EVALUATION OF INFILL DRILLING OPPORTUNITIES USING RESERVOIR CONNECTIVITY ANALYSIS

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Abstract
Infill drilling involves drilling new wells in an existing field within the original well patterns for the purpose of more efficient recovery of petroleum from the reservoir. If the reservoir is incompletely swept, infill drilling provides an opportunity to increase the rate of production in the field and also to add to reserves. Cases of successful and unsuccessful infill drilling program have been reported.
This paper presents the evaluation of infill drilling opportunities using Reservoir Connectivity Analysis (RCA). Two RCA studies that have been carried out in Erha field were used for the study. Erha field is located in OML 133 which is approximately 100 km offshore from Lagos, Nigeria. Results from the first RCA study provide a consistent explanation on the fluid contact distribution across the Erha field. The second RCA study identified both fault juxtaposition and stratigraphic connection windows that were integrated into the connectivity diagram. This is in agreement with the better connectivity and communication across channel complexes indicated by production data.
The second RCA fluid predictions for identified compartments generally support the proposed infill drilling opportunities. Opportunities identified on the west flank by detailed sand mapping were supported by the RCA model to contain oil in the identified compartments.
However, proposed infill drilling opportunities on the east flank, fall lower in the seriatim due to more isolated gas compartments and complex faulting.

The second RCA outlined a potential location for an infill drilling opportunity in the east flank channel complex, which should be validatedwith 4D integration, although faulting in the east flank continues to be a challenge.

Keywords: Infill Drilling, Viability, Reservoir Connectivity, Reservoir compartment, Fault juxtaposition, Stratigraphic
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1.0 INTRODUCTION

INFILL drilling means drilling additional wells, often between the original development wells in order to produce unrecovered hydrocarbon. Infill drilling involves drilling new wells in an existing field within the original well patterns for the purpose of more efficient recovery of petroleum from the reservoir [1]. According to Frank et al [2], hydrocarbons can remain un-drained for a number of reasons:

i. Attic / cellar oil may be left behind above (or below) production wells
ii. Oil or gas may be trapped in isolated fault blocks or layers
iii. Oil may be bypassed by water or gas flood
iv. Wells may be too far apart to access all reserves.

Generally, Infill drilling can be considered feasible and successful as long as the amount of production increment covers the cost of the extra wells and associated pipe works at small financial risk.
Cases of successful and failures of infill drilling program have been reported [3, 4, 5, 6, 7, and 8].
Studies [9, 10, 11, 12, 13, 14 and 15] have also shown that unless there is continuity between the injecting and production wells during a water flood, the reservoir will be incompletely swept. If the reservoir is incompletely swept, infill drilling provides an opportunity to increase the rate of production in the field and also to add to reserves [16]. Reviere and Wu [17] further stated that Infill drilling performance is sensitive to water cut at infill, reservoir heterogeneity and degree of cross flow between layers.

Connectivity and compartments represent some of the fundamental properties of a reservoir that directly affects recovery. If a portion of a reservoir is not connected to a well, it cannot be drained [18]. Generally, two connectivity are defined, Geobody or Sandbody connectivity and Reservoir – well connectivity or simply reservoir connectivity. Geobody or Sandbody refers to the connectivity of individual elements in the reservoir. Reservoir – well connectivity or reservoir connectivity is the proportion of the reservoir that is connected to the well. Reservoir compartment are non-connected part of the reservoir.
Furthermore, some reservoirs are characterized of thin pay thickness particularly in the Niger Delta. When reservoir thickness is less than the height of the trap closure and when faults stratigraphic facies changes provides lateral seals hydrocarbon contacts in petroleum reservoirs become complex. This makes fluids contacts apparently unpredictable and the development and production of the reservoirs inefficient [19]. Hence in infill drilling program be should designed to cognizance of the reservoir connectivity.
The Reservoir Connectivity Analysis (RCA) provides a method for combining complex stratigraphic and structural models

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with fluid observation to define reservoir connections and compartments.

This paper presents the evaluation of the viability of infill drilling opportunities using reservoir connectivity analysis. Two RCA studies that have been carried out in Erha field were used for the study.

1.1 HISTORY OF ERHA FIELD

Erha field is located in OML 133.OML 133 is located approximately 100 km offshore from Lagos (Figure 2.1). It is approximately 1,100 km^2 and reflects the 50 percent relinquishment outline of the former OPL (Oil Processing Licence) 209 required as a condition for the February 2006 conversion of the OPL to the OML (Oil Mining Licence) by the Esso Exploration and Production Nigeria Ltd. (EEPNL) and its co-venturers. Water depths range from 800 m to 1960 m [20]. Erha field was discovered with the drilling of the Erha 1 well in February 1999 and was further delineated with the drilling of the Erha 2 well later in 1999 and Erha 3 and Erha 3ST1 wells in 2001.

The Erha structure is a NNW-SSE trending, shale-cored anticline that plunges towards the NNW. It is developed in the N4 reservoir, which comprises of Middle Miocene confined channel complexes. Twenty three development wells (sixteen producers - including one redrill and one sidetrack, four gas injectors and three water injectors) have been successfully drilled to date. Erha began production on March 27, 2006 from the eastern drill center (DCE). Production from the western drill center (DCW) was brought online on May 17, 2006. Continuous injection of both gas and water occurred in June 2006 and has continued since then. Erha field has produced 188 MBO as at the end of 2009, and has 2P (proved and probable) reserves of 492 MBO.

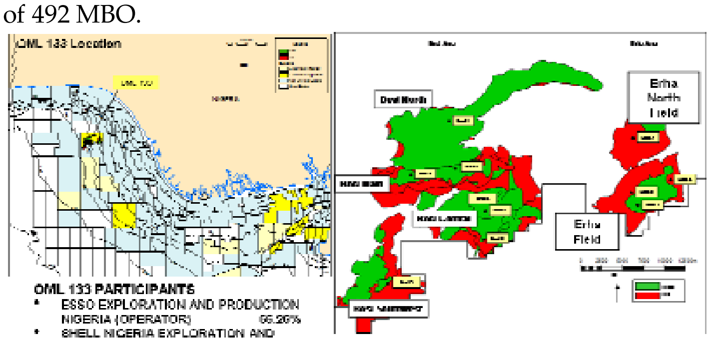

Figure 1: OML 133 Location

1.1.1 ERHA INFILL DRILL OPPORTUNITIES

Nine (9) potential drill well locations (Figure 2) were delineated from the Erha field study effort. The study utilized the 2005 high resolution 3D seismic data (6.25x12.5 bin size), twenty eight development wells and dynamic data integration which resulted in a more robust stratigraphic and structural framework.

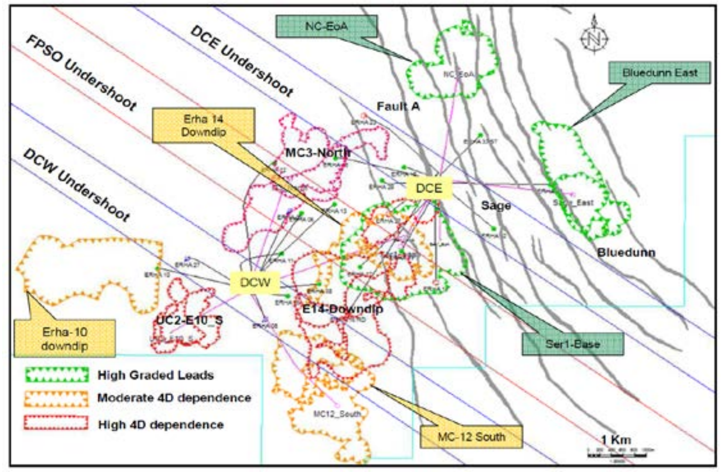

Figure 2: Erha infill drill well locations

1.2 RCA HISTORY

Based on the results of Erha-1 and Erha-2 wells, a field wide common contact was assumed for the east and west flanks of the field (Figure 3), which formed the basis for the STOIIP calculation. The OWC (Oil Water Contact) is interpreted to be controlled by a synclinal spill to the west at 3518 m (TVDSS) and GOC (Gas Oil Contact) at 3144m is controlled by capillary leak at the crest.

However, Erha-3OH and Erha-3ST drilled in October 2001 encountered higher contacts relative to Erha 1 and Erha 2 (Erha-3OH: GOC 3108m, OWC 3211m, Erha-3ST: OWC 3264). The different contacts encountered suggested compartmentalization. It initiated the Reservoir Connectivity Analysis (RCA) study to understand the field segmentation and contacts control.

1.2.1 ERHA DISCOVERY POST-DRILL ANALYSIS

i. Erha-2 Appraisal December 1999
ii. GOC 3144 mss, OWC 3518 mss
iii. Assumed field-wide common contacts in base case; East Flank risked in 1999 GPF Erha-1 Discovery February 1999 (COS 72%)
iv. Oil exit by synclinal spill to west and gas exit by capillary leak at crest

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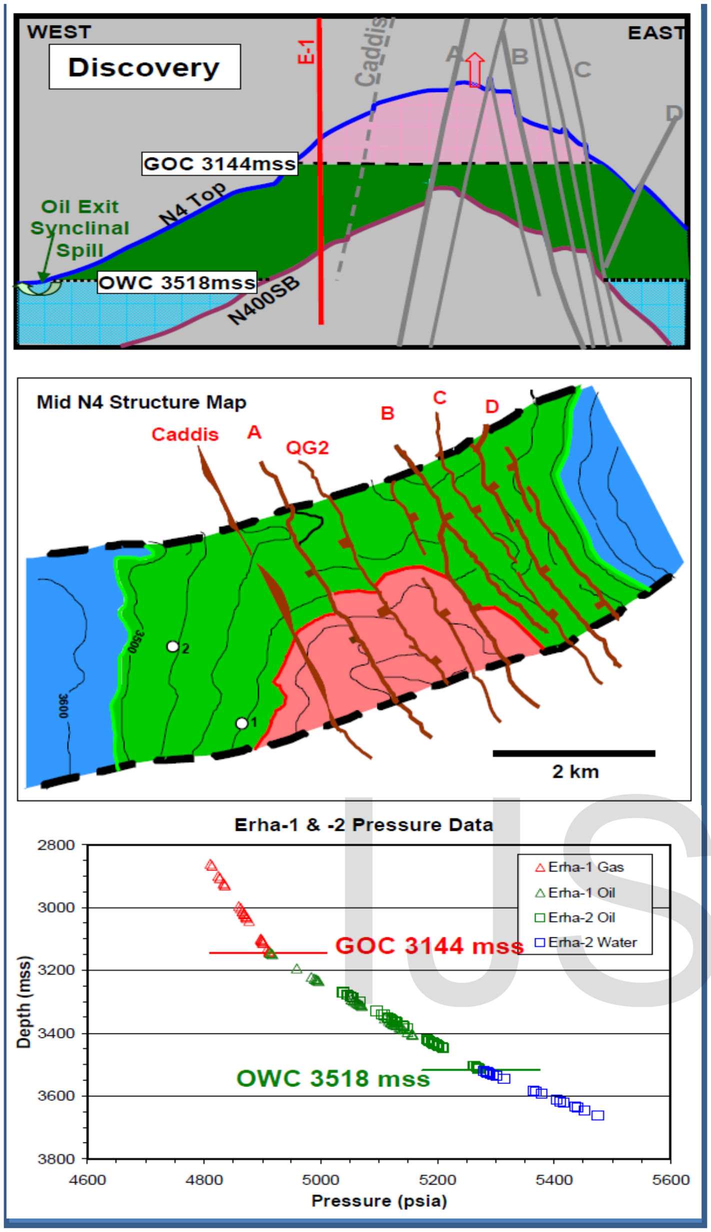

Figure 3: Erha Discovery Post Drill Analysis

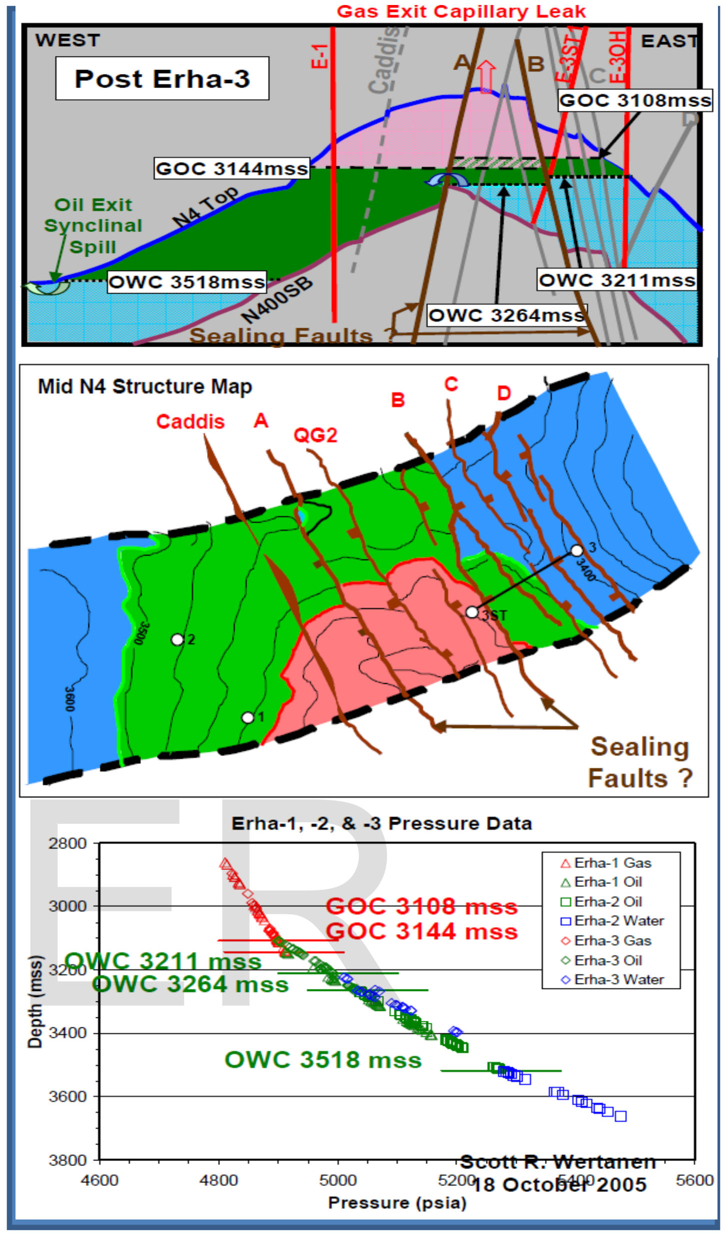

Figure 4: Post Erha-3 & Erha-3st Fluid Contacts

1.2.2 POST ERHA-3 & ERHA-3ST FLUID CONTACTS

i. East flank Erha-3OH & -3ST October 2001, encountered significantly higher aquifer pressure and OWCs relative to Erha-1, -2
ii. Erha-3OH GOC 3108 mss and OWC 3211 mss; Erha-3ST OWC 3264 mss
iii. Different fluid contacts associated with fault seal or perched water (base-seal breakover)
iv. Ultimate oil exit by synclinal spill to west and gas exit by capillary leak at crest

2.0. MATERIALS AND METHODS

2.1 MATERIALS

Two RCA studies that have been carried out in Erha field were used for the study. The first RCA study was carried out in 2004 to understand the OWC distribution after Erha-3 and Erha-3st were drilled. This RCA study was later updated to incorporate more data and new observations from the early development drilling.

The recent RCA study was conducted in 2009 and triggered by the Phase 5 stratigraphic framework change. The framework change resulted in a new RCA static model and plumbing network for fluid movement.

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2.2. METHODS

The typical RCA workflow is shown in Table 1.

TABLE 1: TYPICAL RCA WORKFLOW

Basic Process	Process defined
Identify and describe reservoir compartments	Identify potential compartments defined by structure and stratigraphy (map analysis)
	Establish constraints on fluid contacts in each well.
	Analyse fluid pressure and compositional data and establish pressure lines
Identify and define Connections between compartments	Identify structural connections between map compartments
	Identify stratigraphic connections between map compartments
Build an Integrated model	Integrate fluid and map data to establish contacts/contact constraints in penetrated compartments
	Identify potential system exit pathways – ultimate control on hydrocarbon fill
	Build a model that explains how fluids exit each compartment to reach a system exit
	Use this model to predict fluid contact elevations in remaining compartments

Sound stratigraphic and structural frameworks are formidable foundations for RCA study and define the static model. Any change in the framework will lead to modification of the static model. Pressure data and fluid observations are integrated with the RCA static model to identify the potential fluid exit pathways from one compartment to another until the ultimate spill point is reached. The final RCA model is used to predict fluid contact elevations in the remaining un-penetrated compartments.

3.0 RESULTS AND DISCUSSION

3.1 RCA PRESSURE DATA PLOT

There are a few important observations from the excess pressure plot (Figure 5).

a) Gas pressure falls on a single pressure line and little offset is observed in the gas column. It implies that gas is in pressure communication for most part of the field.

b) The pressure offset observed in oil column is small; intra-well pressure offset is ~2psi, interwell pressure offset is ~10psi. The pressure communication is often observed across a significant shale interval. At present, two compartments have been identified in oil column based on the pressure data; west of Sage fault and east of Sage fault. The pressure separation is ~14psi.

c) The largest pressure offset is observed in aquifer (Figures 5 and 6). The pressure difference is >200psi between the east flank and the west flank. It implies that most compartmentalization occurs in the water leg and the aquifer in the east flank is not in communication with the west flank. The higher water pressure in the east flank suggests that the water is isolated or perched from the rest of the field aquifer.

d) Four Oil and water contacts in the western flank are confirmed either by penetration or by pressure data. The OWC step-down to the west suggests that four water compartments give rise to the different OWCs and the water pressure in each compartment decrease towards the west until reaching the ultimate control point – synclinal spill.

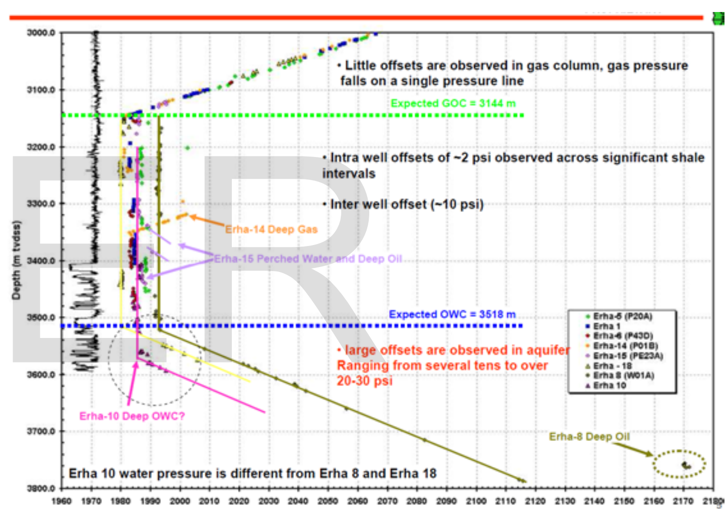

Figure 5: Erha MDT (Modular Dynamics Formation Tester) Excess Pressure (Oil) data

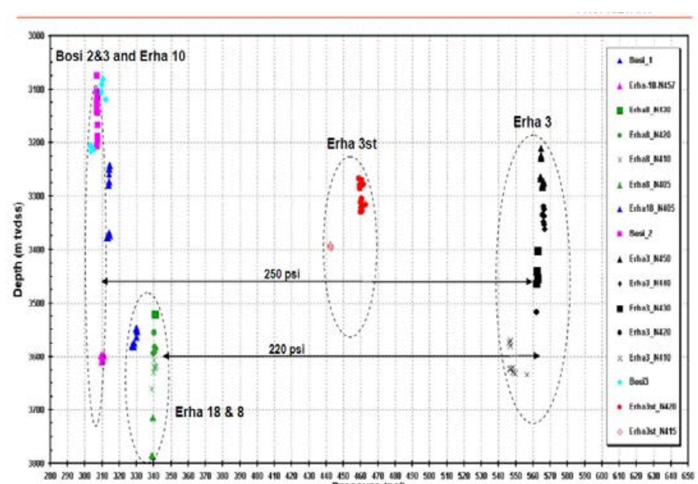

Figure 6: Bosi & Erha—Water Excess Pressure data

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3.2 RESULTS FROM THE FIRST RCA

Results from the first RCA study are summarized in Figure 7. It provides a consistent explanation on the fluid contact distribution across the Erha field.

a) There are three GOCs; 3144m on the western flank, 3112m on the crest, and 3108m on the eastern flank. The existence of three GOCs suggests the oil column is segmented into three compartments. The different oil pressure in each compartment causes the different GOC elevation.

b) Seven OWCs are stepped down from the east to the west until reaching the synclinal spill point in the west, which is interpreted as the ultimate control for oil to exit from Erha. The step-down pattern implies that the aquifer pressure decreases from the east to the west. The different water pressure in each aquifer compartment causes the different OWC elevation.

c) Multiple OWCs do not necessarily mean that the field is segmented. Oil can be in communication.

d) The OWC control point is believed to be a break-over point, which is the up dip point that shale interval is eroded. Higher density fluid (water) spills across the break-over point from a higher pressure compartment to a lower pressured compartment.

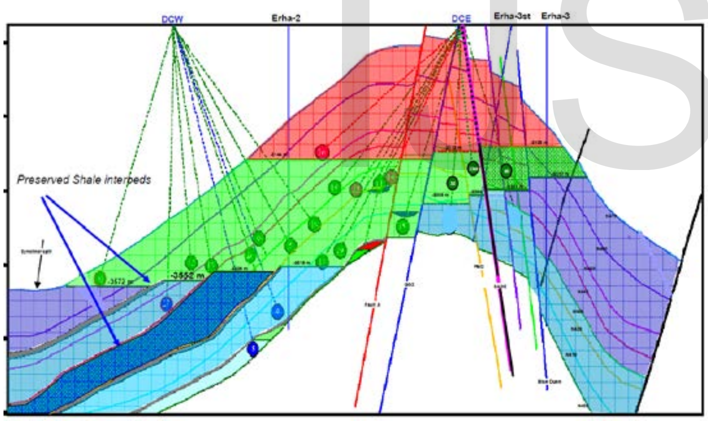

Figure 7: Erha Hydrocarbon Distribution Cross-section

3.3 RESULTS FROM THE FIRST RCA (2009 RCA Study: Post-Production)

The 2009 RCA study used an integrated approach in developing a static RCA model that explains how fluids moved from identified compartments to the known system exits that is consistent with observed fluid elevations, pressure observations and production data.

The major difference between the Phase 5 and Phase 4 frameworks is in the channel stacking pattern.

The phase 5 framework is incisonal, whereas the phase 4 is more aggradational (layer cake).

This difference suggests that the plumbing system is different.

A set of compartments are delineated based on structure maps. The spill and break-over points are identified for each compartment. Figure 8 shows an example of the compartment identification.

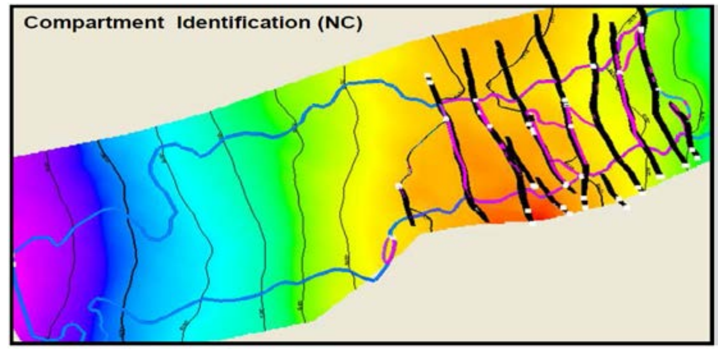

Figure 8: Erha Compartment Identification

The 2009 RCA study identified both fault juxtaposition and stratigraphic connection windows that were integrated into the connectivity diagram. This is in agreement with the better connectivity and communication across channel complexes indicated by production data.

Stratigraphic connection windows associated with channel incision across channel complexes were identified and incorporated into the connectivity diagram. These connections across different compartments across channel complexes provide a more robust understanding of reservoir plumbing.

Fault juxtaposition connection windows connecting hanging wall and foot wall sections of channel complexes (across same channel or multiple channels) were delineated to address the cross- fault connectivity and identify fault compartments. Figure 9 shows an example of the fault juxtaposition analysis.

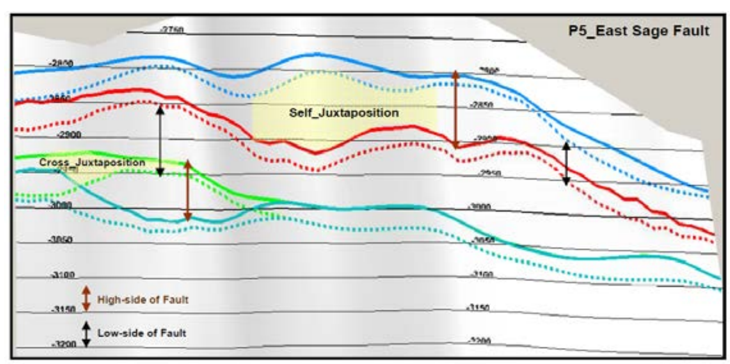

Figure 9: Erha Fault Juxtaposition Analyses

An integrated static RCA model detailing fluid flow (gas and oil) through identified compartments to the system exits for oil and gas was plotted, using all available well, pressure and production data as control points. Predicted Hydrocarbon distribution maps and charts were developed from the RCA model for each of the nine channel complexes (Figure 10).

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Integrated Connectivity Diagram

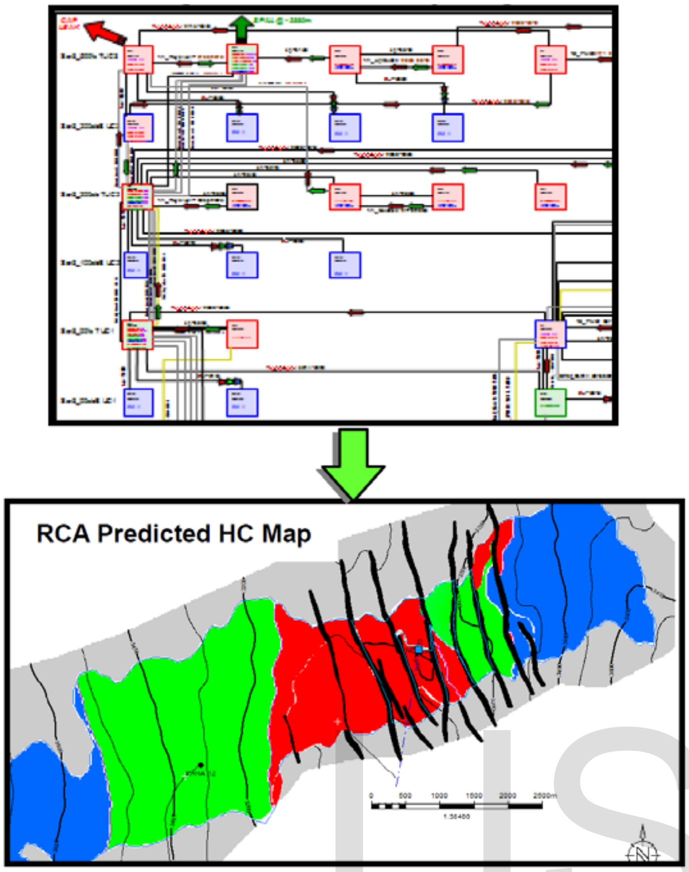

Figure 10: Erha RCA Connectivity Diagram

The 2009 RCA model shows the Phase 5 reservoir characterization to be internally consistent. This is based on the agreement of input production data with the phase 5 stratigraphic framework.

The RCA model predicted more isolated gas and perched water compartments than formally known from pressure data analysis.

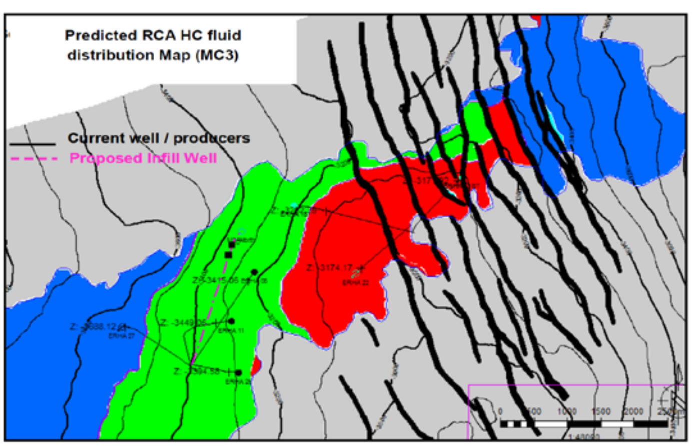

Figure 11: Predicted RCA HC Fluid Distribution Map (MC3)

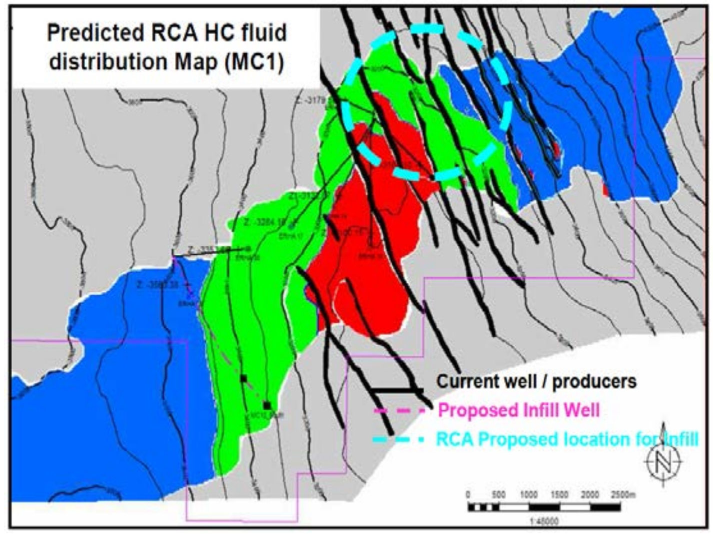

Figure 12: Predicted RCA HC Fluid Distribution Map (MC1)

Conclusions

2009 RCA fluid predictions for identified compartments generally support the proposed infill drilling opportunities. Opportunities identified on the west flank by detailed sand mapping were supported by the RCA model to contain oil in the identified compartments.

However, proposed infill drilling opportunities on the east flank, fall lower in the seriatim due to more isolated gas compartments and complex faulting.

2009 RCA outlined a potential location for an infill drilling opportunity in the east flank (MC1) channel complex, which should be validated with 4D integration, although faulting in the east flank continues to be a challenge.

Acknowledgment

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NOMENCLATURE

2P = Proved and Probable
COS = Cost
DCE = Eastern Drill Center
DCW = western Drill Center
EEPNL = Esso Exploration and Production Nigeria Limited
GOC = Gas Oil Contact
GPF = Gross Project Fee
HC = Hydrocarbon
LC = Lower Channel
MBO = Thousand Barrels of oil
MC = Middle Channel
mss = Metre Subsea
OML = Oil Mining License
OPL = Oil Processing License
OWC = Oil Water Contact
RCA = Reservoir Connectivity Analysis
STOIIP = Stock Tank Original Initially In Place
TVDSS = True vertical Depth Subsea
UC = Upper Channel

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