3-Dimensional seismic interpretation and fault seal assessment of Ganga Field, Niger Delta, Nigeria

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ABSTRACT

3-dimensional seismic and fault seal assessment were carried out in Ganga, a hydrocarbon bearing field in the Central swamp depobelt of Niger delta basin, Nigeria. The study aimed at assessing the risk associated with fault related hydrocarbon traps by evaluating the fault seal. Fault seal assessment has been identified as an important part of hydrocarbon exploration process especially in the case of exploration for fault-related structural hydrocarbon traps. Fault seal assessment results is also utilized for proper development of faulted reservoirs. Fault seal may occur from a variety of processes such as lithological juxtaposition, shale or clay smear, among others. The approach employed in this study involved structural, stratigraphic interpretations and seismic attribute analysis. The structural framework derived from the

INTRODUCTION

Various studies such as highlight the need to make trap evaluation an essential part of prospect analysis and risk assessment in the oil and gas industry. Rudolph and Goulding categorized well failure into three, based on post-drill evaluation [1-8]. But their study discovered that for about 50% of the well failures that can be attributed to trap and seal elements, most are dominated by fault seal and top seal problems more than closure. Even in proven petroleum provinces such as the Niger Delta, well failure and dry hole from trap and seal rock is still preeminent. Fault seal assessment provides useful information that is essential to successful development of hydrocarbon fields and helps to reduce the risk on prospects and investments.

Faults seals may result from a diverse set of processes. These processes are lithological juxtaposition, gouges from fault rocks, clay smear, cementation, reduction in grain size and various diagenetic processes [9]. The importance of each mechanism with respect to the others is often interpreted based on the knowledge from theoretical fault models, outcrop studies [3, 10-14] and localized field studies. It has been shown from various studies such as Allan, [15] that in shale rich sequences, juxtaposition of sand shale beds is the primary factor determining fault seal. Also, in shale rich sequences, fault seals can also occur in sand-on-sand fault contacts. It is understood that this is made possible by Clay Smear Potential (CSP) [1,16] or Shale Gouge Ratio (SGR) [17]. Sand-on-sand sealing can also occur in sequences or reservoir sections with low clay or shale content. However, in this case, fault seal capacity is understood to result from a combination of bed orientation, throw [18], conditions of faulting that may destroy permeability along the fault core and self-healing undergone by the fault rock [19,20].

For this study, a 3D seismic data was interpreted with the aim to build or develop a structural framework model for the Ganga field. We expect that the results of this study may be utilized in planning for proper development of the Ganga field and minimize the risk of poor investment decisions in the field.

Geology of the study area

interpreted faults, horizons and well logs served as input data in the Midland Valley move software for fault seal assessment, sand on shale lithological juxtaposition and shale gouge ratio. Reservoir assessment was also done to determine prospective intervals. In the Ganga field, the structure is a faulted rollover anticline containing major and minor faults. Faults occur as sets of conjugate synthetic and antithetic syn-depositional normal faults (growth faults). Three distinct structural zones were recognizable on the variance edge attribute volume derived from the seismic volume. Major fault occurrence is restricted to the reservoir interval, the Agbada Formation. Two reservoir intervals were identified from petro-physical analysis. From Fault seal assessment of the major and minor faults for sand on shale lithological juxtaposition seals and fault rock membrane seals (shale gouge ratio), the best sealing interval is above 4200 ft. The reservoir sands identified represent high-risk prospects.

Key Words: 3-Dimensional; Seismic interpretation; Fault; Fault seal; Juxtaposition; Niger Delta

provinces: the Northern delta, Greater Ugheli, Delta edge, Central swamp, Coastal swamp and offshore depobelts (Figure 1). The framework for the development and evolution of these provinces is controlled by fracture zones which developed in the Cretaceous, which form a network of trenches and ridges in the deep Atlantic. The Niger delta basin is part of a rift system whose initiation has been traced into the late Jurassic and continued into the middle Cretaceous [21]. Gravity induced shale tectonism has been the primary mechanism responsible for the structural style observed in this basin [22,23].

The Delta is along the continental margin of West Africa. The tertiary section of the delta has been divided into three formations [24,25]. These formations are predominantly made up of prograding facies, distinguishable based on facies variations. The Benin Formation which is the youngest formation is made up of predominantly sand facies of continental origin with few occasional shale breaks or shale deposits (Figure 2). This formation passes both vertically and laterally into the Agbada formation. The Agbada Formation is a characteristic paralic deposit. This formation passes offshore into marine shales of the Akata Formation. The Akata Formation is a thick massive shale sequence with few or occasional occurrence of sand deposits likely turbidites.

The study area is in the southern part or region of Nigeria and lies along the Gulf of Guinea on the West Coast of Central Africa. The area is made up of savannah-covered lowlands and spans an extent of about 187 Km². It is part of one of the largest deltaic systems in the world, the Niger Delta.

Hydrocarbon trap and seal formation have been greatly influenced by the structural and stratigraphic evolution of the delta. Structural traps more than stratigraphic traps have proven to be the more favorable exploration target. Some examples of the play styles which have proven to be successful exploration targets are; shallow or deep simple/faulted rollover, k-type structures, reversed footwall closure, back-to-back structure and inversion structures.

MATERIALS AND METHODS

The Niger Delta is tectonically divided into six regions or structural

For this study, the dataset that was used includes a 3D seismic volume,

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Figure 1) The position of the study area with respect to tectonically derived depobelts or depocentres, often called structural provinces within the Niger Delta (modified after Doust and Omatsola, 1989).



Figure 2) Schematic diagram of Niger Delta regional stratigraphy (adapted from Lawrence et.al. 2002)

a suite of well logs for 24 wells, check-shot data for about six wells. Fault and horizons were interpreted on the 3D seismic volume. A time-depth relationship was generated from the check-shot data and used to convert the surfaces generated from the fault and horizon interpretation from time to depth. The interpreted faults and horizons were used to generate the structural framework, which serves as the main or key input for the fault seal assessment. Petro-physical analysis was carried out to identify prospective reservoir intervals. Fault seal assessment for lithological juxtaposition and SGR seals was carried out using the gamma ray logs from the wells. Fault seal assessment was done to determine the risk associated with the identified reservoir intervals. Horizons were interpreted from which the throw on the fault was determined. Single well reservoir assessment was done to determine prospective intervals along the faults and field. The interpreted faults were then analysed for sealing using the methods of juxtaposition (sand on shale) and SGR first in 1D using triangle diagrams then in 3D producing fault plane juxtaposition and SGR maps.

Structural interpretation

The Ganga Field is a deep-faulted rollover anticline, characterized by an east, north-west trending major growth fault system. The faults are divided into major and minor faults. The major fault divides the field into four blocks A, B, C and D (Figure 3). There are other minor faults which occur as sets of antithetic and synthetic syn-depositional normal or growth faults. The minor faults increase the complexity of the structural style of the field (Figure 4). Variance edge attribute volume shows evidence of structural zonation or differentiation with all the faults restricted to the interval interpreted to be the Agbada formation. Fault dip is variable changing across the plane of the faults. All the faults dip southwards and fault dips vary between 80 degrees-78 degrees in shallow parts and declines progressively to less than 30 degrees in deeper sections under the field.

For both major and minor faults, along the length or axis of the fault planes, down-thrown blocks of the faults are deformed into broad anticlines, and form double-plunging axes which run parallel to the adjacent cuspate fault trends. Seismic reflections show evidence of folding across anticlines in deeper sections and, an increase in displacement across faults, of seismic facies.

Also, there are lateral changes from zones of low signal strength to zones of continuous reflections in the basal parts of the seismic record which occur at shallow depths under the footwalls of fault blocks next to major faults under down-thrown fault blocks. The boundaries of these low amplitude discontinuous to transparent reflection zones are variable, often abrupt and in some locations are diffuse or gradational. These changes in the boundaries were interpreted to reflect deposits that have been fractured by overpressure

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Figure 3) Time slice of Variance Edge Volume taken at 1.1 s showing the growth faults.



Figure 4) Seismic section with some of the wells and logs and south dipping synthetic normal growth faults.

and perhaps have been displaced from the buoyancy of underlying strata.

On seismic dip sections, reflections within anticlines are broadly horizontal, parallel to the fold axis. Also, along the northern edges of the field, from south to north, anticlines become separated by zones of folded reflections next to the cuspate edges of major faults and by zones where the transparent seismic patterns become shallower.

Also, on seismic strike sections, in the southern parts of the field, because anticlinal structures in this portion of the seismic volume are basin ward of the deposited strata, they appear to be more distinct. And these structures often visible from strong reflection extend to deeper depths.

Within the Agbada Formation, the reservoir interval was chosen because it cut across all the key structures within the field and was used to define broad patterns of displacement across faults and deformation of fault blocks at that stratigraphic interval (Figure 5 and Figure 6).

Petrophysical analysis

Single well petro-physical analysis revealed two key reservoir intervals for well

GB-3, labelled Res A and Res B (Figure 7 and Figure 8). Res A was deposited at the beginning of a low stand while Res B was deposited within a high stand. The low blocky gamma ray reading of these reservoirs on the electric log likely records the accumulation of sandy fluvial channel deposits within incised valley fill. Well log signatures for the resistivity logs compared to the gamma ray logs show the Res B is more heterogeneous than Res A (Figure 9 and Figure 10). Petro physical analysis confirmed that the reservoirs have the properties to serve as good prospects. The Table 1 below is a summary of the results of the petro physical analysis.

FAULT SEAL ASSESSMENT

Analysis of fault seal revealed that there is both lateral and vertical variations in the influence of each sealing mechanism analysed that is, lithological juxtaposition (sand on shale) and SGR (Figure 11 and Figure 12). Fault plane analysis shows that along the fault plane, from the shallowest portion of the fault to deeper areas, both lithological juxtaposition and SGR are significant sealing mechanisms. Beyond a certain depth, the influence of SGR is greatly reduced and lithological juxtaposition becomes the dominant sealing



Figure 5) Isopach map of horizon used to define broad structural deformation and style of the field corresponding to a flooding surface on the gamma ray log in the wells.



Figure 6) Isochore map of horizon used to define broad structural deformation and style of the field corresponding to a flooding surface on the gamma ray log in the wells.

TABLE 1

The properties of	the	reservoir	intervals	Res	В	and	Res	A.
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Well	Zones	Flag	Net to Gross	Average Water Saturation	Average Porosity	Average Shale
GB-3	Res B	Rock	0.837	0.643	0.276	0.245
GB-3	Res B	Res	0.675	0.64	0.265	0.249
GB-3	Res B	Pay	0.413	0.502	0.274	0.22
GB-3	Res A	Rock	0.713	0.65	0.232	0.234
GB-3	Res A	Res	0.713	0.65	0.232	0.234
Gb-3	Res A	Pay	0.34	0.434	0.24	0.218

mechanism. Given the nature of the faults that is, they are growth faults, the depth at which the SGR stops being a significant sealing mechanism was interpreted to be the depth of maximum throw. Beyond this depth, lithological juxtaposition becomes the dominant sealing mechanism. The threshold for sealing from SGR to occur was interpreted to be 0.2 or greater. Zones where the value of the SGR is less than 0.2 would leak hydrocarbons. Lateral variations in seal integrity were recognized for lithological juxtaposition with patchy network style of sealing (Figure 13). This was interpreted to be due to the high variability in facies variation within the wells, which is common in

deltaic sequences. Sealing from SGR was more uniform (Figure 14). Sealing from SGR and lithological juxtaposition were combined, and the zone where each sealing mechanism was guaranteed was interpreted as the most viable intervals for trapping and hydrocarbon accumulation. There is a high risk for hydrocarbons to leak laterally and vertically from poor seal integrity. Growth structures such as growth faults cause a complex relationship between bed strata on both the hanging wall and foot wall and bed thickness is greatly reduced as one moves deeper along the fault plane. Prospects that are deeper than 4200 ft have high risk associated with fault seal leak for both gas and

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Figure 7) Well log section showing the gamma ray log, porosity logs and resistivity log and a reservoir interval of interest named RES B.



Figure 8) Well log section showing the gamma ray log, porosity logs and resistivity log and a reservoir interval of interest named RES A.



Figure 9) Well section showing the gamma ray log, porosity and water saturation for a reservoir interval of interest named RES B.



Figure 10) Well section showing the gamma ray log, porosity and water saturation for a reservoir interval of interest named RES A.



Figure 11) Triangle diagram showing lithological juxtaposition for faults 3 showing areas of sand on shale juxtaposition.



Figure 12) Triangle diagram showing SGR for faults 3 for areas of sand on shale juxtaposition.



Figure 13) Fault plane map showing lithological juxtaposition for sections of the major fault.



Figure 14) Fault plane map showing SGR for sections of the major fault.

oil reservoirs. Both Res B and Res A represent high-risk prospect because they lie outside the depth window for greater chance of fault sealing from juxtaposition and SGR.

CONCLUSION

The study revealed two key reservoir intervals in the study area. Structural analysis showed the existence of a viable structure which can serve as a petroleum trap in the field which is a faulted rollover anticline. But fault seal analysis showed that though the faults may serve as valuable baffles to hydrocarbon flow thereby increasing the viability of the structure to host hydrocarbons, it also revealed that there are intervals laterally where seal integrity from both lithological juxtaposition and fault rock seal from shale smear maybe breached. The probability of the faults to seal as a function of depth is also variable.

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