with well information.

Root mean square Amplitude

RMS was calculated from the 3D seismic data for each of the reservoir referenced from interpreted top horizon. Figures 7 show the amplitude draped on the top maps for the C8000 and C9000 reservoirs respectively. Where a clear shut-off at the hydrocarbon water interface is seen, a cross plot of amplitude versus depth map can be used to predict the most likely fluid contact.

C8000 Reservoir

The C8000 map reveals a patchy amplitude signature with no definitive amplitude shut-off. In this situation the amplitude was not reliable in predicting fluid contact. Semblance attribute (discussed in the next paragraph) was used to improve our understanding of the geological controls of the varying fluid contacts seen in the C8000 reservoir particularly the deeper than expected ODT encountered by Well A2 as discussed in petrophysical evaluation section.

C9000 Reservoir

The C9000 reservoir is characterized by clearly defined amplitude shut-off across the hydrocarbon water interface. The amplitude distribution for this reservoir formed the basis for applying amplitude versus depth technique in predicting the fluid fill and contact. Figures 8

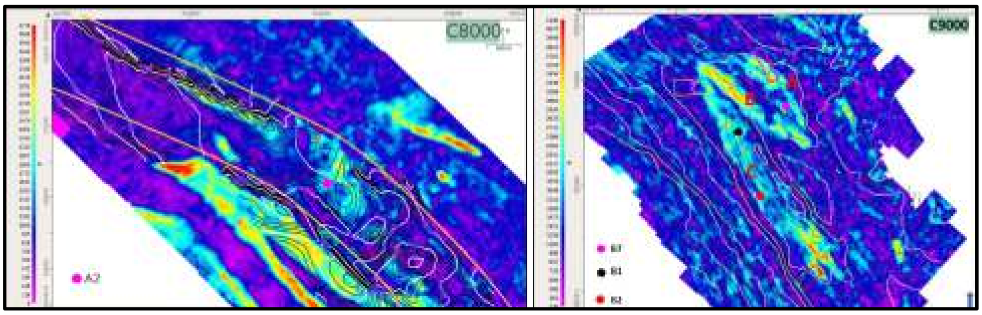

Figure 7: RMS amplitude maps for C8000 and C9000 reservoirs respectively. C8000 amplitude map appear to be patchy within block of interest defined by boundary faults in beige color.

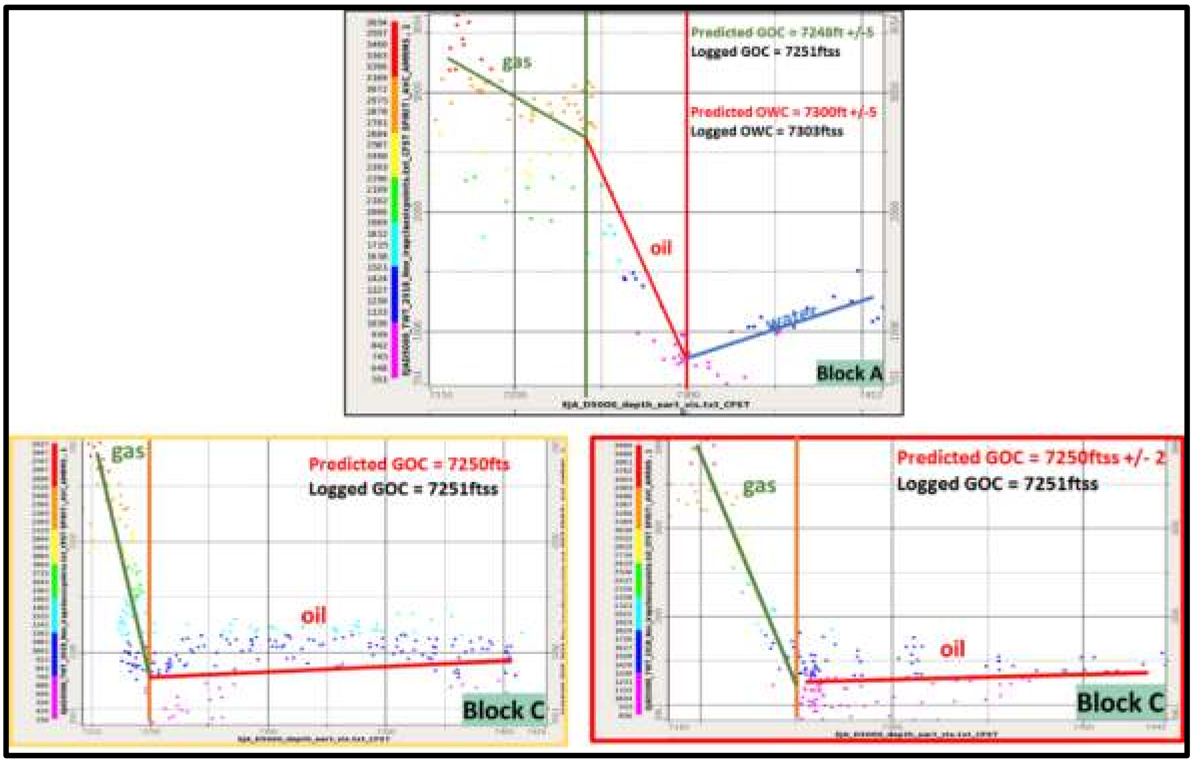

Figure 8: Amplitude Vs. Depth plot indicating predicted fluid contacts in C9000 reservoir.

a, b and c are three amplitude versus depth cross plot constrained by polygons drawn across two of the major fault blocks – A and C within the C9000 reservoir. The cross plot in Figure 8a is based on the polygon drawn in block A, showing three amplitude gradients indicating the presence of three fluid types. The inflection points on this cross plot defines the change from one fluid type to the other and can be interpreted as the fluid contact. Polygons taken across block C underpins the cross plots in Figures 8b and c. Both cross plots show only two fluid gradients with a single fluid contact.

Semblance Attribute

Semblance measures the discontinuity of the seismic data in the specified window. It is useful for highlighting structural and stratigraphic discontinuities (i.e. faults and channels). The semblance function calculates trace-to-trace similarity with an added advantage of improving the resolution of the seismic data despite the presence of background noise. This way both structural and stratigraphic features can be revealed which might not have been clearly visible from the raw reflectivity seismic data. Semblance was calculated over the C8000 reservoir revealing a distinct depositional architecture prevalent in the C8000 reservoir.

Seismic Acoustic Impedance

Seismic inversion is a process that converts raw reflectivity seismic data to a model that describes the subsurface and is consistent with the data (Brown, 2011). Most often reflectivity seismic data is inverted to an acoustic impedance volume. Acoustic impedance or P-impedance is the product of rock density and P-wave velocity. Compared to raw reflectivity seismic data which is an interface property, AI is a rock property that can easily be calibrated using measured well data. So, inverting a seismic data implies that each seismic trace is transformed to pseudo-acoustic impedance logs. A trace based constrained sparse spike (CSSI) inversion technique was adopted for this study. This technique uses

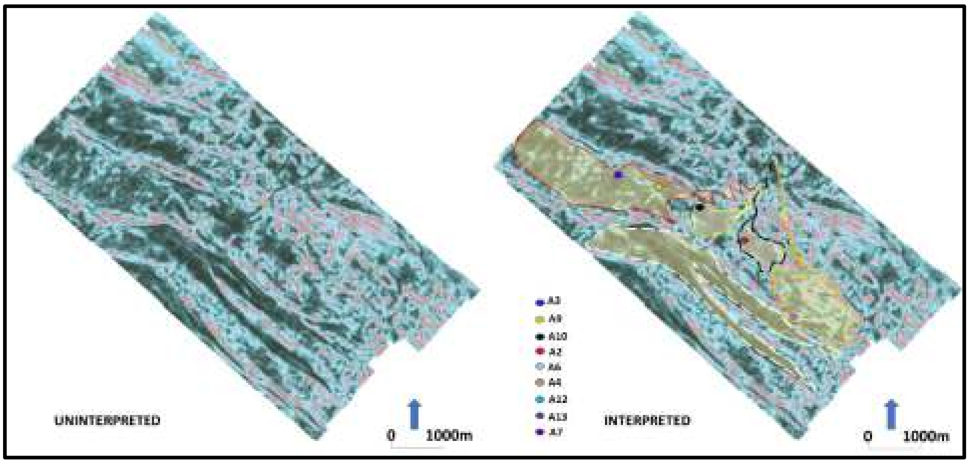

Figure 9: Uninterpreted and interpreted version of semblance map for C8000 reservoir. A Multi-channelized fan system is clearly revealed.

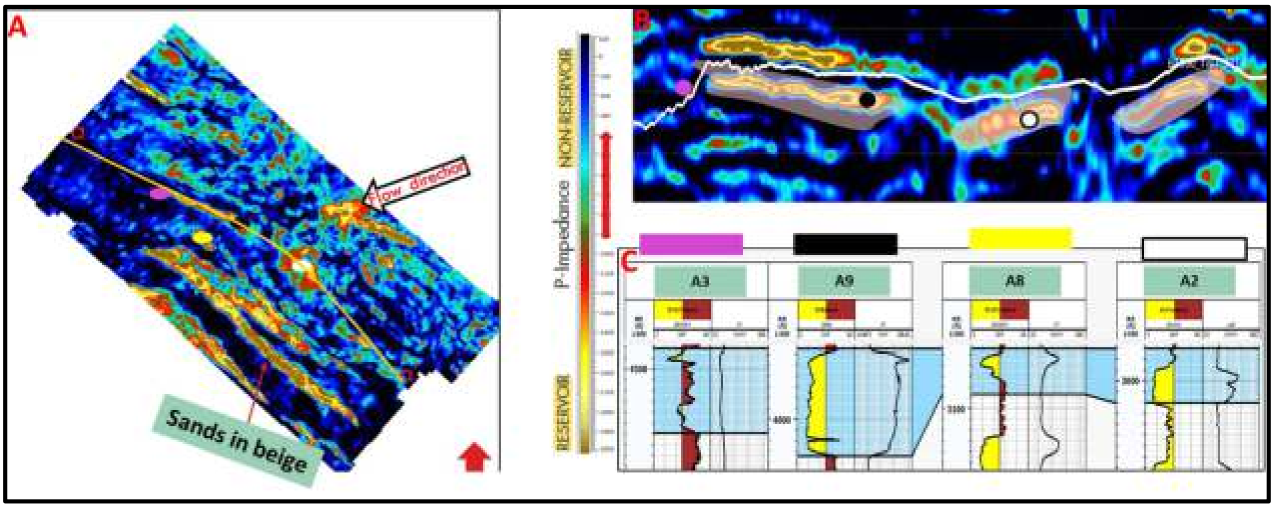

Figure 10: Acoustic impedance attribute in map (A) and section view (B) revealing the isolated nature of the channelized fan system. The acoustic impedance model agrees with gamma ray and resistivity logs at well location.

seismic trace data to model the subsurface reflectivity with minimum number of reflection coefficients. the resulting relative impedance values is converted to absolute impedance by combing the relative acoustic impedance model from seismic frequency range with a low frequency model resulting in a full band or absolute inverted impedance volume (Chudi, 2017). The full band acoustic impedance model has been widely used as a proxy for lithology discrimination and for predicting porosity.

For this study acoustic impedance model was built particularly for the C8000 reservoir to better understand its depositional architecture and to possibly infer the geological controls on the varying fluid contacts. Figure 10A below is a map of acoustic impedance draped on the C8000 structure. A line of section along strike (Figure 10B) reveals the depositional architecture of the C8000 reservoir and the predicted lithology is seen to agree nicely with gamma ray and resistivity logs (Figure 10C) at well locations.

RESULTS AND DISCUSSION

C8000 Reservoir

Interpreted semblance map (Figure 9) and acoustic impedance inversion in section view (Figure 10B) computed from seismic suggests that the C8000 depositional architecture is a multi-channelized fan system with varying degree of channel incisions. Well A2 encountered an isolated channel-fan element which is interpreted as being responsible for the contrasting fluid contacts logged hence defining the C8000 reservoir to be stratigraphically compartmentalized. Current study was completely different from previous interpretation of a structural controlled compartment. This proved useful in defining the development strategy for the reservoir with respect to selection of subsurface targets.

C9000 Reservoir

The amplitude versus depth (AVD) plot revealed gas-oil contact (GOC) and oil-water contact (OWC) in block A at 7248ftss and 7300ftss respectively. This closely agrees with the GOC and OWC 7251ftss and 7301ftss observed from wells drilled in this block (Figure 8A). The seismic based result from block A that ties with well data serves as prove of concept and therefore calibrates the results from Block C. The AVD plots for block C- the key block of interest revealed a single contact at 7250ftss (Figures 8B and C). This value coincides with the logged GOC in blocks A and B. Considering that resistivity log acquired from Well B1 located in Block C defines a hydrocarbon-water (HCWC) contact at 7294ftss, it therefore implies that a 44ft of oil column exist in the block C with the OWC at 7294ftss closely tying with the OWC of 7300ftss seen in blocks A and B. The seismic based results therefore suggest that block C is possibly in hydraulic communication with blocks A and B.

IMPLICATION FOR RESERVOIR MODELLING & FIELD DEVELOPMENT

C8000 Reservoir

The results above suggest that the multi-channel fan system with varying degree of incision is responsible for the varying oil contacts seen in the C8000 with Well 2

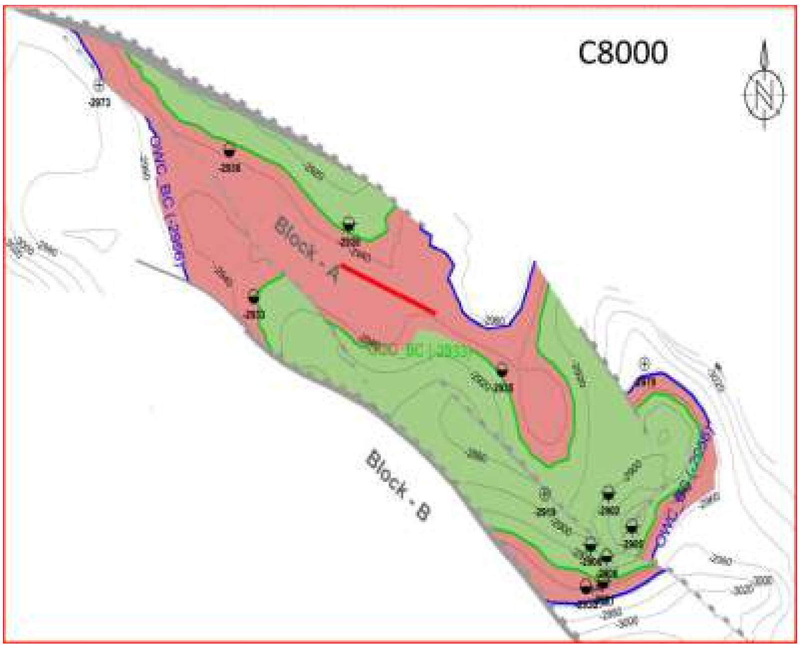

Figure 11: Top structural map of C8000 reservoir showing location of planned development well with red line.

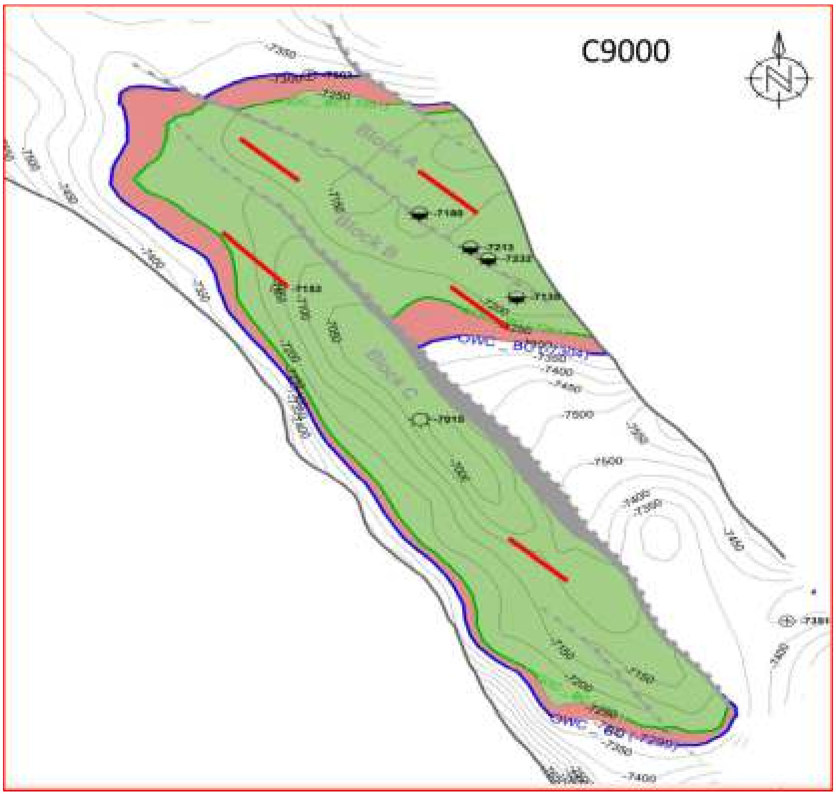

Figure 12: Top structural map of C9000 reservoir showing location of planned development wells in red lines.

penetrating a deeper contact compared to other wells. Although clearer understanding of the variation in contact has been achieved from the seismic data, the actual OWC logged within the "Well 2" channel-fan is yet to be resolved as the amplitude map does not support the use of amplitude versus depth technique. To manage this uncertainty, two geological concepts were defined:

a) A geological concept where communication across the reservoir was invoked with a single average contact defined across the reservoir

b) A geological concept where channel incision was model around Well A2 with relatively deeper OWC as observed from the log.

The outcome of uncertainty parameter screening shows that the impact of channel incision around well 2 with deeper contact is less than 5% on recovery. With a single horizontal well planned to develop the C8000 (Figure 11).

C9000 Reservoir

The initial understanding based on previous subsurface studies suggested that blocks A and B where compartmentalize from block C and therefore an appraisal well or pilot hole was proposed to de-risk contact uncertainty in Block C. However, based on the current understanding from seismic data, fluid contact in block C has been de-risked based on the integration of seismic data and well information, thereby eliminating the need for an appraisal well or pilot hole and bringing down the well count from 6 to 5 wells (Figure 12) with a cost savings of about $50M.

CONCLUSION

A reliable technique based on the integration of well data and seismic attributes have been used to resolve the fluid type and contact uncertainty in Egu field located shallow offshore Niger Delta. Through the integration of semblance and acoustic impedance models the C8000 reservoir has been interpreted to be predominantly a channelized fan system. With each channel characterized by varying degree of incision. This is believed to be responsible for the varying fluid contact seen in the C8000 reservoir. Despite the varying contacts, its impact on recovery is minimal.

Although the C9000 reservoir is observed to be segmented into three major fault blocks, seismic amplitude versus depth plot integrated with well data suggests that blocks A, B and C are in hydraulic communication with similar GOC and OWC of 7250ftss and 7300ftss respectively. This opposes the previous understanding of a structurally compartmentalized reservoir and therefore eliminates the need of drilling an earlier planned pilot well in block C resulting in a cost savings of $50M.

REFERENCES CITED

Badley, M. E. (1985). Practical seismic interpretation, United States of America, D. Reidel Publishing Company.

Brown, A. R. (2011). Interpretation of three-dimensional seismic data. AAPG Memoir, 42, 295-308.

Chudi, O., Anaevune, A. (2017). An integrated rock physis and seismic inversion analysis for reservoir characterization and optimising infill well location in the K8 reservoir, Koko field, onshore Niger Delta. Presented at the 2017 Nigerian Association of Petroleum Explorationists (NAPE) International Conference, Nigeria.

Doust, H. & Omatsola, E. (1990). Niger Delta. In:Edwards,J.D., Santogrossi, P.A (Eds), Divergent/Passive Margin Basins. American Assoiciation of Petroleum Geologist, 4, 239-248.

Ejedawe, J., Coker, S., Lambert-Aikhionbare, D., Alofe, K. & Adoh, F. (1984). Evolution of oil-generative window and oil and gas occurrence in Tertiary Niger Delta Basin. AAPG Bulletin, 68, 1744-1751.

Evamy, B. D., Haremboure, J., Kamerling, P., Knaap, W. A., Molly, F. A. & Rowlands, P. H. (1978). Hydrocarbon habitat of Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin, 62, 1-3.