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Integration of 3D seismic and well log data for the exploration of Kini Field, offshore Niger Delta

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Abstract

Initial interpretation of the available data in Kini-field offshore Niger Delta suggests huge uncertainty in the hydrocarbon volume. Thus, additional exploration procedure is required to minimize economic risk before progressing to the next stage of the field development. An independent interpretation of the 3D seismic data and well logs of the Kini-1 well was carried out to highlight the sources of the key uncertainties in the geology and make a necessary recommendation on additional data acquisition to minimize the uncertainties. Four oil-bearing grains of sand (A, B, C and D reservoirs) were identified for petrophysical evaluation. These sands have a good gross thickness ranging from 21 to 33 m and average net-to-gross (NTG) of 0.62. Porosity varies between 0.22 and 0.30 indicating good reservoir quality having hydrocarbon saturation (S_h) between 69 to 76 %. Kini-1 well did not encounter hydrocarbon water contact thereby creating uncertainty in the fluid contact, hydrocarbon column and in a way the extent of the hydrocarbon fluid in the reservoir. This study also revealed that the seismic data did not completely capture the overall extent of the reservoir structures as indicated in the top structure maps of the four reservoirs and thus could not properly describe the trapping system of the NW-SE striking anticline as well as the area extent of the hydrocarbon bearing zone because the northern arm of the structure was not captured by seismic. Few east-west striking synthetics (F1, F2, F3, F6, F7) and antithetic (F4, F5, and F8) faults identified in the southern part of the field did not appear to control the fluid entrapment in these reservoirs. Only low case gross rock volume (GRV) and hydrocarbon reserve (of 663 MMbl) were calculated using oil-down-to (ODT) of Kini -1 well because of the highlighted huge structural uncertainties do not permit base and high case estimates. Consequently, it was recommended that the result should not be used to make an economic decision unless until more data are available to minimize the risks. To minimize the highlighted uncertainties, additional 3D seismic data covering an area extent of about 1430000 square meters was proposed at the northern and eastern parts of the field. This is expected to fully capture the reservoir structure and help estimate the GRV more accurately. Two wells (Kini-2 and Kini-3) were strategically positioned to target the fluid contact, examine lateral variation in the petrophysical properties and ultimately yield a more reliable hydrocarbon volume estimates.

***Keywords**: Exploration; reservoir structure; stratigraphic trap; uncertainty; petrophysical property.*

1. Introduction

Kini field is located at a water depth of about 1000 m at offshore Niger Delta (Fig. 1). The field was discovered by Kini-1 well which encountered stacked reservoir set with notable thickness. After discovery, additional exploration is required to ascertain the petroleum potential of the field as well as to meet the future production forecast of the field. Hence, the knowledge of exploration potentials is vital for the Kini field. Regional studies carried out in the offshore area indicated structural complexity which poses serious challenges to Geoscientists as a number of exploration wells that drilled at other fields did not yield meaningful results [1-5]. Thus, to minimize such economic risk in Kini field and ultimately firm up the technical confidence of the subsurface geology, more exploration data are needed.

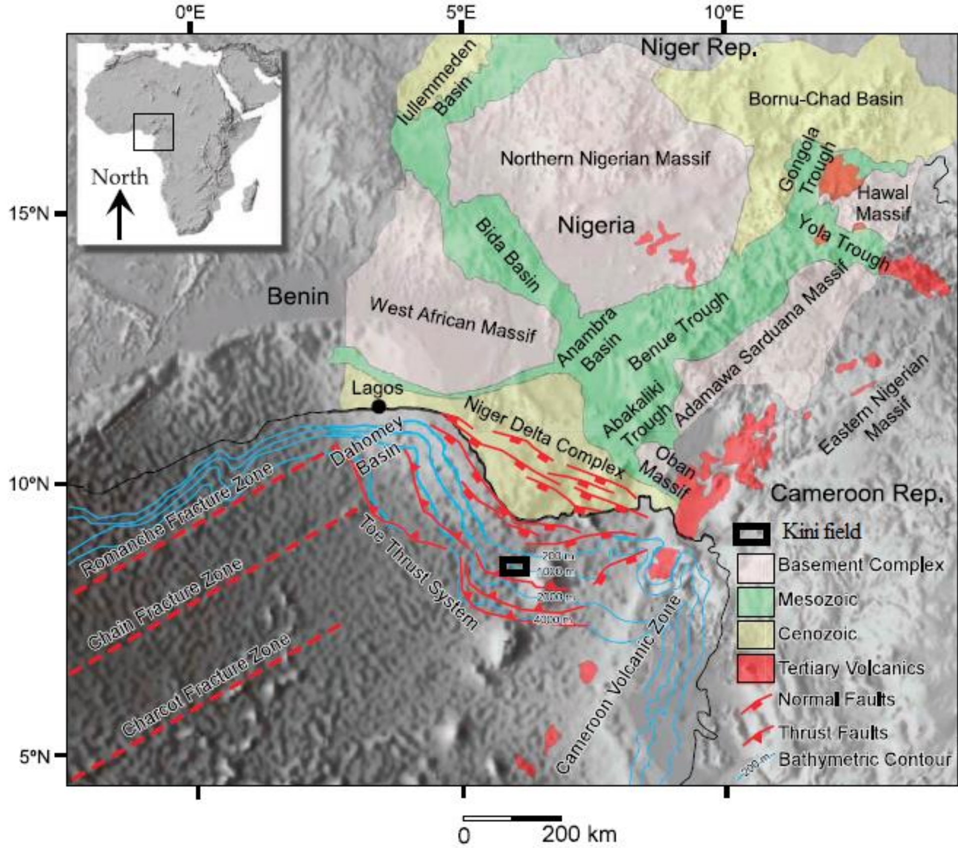

Fig. 1. Location Map of Kini Field Offshore Niger Delta, Nigeria *(Modified from Corredor et. al. [15])*

Previous studies have shown that integration of 3D seismic data and well log data could serve as a useful tool to understand the structural frame work and to estimate reserves [6-8]. Therefore, this study was undertaken to present the initial interpretation of the available information about the subsurface geology with the objectives of proffering recommendation procedure for data acquisition and to highlight the sources of the key uncertainties to minimize the uncertainties in the field.

The proposed acquisition is expected to capture the whole extent of the reservoir structure, and its interpretation should provide a more reliable hydrocarbon potential of the field thereby minimizing economic risk while progressing to the next stage of the field development.

2. Geological framework

The Niger Delta basin was formed during the breakup that occurred between the plates of South America and that of Africa at the failed arm of a triple junction. The basin is made up of three main Formations: Akata, Agbada, and Benin (Fig. 2). The oldest (Akata) formation is about 6000 m thick and mainly composed of marine shale that is believed to have changed the form of the clastic wedge of the Niger Delta Basin [9]. Streaks of sand found in the formation are believed to be of turbidity origin flow. The effect of over-pressure, ductility, and depth of this marine shale in the Akata formation led to the formation of syndepositional normal faults formed during progradation of the delta. The overlying formation is a paralic sequence of fluvial-deltaic sand and marine shale of about 4,000 m thick notably Agbada formation. It is Eocene to Pleistocene in age [9]. The youngest Formation is the Benin Formation which composed of non-marine sands believed to be of upper coastal plain or alluvial origin [9]. The Benin Formation is Oligocene to Recent in age [10].

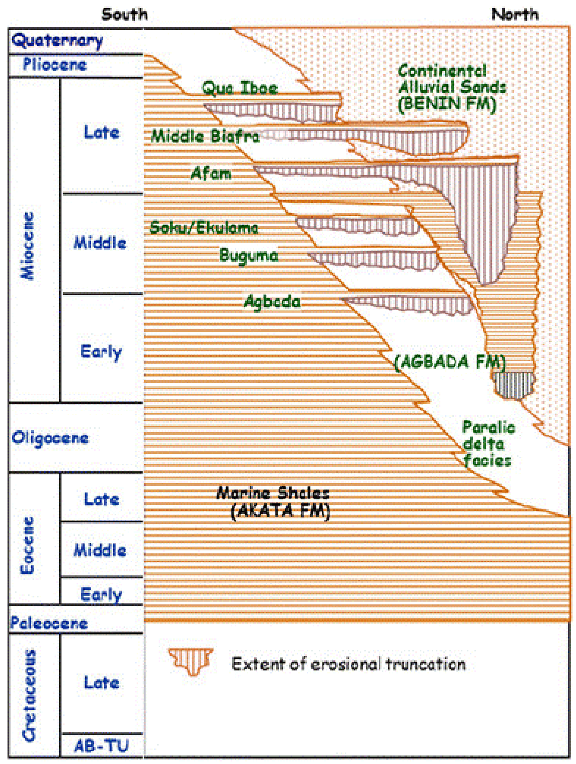

Fig. 2. Regional stratigraphy of the Niger Delta *(modified after Corredor et al. [15])*

Akata Formation is the main source rock while Agbada Formation is the main reservoir rock in the Niger Delta basin. The interbedded shale in the Agbada Formation serves as the primary seal rocks [9,11-13].

The Niger Delta is known to have accumulations of a lot of giant oil and gas and many unexplored opportunities that are being trapped in many structural styles ranging through the continental shelf to the continental slope within the Nigerian Offshore depobelt. The gas-to-oil ratio is believed to increase towards the south within the depobelts in the Niger delta basin. This is as a result of the complex hydrocarbon distributions in the Niger Delta [9].

3. Datasets and methodology

Available 3D seismic data and Kini-1 well log suite data were processed and interpreted using *Petrel* software to describe the structure and the intrinsic properties of the hydrocarbon bearing sands (reservoirs). These were used to evaluate the petrophysical parameters and Gross Rock Volume (GRV) of the reservoirs**.** Structural features were identified and mapped on the seismic section and the reflection events (horizons) that correspond to hydrocarbon bearing sands were mapped after well to seismic tie. Time structure maps of these horizons were then generated and then converted to depth maps which were used to calculate the GRV and the hydrocarbon volume. Petrophysical parameters (such as porosity, the volume of shale (V_{shale}), net-to-gross (NTG), net sand, water saturation and hydrocarbon saturation) of the selected reservoirs were calculated at Kini-1 well location using necessary log suites and equations.

4. Results and discussion

Four oil-bearing reservoirs (A, B, C, and D) with significant gross sand thickness were identified considered for this evaluation (Figure 3). Observable Gross sand thickness of these reservoirs ranges from 21 to 33 m with an average net to gross of 0.62 (Table 1). Porosity generally reduces with depth ranging between 0.22 and 0.30 indicating that the reservoirs are generally of good sand quality with hydrocarbon saturation (S_h) between 69 to 76 %. Kini-1 well did not encounter Oil Water Contact (OWC) in any of these reservoirs thus creating uncertainty in fluid contact.

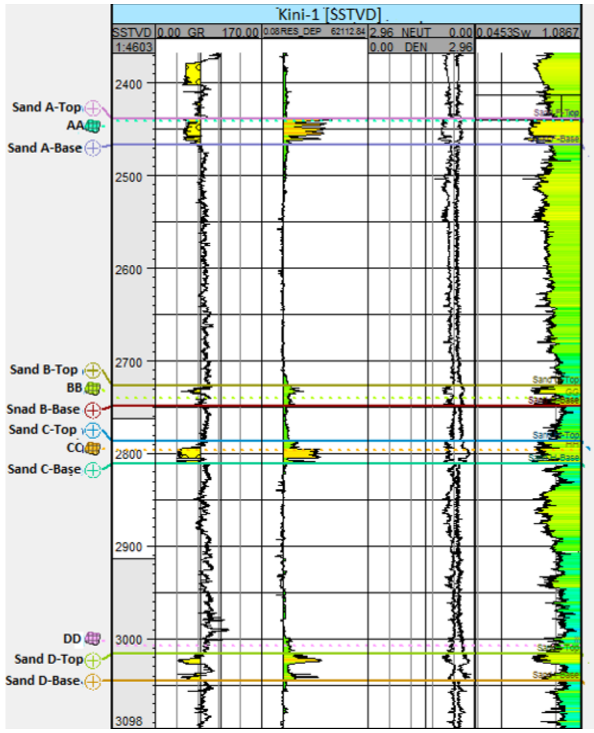

Fig. 3. Log signature of reservoirs A, B, C and D in Kini-1 well

Table 1. Summary of petrophysical properties of the selected reservoirs at Kini-1 well location

Well	Reservoir	Top (m) tvdss	Base (m) tvdss	Gross (m)	Net (m)	NTG	Av. ϕ	Sw	Oil Down To (m) tvdss
Kini-1	A	2433.71	2466.88	33.17	24.17	0.73	0.30	0.24	2462.01
Kini-1	B	2727.18	2748.55	21.37	12.37	0.58	0.25	0.31	2748.55
Kini-1	C	2785.21	2809.03	23.82	14.82	0.62	0.25	0.30	2809.03
Kini-1	D	3016.67	3045.18	28.51	15.51	0.54	0.22	0.30	3045.18

Notable structures identified are growth faults and channels. Synthetic faults (F1, F2, F3, F6, F7) generally strike east-west (E-W) and dip to south while the antithetic ones (F4, F5, and F8) are north dipping following the regional structural framework of offshore fields in Niger Delta province [3,14-15], Fig. 4).

Top structure maps (Figure 5a-d) of the selected reservoir shows that the seismic data did not capture the overall extent of the reservoir structures, and thus one could not properly describe the trapping mechanism and the area extent of the hydrocarbon bearing zone as the northern arm of the structure which could likely give a clue to the trapping system was not covered by the available seismic data. However, the structure appears to be a NW-SE striking anticline penetrated at the crest by Kini-1 well. This suggests either a three-way, a four-way dip closure or a combination trap. Since no fluid contact was established only low case GRV and hydrocarbon reserve were calculated using ODT of Kini -1 well. The huge uncertainty in the area extent of the hydrocarbon bearing interval and the contact do not permit the definition of base and high case hydrocarbon volumes as indicated in Figure 6.

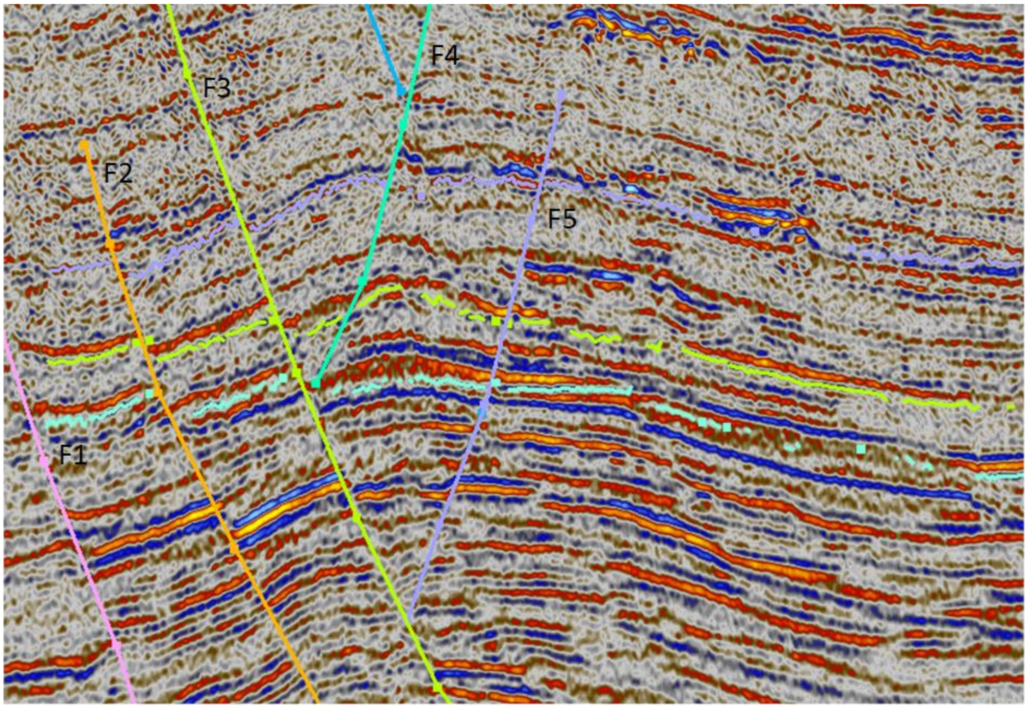

Fig. 4. Synthetic and Antithetic Faults identified in Kini field

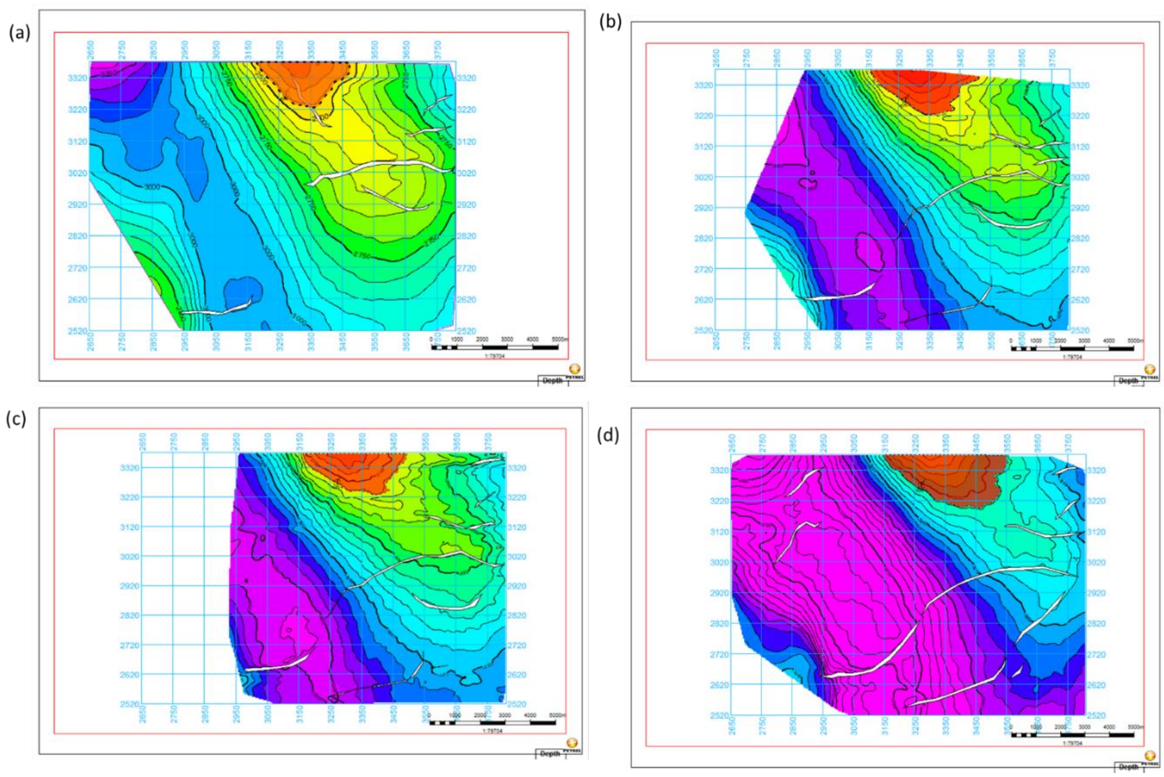

Fig. 5. (a) Top structure map of reservoir sand A showing ODT (brown) of Kini-1 well (b) Top structure map of reservoir sand B showing ODT (brown) of Kini-1 well (c) Top structure map of reservoir sand C showing ODT (brown) of Kini-1 well (d) Top structure map of Reservoir D showing ODT (brown) of Kini-1 well

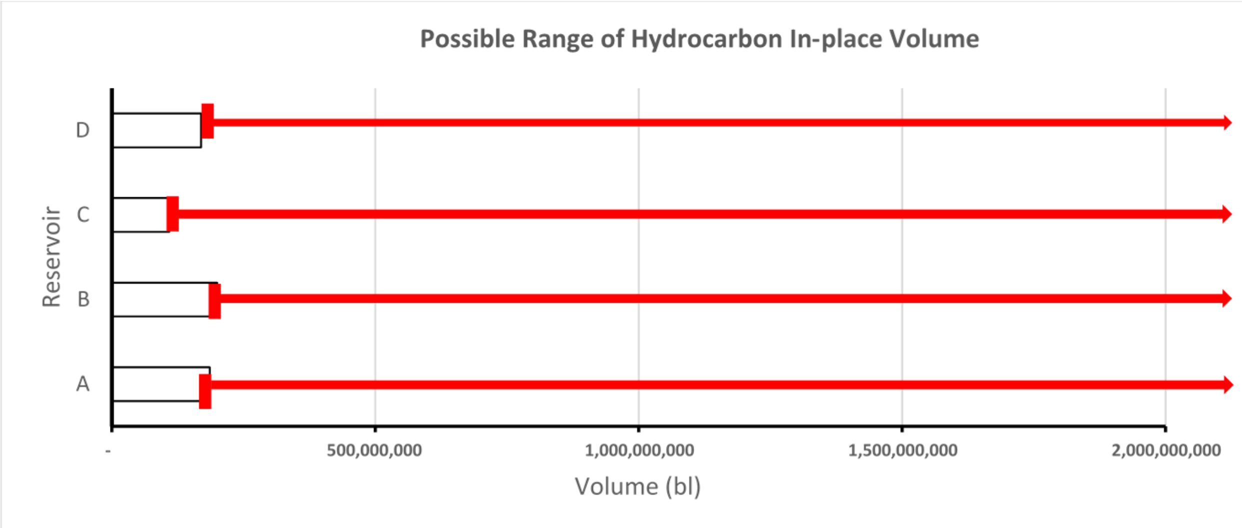

Fig. 6. Possible range of hydrocarbon volumes in reservoirs A, B, C & D

GRV and hydrocarbon-in-place volumes were estimated using only the area filled with a hydrocarbon in the seismic data and the ODT in Kini-well 1. It should be noted that this could underestimate the low case volume provided in Table 2. All the reservoirs have STOIIP of 663 MMbl (Table 2).

Table 2. Hydrocarbon volume in-place (low case)

Reservoirs	STOIIP (bl)	Reservoirs	STOIIP (bl)
A	185,825,708	C	108,832,435
B	199,645,173	D	169,363,684

Figure 6 shows a pictorial representation of the estimated hydrocarbon volume. However, the left bar indicates the lowest possible volume which is subject to uncertainty in the area extent of the hydrocarbon in the reservoir and fluid contact. However, this low case could be greatly underestimated as the cumulative effect of the major parameters of uncertainty. Thus, this result should not be used to make an economic decision. The red arrows indicate that the upper limit could not be defined as a result of insufficient data (especially in the seismic coverage).

4.1. Further exploration proposal

As a result of huge subsurface uncertainties in Kini field, this study highlighted key subsurface uncertainties in order of importance and then recommended exploration procedures as seen in Table 3.

Table 3. Key Subsurface uncertainties and the recommended data acquisition

Key subsurface uncertainty	Volume parameter	Recommendation
Geometry and size of Reservoir Tank	GRV	Seismic Data Acquisition
Fluid contact	GRV	Drilling well
Reservoir structure	GRV	Seismic Data Acquisition
Uncertainty in reservoir properties	Petrophysics	Drilling Well
Compartmentalization of the reservoirs	GRV	Drilling Well
Aquifer Activity	Petrophysics	Production test
Fault sealing	GRV	Drilling Well

As shown in Table 3, the major source of uncertainty in the area extent of the reservoir filled with hydrocarbon bearing, fluid contact, reservoir structure, compartmentalization and fault sealing. These create huge uncertainty in GRV. Other sources of uncertainty include reservoir properties and aquifer activity.

However, much effort should be focused on minimizing structural uncertainty as described below.

4.2. Seismic data acquisition

Due to uncertainty associated with the subsurface structure, additional 3D Seismic data covering a total area of about 1430000 square meters is proposed to be acquired at the northern and eastern segment of the field (Figure 7). This will help capture the reservoir structure, estimate the area extent of the hydrocarbon bearing zone and ultimately inprove confidence level in GRV estimates and hydrocarbon reserves.

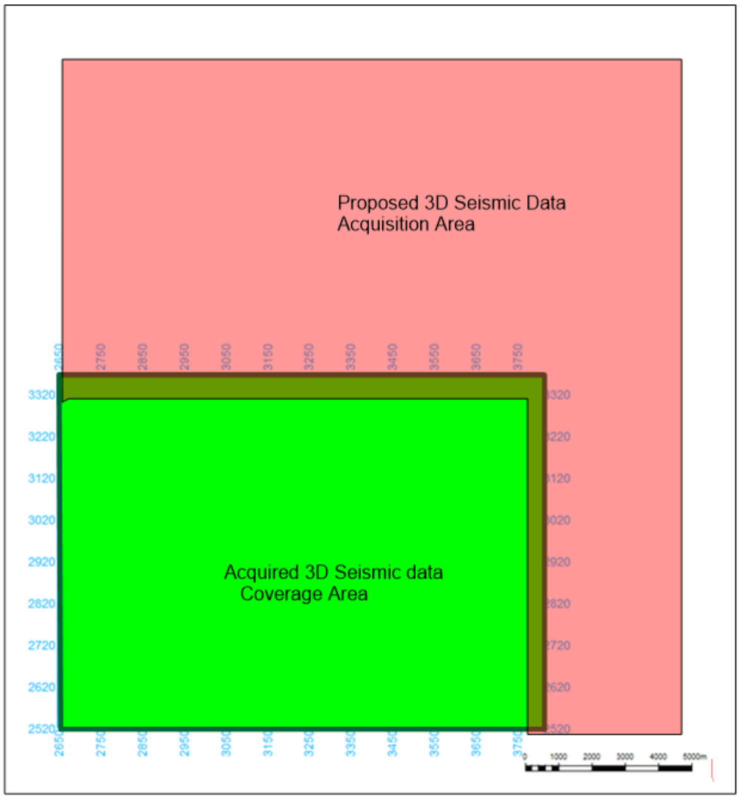

Fig. 7. Proposed 3D seismic data acquisition

4.3. Well drilling

Two appraisal wells (Kini-2 and Kini-3) are proposed down dip of Kini-1 after acquiring additional 3D seismic data and field re-evaluation to target fluid contacts in selected reservoirs, determine petrophysical properties and further explore deeper prospects (Figure 8). Kini-2 should be drilled first and the result obtained will determine whether to proceed with drilling Kini-3. However, the locations of the wells might change after interpreting the proposed seismic study.

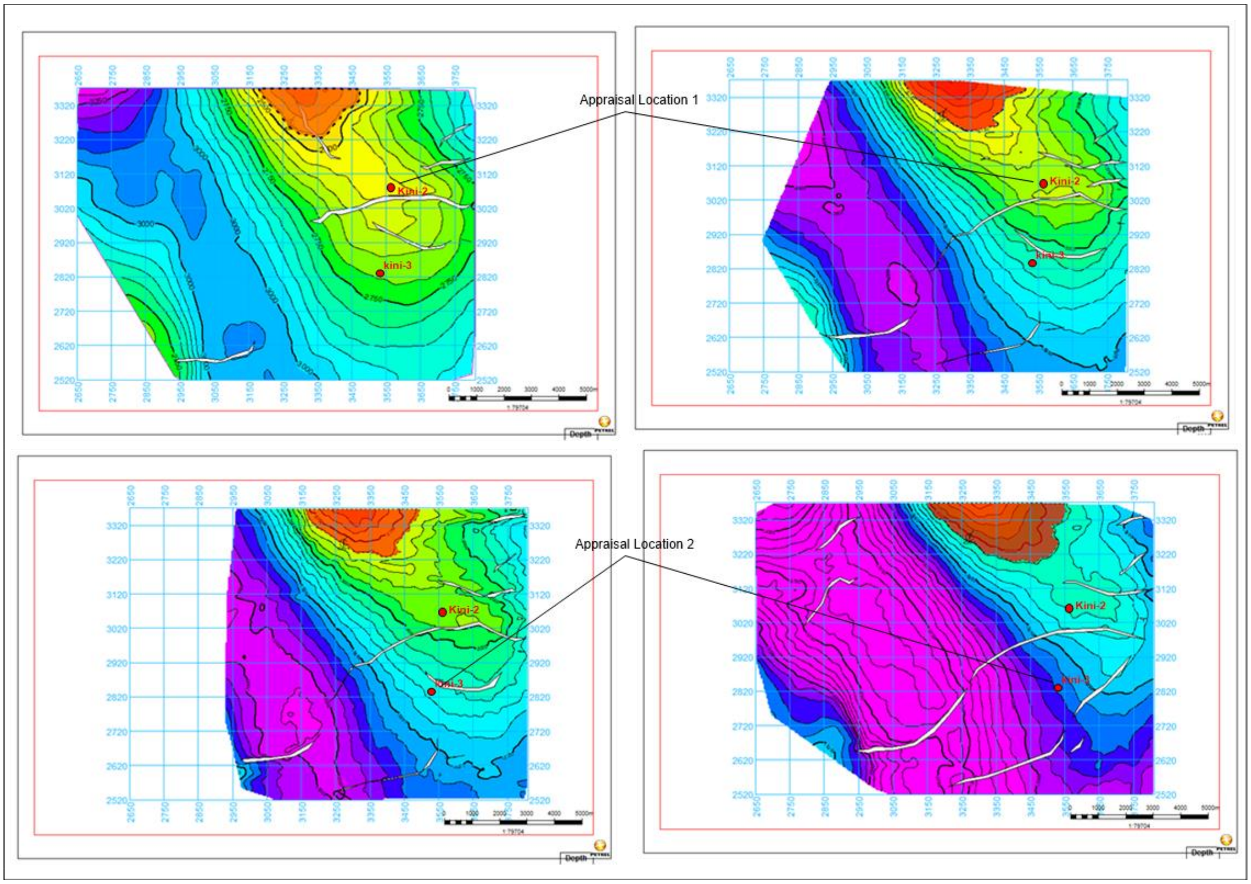

Fig. 8. Location of the proposed wells (Kini-2 and Kini-3 wells)

The exploration/appraisal program will help to estimate a more reliable range of in-place hydrocarbon volume by addressing the major subsurface uncertainty in Kini field which includes reservoir structure and trapping mechanism, area extent of the reservoir, fluid contacts, reservoir petrophysical properties, and compartmentalization. This procedure will impact decisions related to field development and translate into risk reduction, confidence building or higher profitability for the project.

5. Conclusions

This study was carried out using 3D seismic and well log data from one well to describe the subsurface features of the field and recommend on additional data to be acquired to reduce the major uncertainty highlighted in the present study. Four oil-bearing reservoirs (A, B, C, and D) were identified and evaluated for petrophysical characteristics. Kini-1 well encountered hydrocarbon in the selected reservoirs at oil-down-to (ODT) condition creating uncertainty in the fluid contact. Gross sand thickness ranges from 21 to 33 m with average NTG of 0.62. Porosity varies between 0.22 and 0.30 indicating that the reservoirs are of good quality with hydrocarbon saturation (S_h) between 69 to 76 %. The area of the zone covered by hydrocarbon was estimated using the top depth structure maps and was used to estimate low case GRV and hydrocarbon volume in-place. The present interpretation shows that synthetic faults in the field are E-W striking and south dipping while the antithetic faults are north dipping. The top structure maps of the selected reservoir show that the seismic data did not completely capture the overall extent of the reservoir structures and thus one could not properly describe the trapping mechanism and the area extent of the hydrocarbon bearing zone as the northern arm of the structure was not covered. However, the structure appears to be an NW-SE striking anticline penetrated at the crest by Kini-1 well. This suggests either a three-way, a four-way dip closure or a combination trap and that there is no evidence that these faults controlled the fluid distribution. Since no fluid contact was established only low case GRV and hydrocarbon reserve was calculated using ODT of Kini -1 well and area restricted to available seismic. The huge uncertainty in the area extent of the hydrocarbon bearing interval and the fluid contact does not permit the definition of base and high case hydrocarbon volumes. Low case hydrocarbon cumulative minimum (low case) stock tank original oil-in-place (STOIIP) of the four reservoirs amount to 663 MMbl. These uncertainties are related to reservoir structure, area extent of the hydrocarbon bearing zone, fluid contact, compartmentalization and fault seal which created huge uncertainties in the GRV. To minimize the highlighted uncertainties, additional 3D seismic data covering an area extent of about 1430000 square meters was proposed to be acquired at the northern and eastern parts of the field. This is expected to result in structural uncertainty and help to more accurately estimate the GRV. Two appraisal wells (Kini-1 and Kini-2) were strategically positioned to target the fluid contact and also examine lateral variation in the petrophysical properties. This procedure will impact decisions related to field development and translate into risk reduction, confidence building or higher profitability in the field.

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