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Seismic Facies and Geomodel as tools to Play and Prospect Evaluation in the Shallow Offshore Niger Delta, Nigeria

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ABSTRACT
The aim of this work is to integrate seismic facies and geologic model for play assessment and prospect identification. Checkshots, seismic and wireline log data were used for the study. The structural interpretation involved a well–to–seismic tie, faults and horizon mapping on the seismic data, building of isochron, isopach and isochore maps. The seismic facies interpreted include: parallel continuous low to moderate amplitude; wavy continuous low to moderate amplitude; oblique discontinuous low amplitude; high angle oblique continuous; mounded chaotic low amplitude and mounded continuous low amplitude. Well data shows that parallel and wavy continuous facies are associated with channel deposits but possess poor reservoir/seal pair, and may hold little or no hydrocarbons. The oblique, discontinuous low amplitude facies was interpreted as shallow marine prograding complex in a high energy environment. The mounded chaotic and continuous low amplitude facies shows good reservoir/seal pair. The geologic model shows two major down-to-basin growth faults; synthetic boundary fault and counter regional fault that divided the study area into three macrostructures namely fault block-I, fault block-II and fault block-III. Integration of seismic facies and geologic model showed that the fault block I is located in an anticlinal structures with possibility of hydrocarbon accumulation.

Key Words: *Seismic Facies, Geologic Model, Play and Prospect Evaluation, Shallow Offshore, Niger Delta Basin*

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I. Introduction

Niger Delta is a working petroleum province within a passive continental margin (Short and Stauble, 1967; Merki, 1972; Weber and Daukoru, 1975). Many research works have been on-going and lots of literatures are on the public domain for consultations. A lot of works have been done on the stratigraphy and structural configurations (Reyment, 1965; Short and Stauble, 1967; Merki, 1972; Weber and Daukoru, 1975, Evamy *et al*, 1978; Whiteman, 1982 and Reijers, 2011) of the basin. The works of these pioneer authors set the goal for other major researches with some modifications on their works. However, most of the reservoir scale works remain within the library of the major oil and gas companies operating in the region as confidential materials. Anomneze *et al.* (2015) used seismic stratigraphy and structural interpretation to assess play within the eastern Niger Delta. Ajaegwu, *et al.* (2016) used integrated depositional systems and 3rd order sequence stratigraphic interpretation to predict the good quality reservoir sands and their lateral continuity. One of the requirements for hydrocarbon to be in place is the possession of good reservoir – seal pair as one of the play arrangement. Assessment of these plays may not be simple especially where the seismic data quality is poor. Seismic stratigraphy provides a better opportunity in seismic of these plays. The aim of this work therefore, is to integrate seismic facies and geologic model and attempt play assessment as well as prospect identification within the study area.

Three blocks namely Ham, James, and Kate were selected for the study. The Ham, James and Kate blocks are located in the proximal portion of the offshore depositional belt referred to in this study as ‘Shallow Offshore’ (Fig. 1). A total of 15 wells were drilled in these three blocks in the last twenty years. The key statistics/summary of the activities carried out in the blocks is presented below as Table 1 as already discussed by Ajaegwu *et al* (2014).

Table 1: Key statistics of the activities within the blocks studied (after Ajaegwu et al., 2014)

Block (OML)	No. of wells drilled to date	Nature of Wells	Wells used for the study	Area coverage (sq. Km)	Wells under Development
Ham	12 wells (between 1965 & 1989)	6 exploratory 6 appraisal	HaD-001 HaB-001 HaA-001	962	HaI

			HaM-001 Hobo-001		
James	9	3 marginal 2 mainly gas 3 dry hole 1 (2004) prolific: 60ft TVD oil	JaO-001 JaK-001 JaK-002 JaN-001	2, 130	None
Kate	43 (since 1964)	1 producing 6 partially appraised/ un-appraised field 5 marginal field	Kapp-001 Kaue-001 Kora-003 KaF-001 KaI-001 (OML 71) KaR-001	1, 245	None

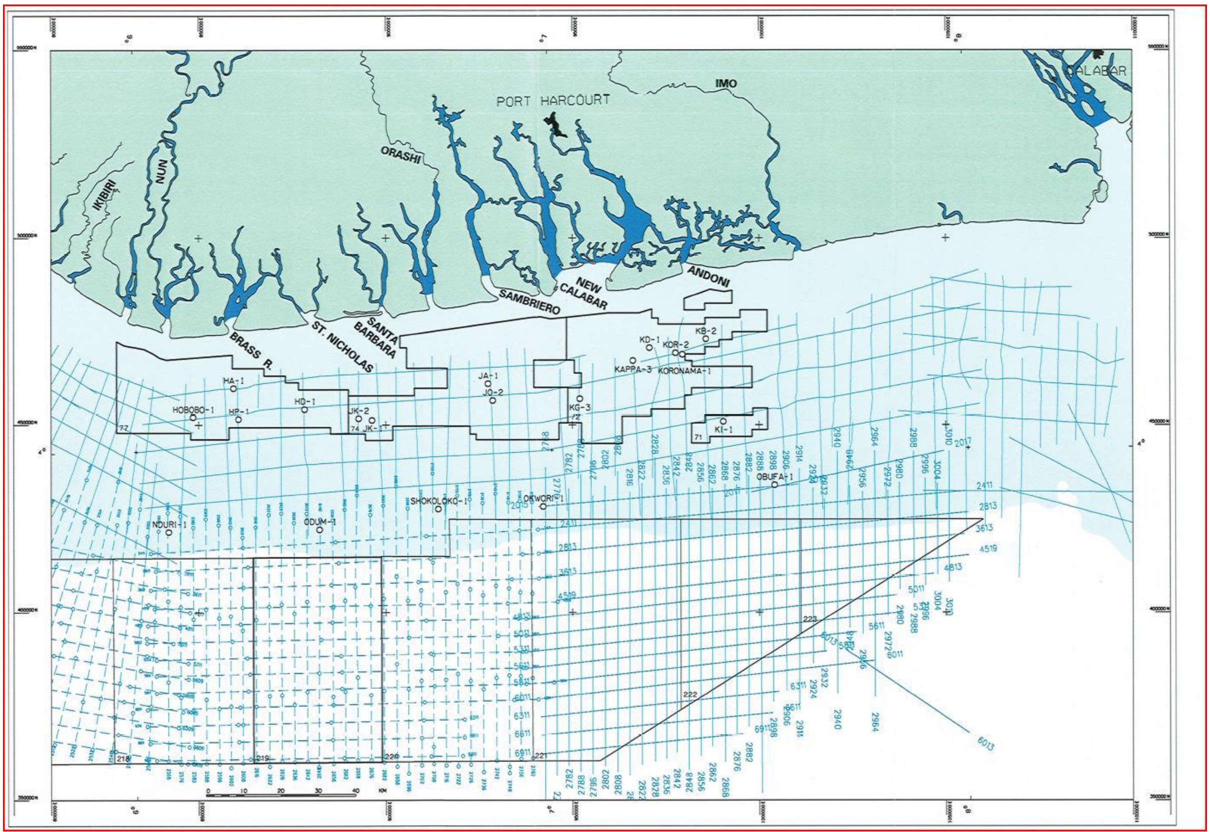

Fig 1: Location map of the study area showing the distribution of selected wells in their respective blocks

Seismic stratigraphy is one of the tools used in sequence stratigraphy, which studies basin fill as a function of eustacy, sedimentation and subsidence. Sequence stratigraphy allows us to map sea-level changes, lateral facies shifts, occurrences of unconformities and tectonic activities through time (Chopra and Marfurt, 2012). The work of Ajaegwu *et al* (2014) in this area dated the Maximum Flooding Surfaces to range from 3.9 to 11.5Ma and the Sequence Boundaries to range from 4.1 to 10.6Ma. Sequence stratigraphy enables the prediction of potential source and reservoir rocks. A key component of seismic stratigraphy is mapping of seismic facies (Chopra and Marfurt, 2012). A seismic facies is a 3-dimentional unit composed of seismic reflection configuration, amplitude, continuity, frequency and interval velocity, which differ from the elements of adjacent facies units (Brown and Fisher, 1979).

1.2 Regional Geology of the Niger Delta

The evolution of the Niger Delta depositional complex is related to the evolution of the Benue Trough, which began in the Cretaceous period during the opening of the South Atlantic that lead to the separation of Africa and South America (Whiteman, 1982). Its development appeared to have been centered on two major subsiding basements, the Anambra embayment in which some 600 to 700 metres thick of sediments accumulated, and a younger more southerly region where subsidence was extensive where over 1,200 metres thick of sediments were deposited (Reyment, 1965). By Late Cretaceous and Early Cenozoic time, subsidence of the continental margin was well underway as oceanic crust cooled. By the Early Palaeocene time, the sea had flooded onto the area's old shoulders and flanks underlain by continental crust such as the Anambra Basin (Whiteman, 1982). This transgressive episode terminated the development of the Anambra Basin Delta Complex and by this time the sea had flooded into the Afikpo syncline; the Cameroon Basin and into the Dahomey Basin. At that time, the Abakaliki and Benue Fold Belt however, were topographically and structurally high and the sea did not extend to them.

The Niger Delta Complex began to evolve in the Palaeocene and Eocene times within this framework, which has dominated the depositional and structural scene at the eastern end of the Gulf of Guinea. According to Whiteman (1982), four major depocentres can be identified as having operated during the Mid Eocene times:

a. the Anambra Depocentre fed by the proto-Benue-Niger systems with the former providing most of the sediment,
b. the Onitsha depocentre fed by sediments derived from the Abakaliki Fold Belt and Onitsha High,
c. the Afikpo depocentre fed by the Cross River System, and
d. the Ikang depocentre on the Calabar Flank.

Well sections through the Niger Delta generally display three vertical lithofacies subdivisions namely the Benin, the Agbada and the Akata Formations corresponding to delta top, delta front and prodelta respectively. The lithological characterizations of these lithostratigraphic units have been described by Short and Stauble (1967), Weber and Daukoru (1975) and Whiteman (1982). The Benin Formation consists of massive continental sands and gravels accounting for about 90% of all the lithofacies with few shale intercalations, which becomes more abundant towards the base. The Agbada Formation consists mostly of shoreface and channel sands with minor shales in the upper part, and alternation of sands and shale in equal proportion in the lower part. Oil and gas reserves in the Niger Delta Basin mainly occurs in sandstone reservoirs throughout the Agbada Formation. The Akata Formation composed mainly of marine shales, sandy and silty beds, which are thought to have been laid down as turbidites and continental slope channel fills.

II. MATERIALS AND METHODS

The materials used for this work consist of 3D seismic volumes, T-Z (checkshots) data, and wireline logs (gamma-ray, resistivity, neutron, density and sonic).

The methods of interpretation involved quality checking of data and creation of projects in both Petrel and nDI Geosign platforms. The sequence stratigraphic framework analysis and genetic correlation of coeval stratigraphic surfaces were carried out using Petrel workstation while structural interpretation and stratigraphic surfaces (MFS and SB) interpretation were done on the seismic data using nDI Geosign. The platform used for the majority of the seismic interpretations, which included well-to-seismic tie, reflectivity pattern, fault and horizon interpretations is the nDI GeoSign.

2.1 Well-to-seismic Tie

The well-to-seismic tie was done using de-spiked density and sonic logs with checkshot from the same wells. The KaF-001, JaK-001 and JaN-001 wells are the representative wells used and one of them is shown as Fig. 2.1 below.

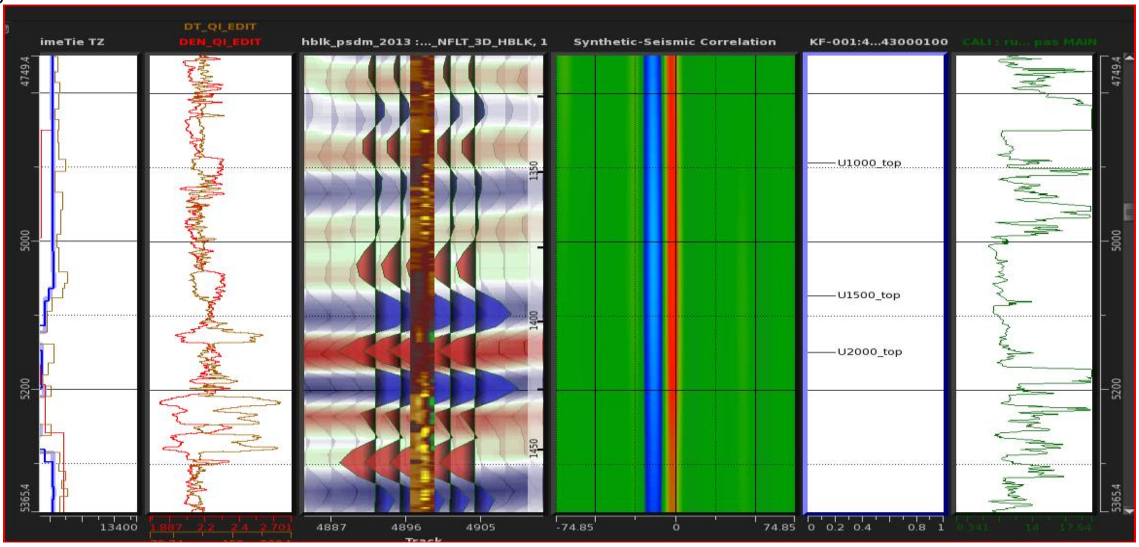

Fig. 2.1: nDi GeoSgn window display of well-to-seismic tie showing how the synthetic matches with the seismic with the reservoir tops corresponding to top of the peak event. The synthetic and seismic lines of correlation are parallel to each other showing the closeness of the tie.

2.2 Fault and Horizon Interpretation

The fault picking was done on a grid of 64 along tracks in traverse view. The semblance map (Fig. 5) produced on the map view clearly shows the faults and their orientations and thus enabled faults to be assigned to a particular group. The display of semblance map at 2000msecs, 2300msecs and at 2600msecs showed that both major and minor faults were better seen at time slice of 2000msecs (Fig 2.2). Up to 20 interpreted faults out of many were assigned with numbers and distinguished with colours in the map view using time slide made at 2000msecs (Fig. 2.2.1).

With the knowledge of the well-to-seismic tie and reflectivity patterns, the maximum flooding surfaces (MFSs) were picked on the trough while the sequence boundaries (SBs) were picked on the peak. The interpretation was done on both track and bin on traverse view using a grid of 64 but varying the grid to 32 and 16 where it becomes necessary to pick closely. Three surfaces comprising 5.0 Ma MFS, 5.6 Ma SB and 6.0 Ma MFS (making up of one complete genetic sequence) were interpreted as horizons on the seismic (Fig. 2.2.2).

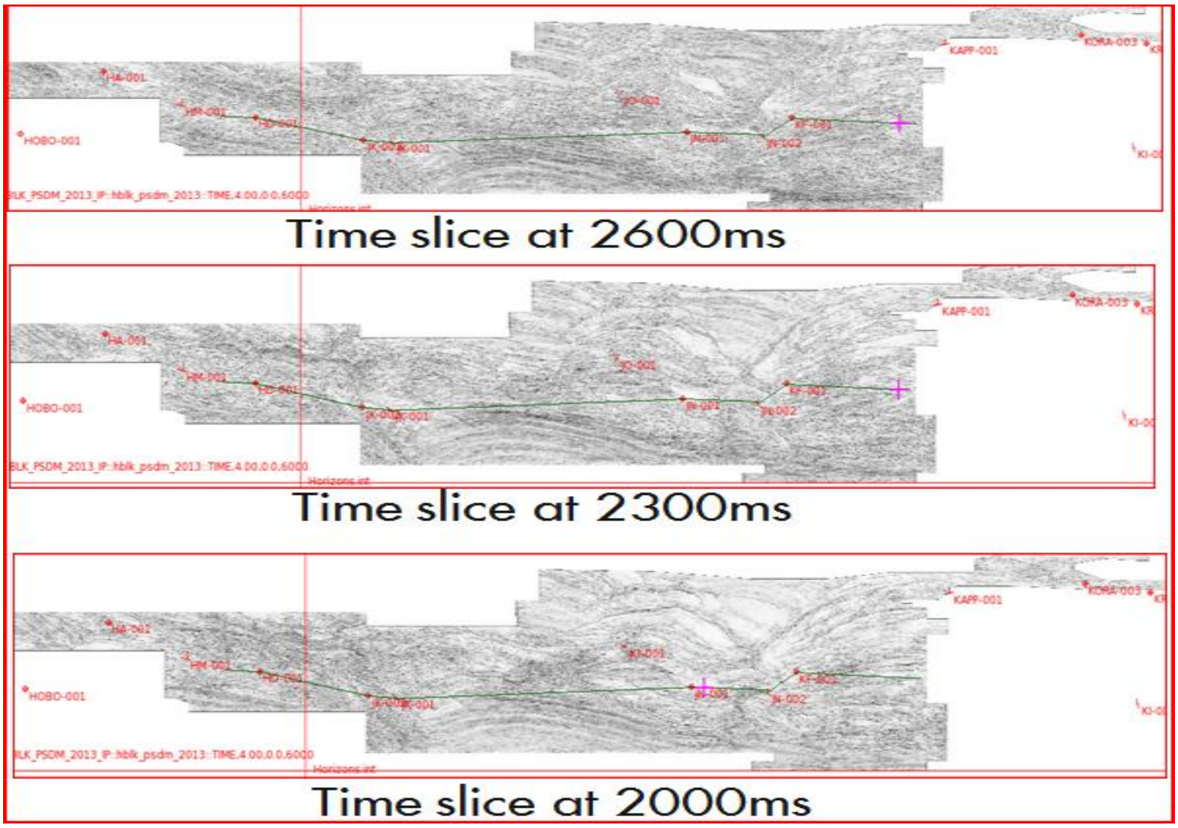

Fig. 2.2: Semblance maps of the entire fields studied, showing various fault plains at different time slices (2600, 2300 and 2000ms). This shows that the faults gradually becomes invisible as the time increases.

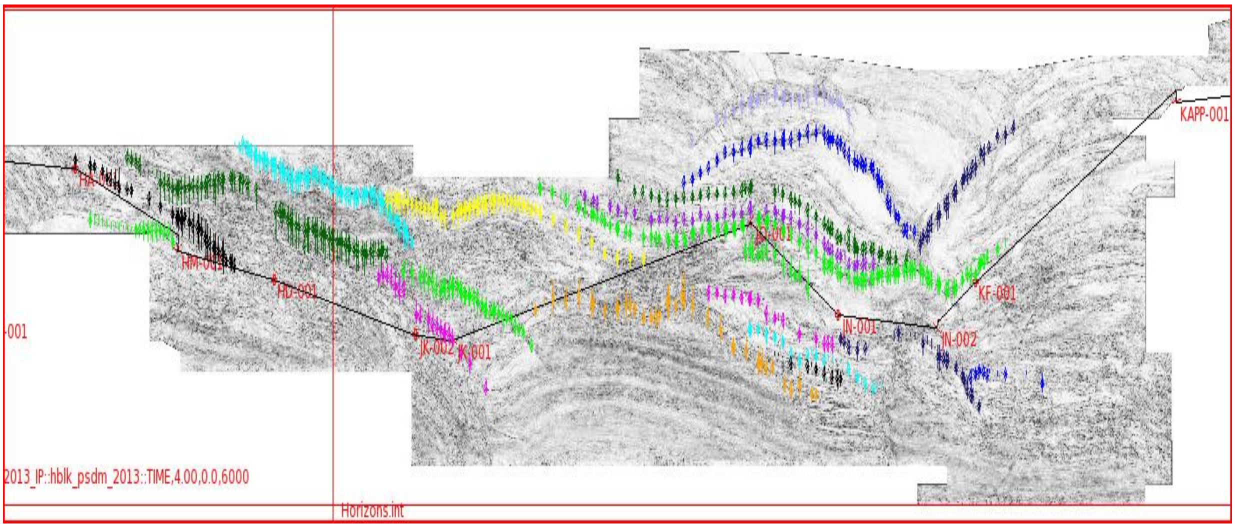

Fig. 2.2.1: Semblance map at 2000ms showing the assigned faults in map view. The assigned faults were demarcated with colours

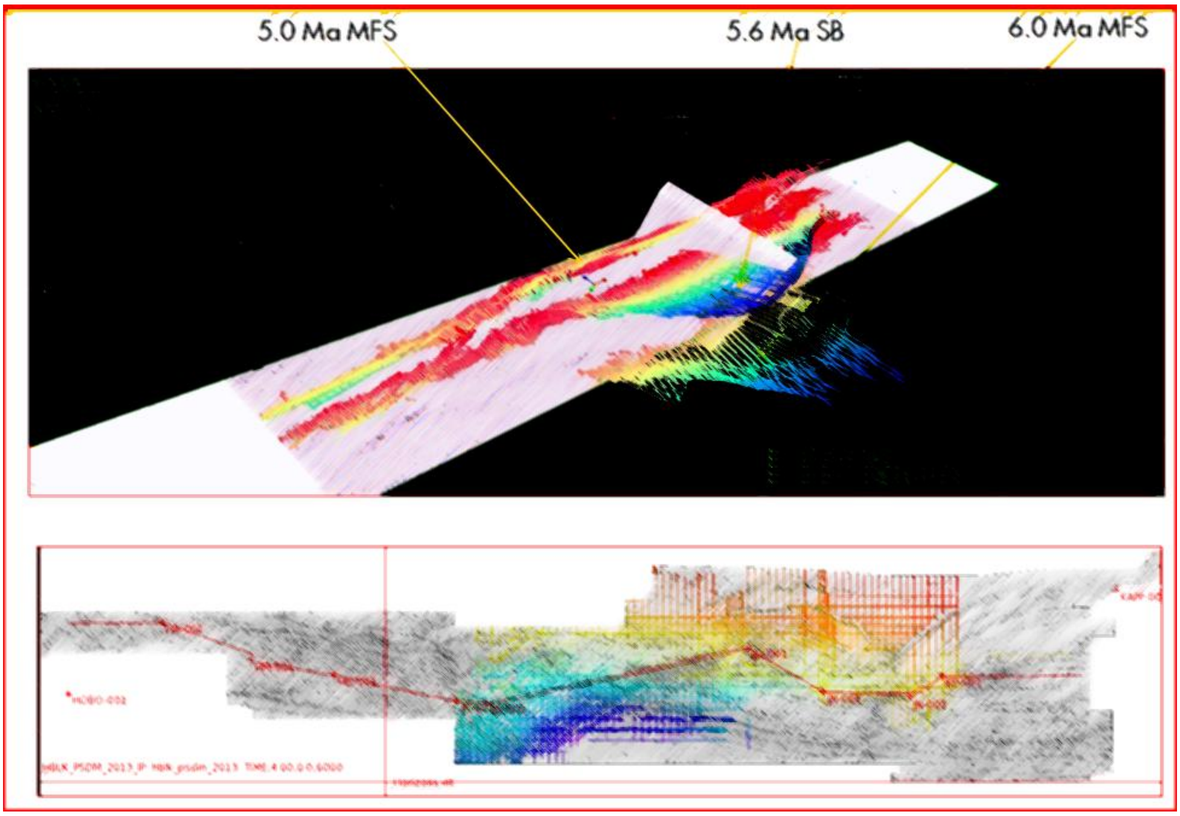

Fig. 2.2.2: 3D window, showing interpreted surfaces displayed in volume view (upper figure) and map view (lower figure) of three surface. The 6.0Ma MFS was not continuous due to poor imaging of the reflectors at deeper depth.

2.3 Geologic Model

The interpreted surfaces in the form of grids were converted to maps in time and depth using Petrel platform. The conversions of time structure map (Isochron) to depth structure map (isopach) were made using the checkshot (velocity function) of five wells (Fig. 2.3).

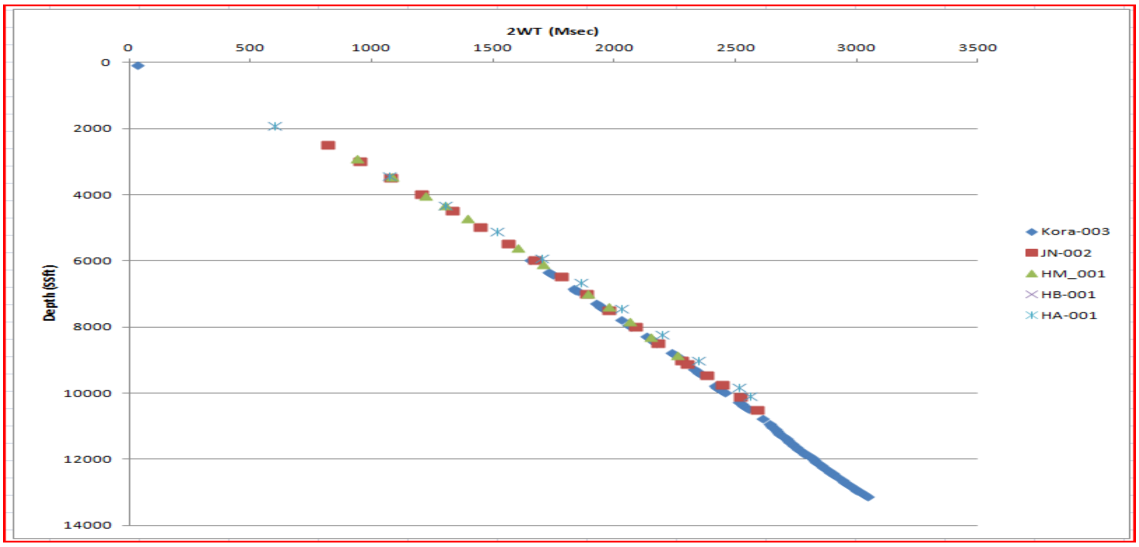

Fig. 2.3: Time-Depth (TZ) plot of representative wells

2.4 Seismic Facies Interpretation

The seismic facies interpretations were performed in order to delineate the lithofacies distributions and environments of deposition. The reference schemes used are those of Brown and Fisher (1984) and Janson *et al* (2011).

2.5 3-D Static Model

The 3-D static model was built by integrating results from structural, stratigraphic and lithological interpretations in the study area. The structural model was produced by pillar gridding the selected faults and converting them to fault surfaces (Fig 2.5). The modelled faults were then aligned to the original faults in the depth structure maps to make sure that they maintain the original trend (Fig. 2.5.1).

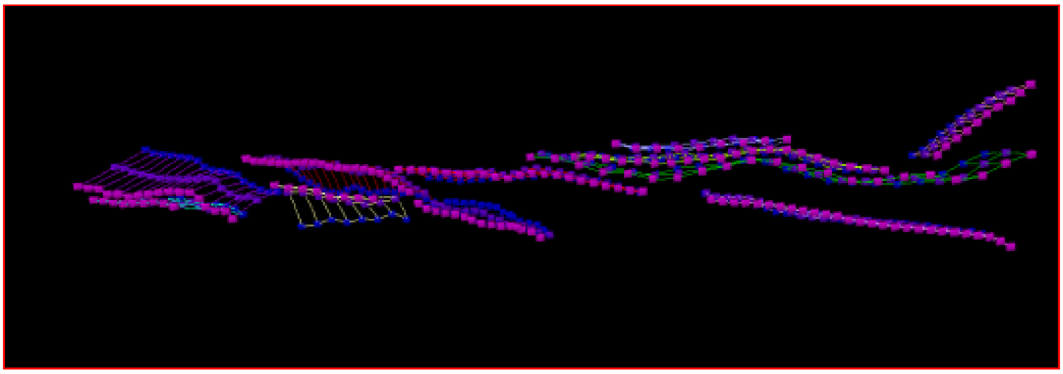

Fig. 2.5: Pillar gridded faults as a build up to making fault surfaces

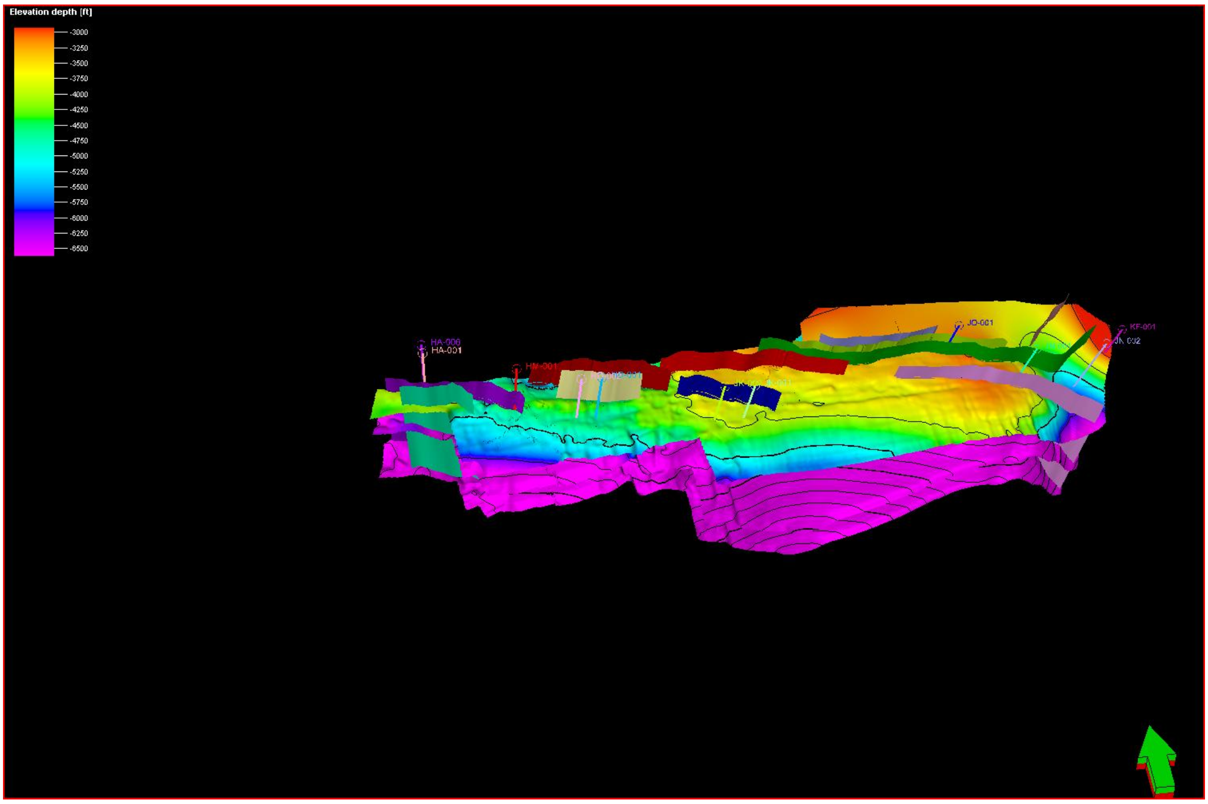

Fig. 2.5.1: Fault model on the depth structures maps

The stratigraphic model was built by interpreting reservoir tops and bases above and below three interpreted surfaces (5.0Ma MFS, 5.6Ma SB and 6.0Ma MFS) and correlating them across the wells. These reservoir tops and bases were converted to isochores (thickness maps). The stacked isochores were layered to accommodate both reservoirs and the shales. The structural and the stratigraphic frameworks were integrated to produce a geologic model using Petrel platform.

III. RESULTS AND DISCUSSION

3.1 Reflectivity Pattern

Observations from the wiggle display (Fig. 3.1) show that the sea bed is the first continuous reflector after the water column and appears as trough in the wiggle display of the seismic data. The water body is always a soft event. Therefore, this first continuous reflector is a hard event. From the wavelet phase in the wiggle display, well information and the well – to **-** seismic tie (Fig. 3.1.1) and using European polarity convention, the shales in the study area appear as trough while the sands as peak. Therefore, the shales in the study area are hard while sands are soft.

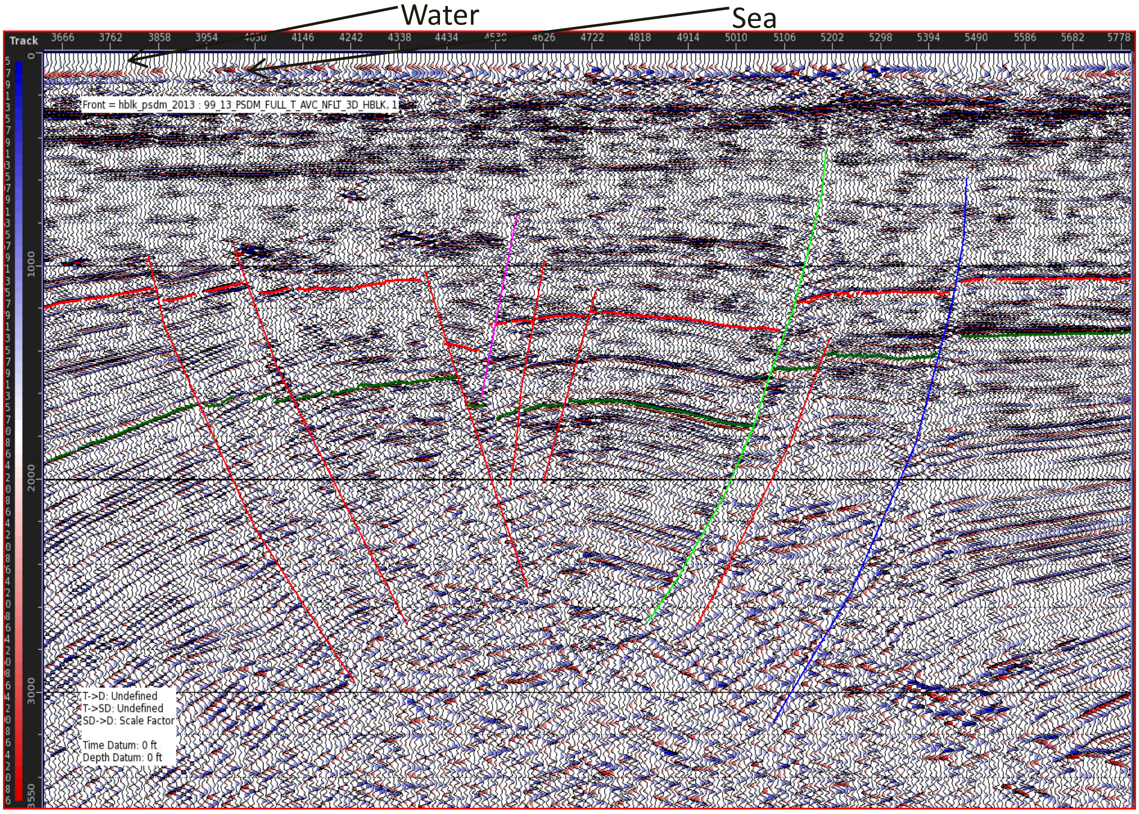

Fig. 3.1: A wiggle display of 3D seismic section serving as the basis for classification of soft and hard events. The display equally show some of the interpreted faults and horizons

3.2 Structural Configuration

Scanning through the traverse view, we observed that the Ham Block is dominated by both synthetic and antithetic faults forming collapsed crest structures. The James Block is dominated by both collapsed crest structures and flank faults, while the Kate Block is dominated by closely spaced flank faults (Fig. 3.2). This trend shows that going from east to west, the structural configuration varies from a simple closely spaced to a more complex fault closures within the crestal areas proving a more or less three way closure system. The implications are that more accommodation is being created toward Ham Block (western portion of the study) and the trapping and sealing systems will be more assured.

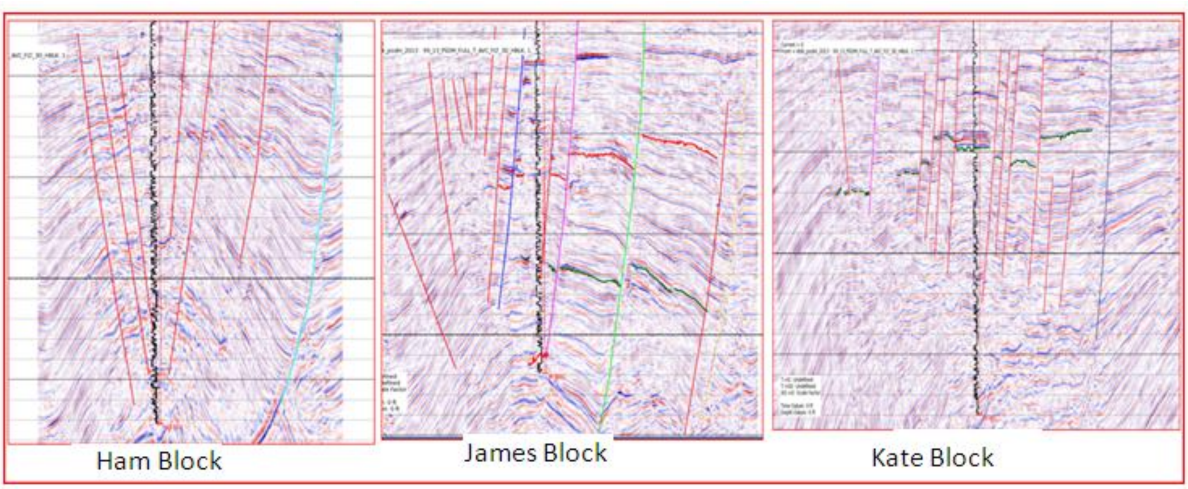

Fig. 7: Structural configurations within Ham, James and Kate Blocks, showing faulting patterns across the fields

3.3 Prospect identification

The isochron and corresponding isopach maps are presented as Fig. 3.3. Observations from the isopach maps at different ages/depths showed that the faults become clearer and more extensive at deeper intervals. The isopach map at 5.6Ma SB showed a display of fault related closures that clustered at the western portion. This may have been the reason why most of the wells are located within the zone. However, there are still opportunities at the central and western parts that showed both contour and fault closures that can serve as good trapping system for hydrocarbon accumulation with fault sealing them. These prospects are indicated by red circles. At the 6.0Ma MFS isopach, a good prospect was equally identify of having a cluster of faults that are closing against one another and are located within an anticlinal (crestal) area. This anticline assured that will be migrated toward it.

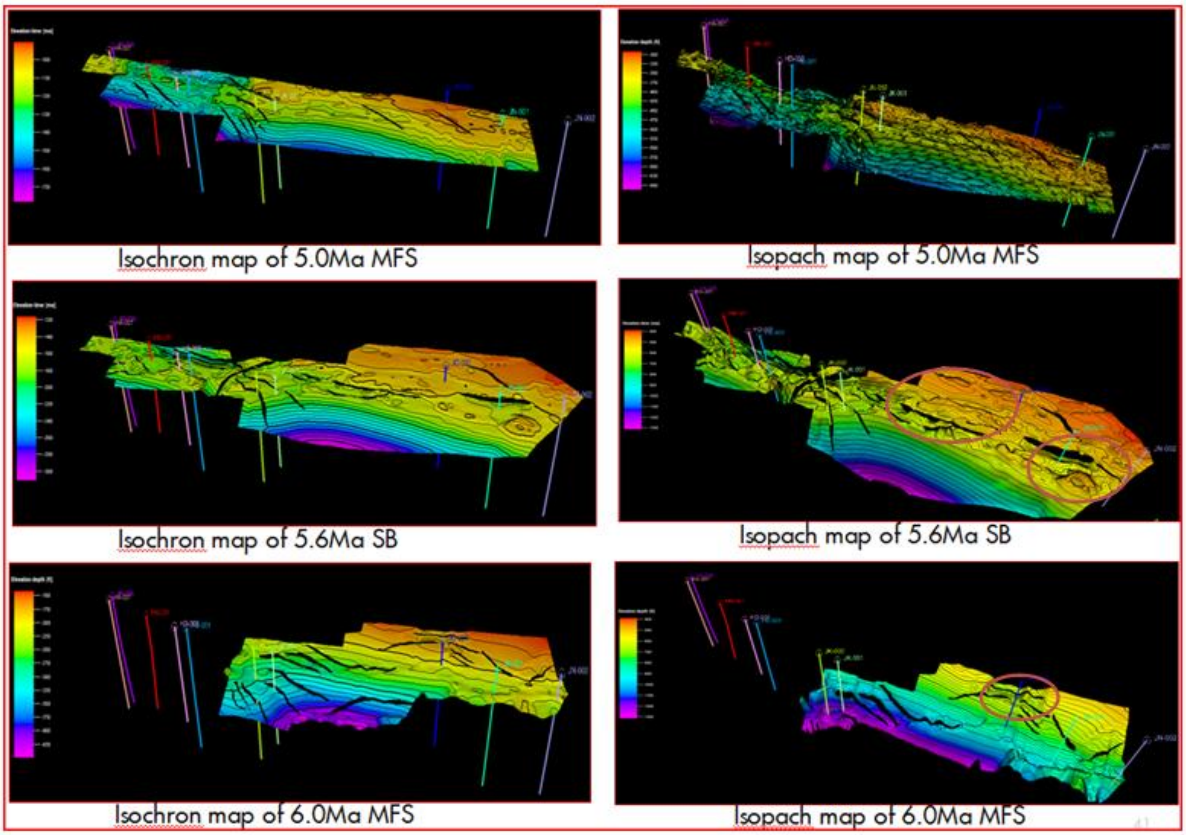

Fig. 3.3: 3D Isochron and Isopach maps, showing the possible fault related closures that can serve as prospects. The prospective areas are indicated by red circles.

3.4 Seismic Stratigraphy

3.4.1 Reflection Termination Patterns

General reflection terminations were interpreted on the seismic. The calibration was done with the interpreted stratigraphic surfaces such as sequence boundaries and maximum flooding surfaces. The onlap terminations were found to be associated with sequence boundaries while the toplaps were found to terminate against MFS. The SBs which were created during various incisions that took place at 5.5Ma and 6.7Ma varies from east to west. In the eastern side, the infill pattern is mainly a prograding fill with the wedge forming an anticlinal structure on which JaO-001 well was sited while at the western side the infill was mainly an onlaping fills (Fig. 3.4.1).

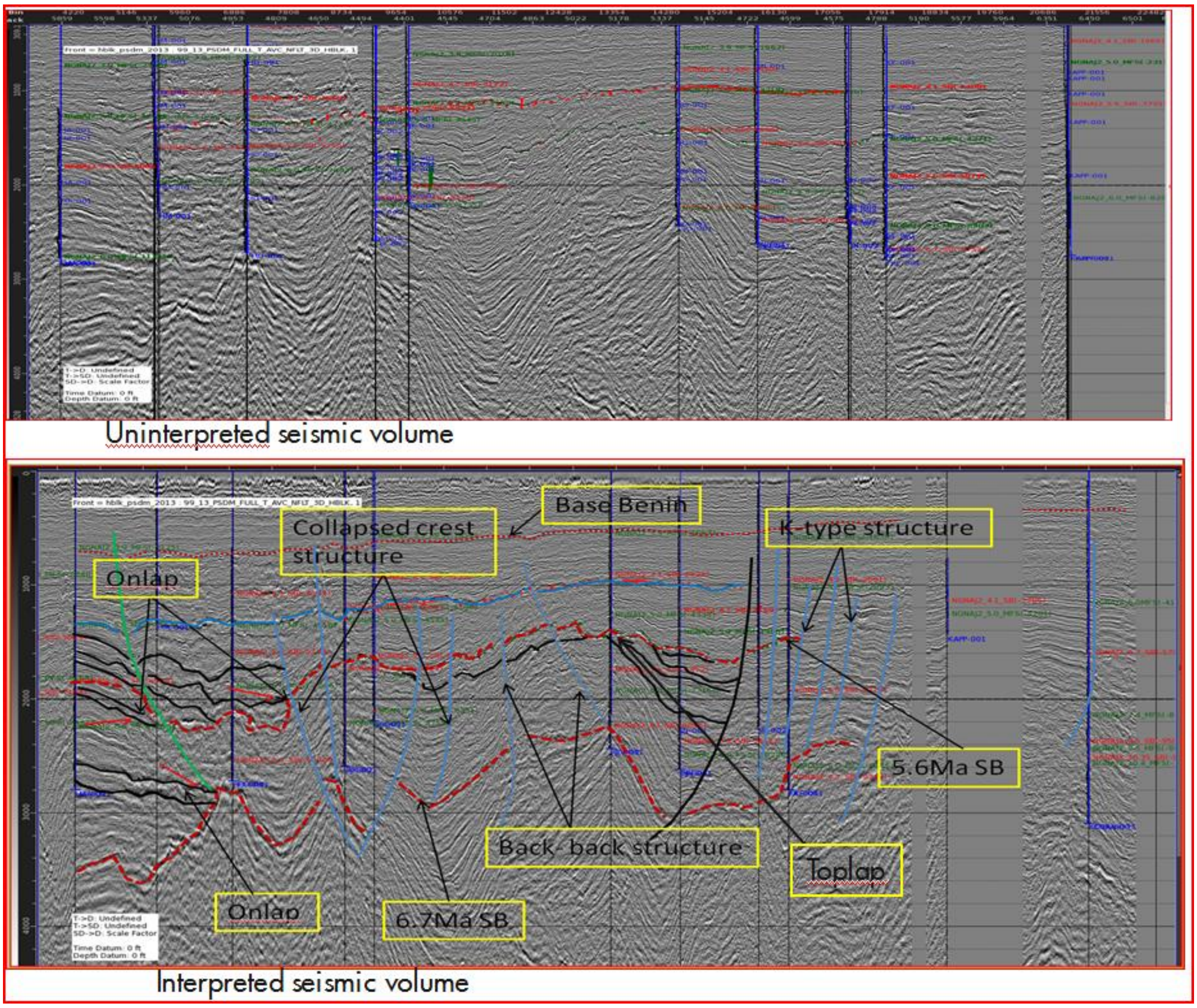

Fig. 3.4.1: Reflection Terminations Patterns against stratigraphic surfaces

3.4.2 Seismic Facies Classification and Interpretation

Six seismic facies were identified based on seismic reflection configuration, continuity, amplitude, frequency and lateral and vertical bounding relationships with other reflectors. The interpreted seismic facies are classified into: (1) Parallel, continuous, low to moderate amplitude, (2) Wavy, continuous, low to moderate amplitude, (3) Oblique, discontinuous, low amplitude, (4) High angle oblique continuous, (5) Mounded, chaotic, low amplitude and (6) Mounded, continuous, low amplitude. The reflection attributes used in defining each of these listed seismic facies are illustrated in Fig. 3.4.2 while their calibrations with well information are shown in Fig. 3.4.3.

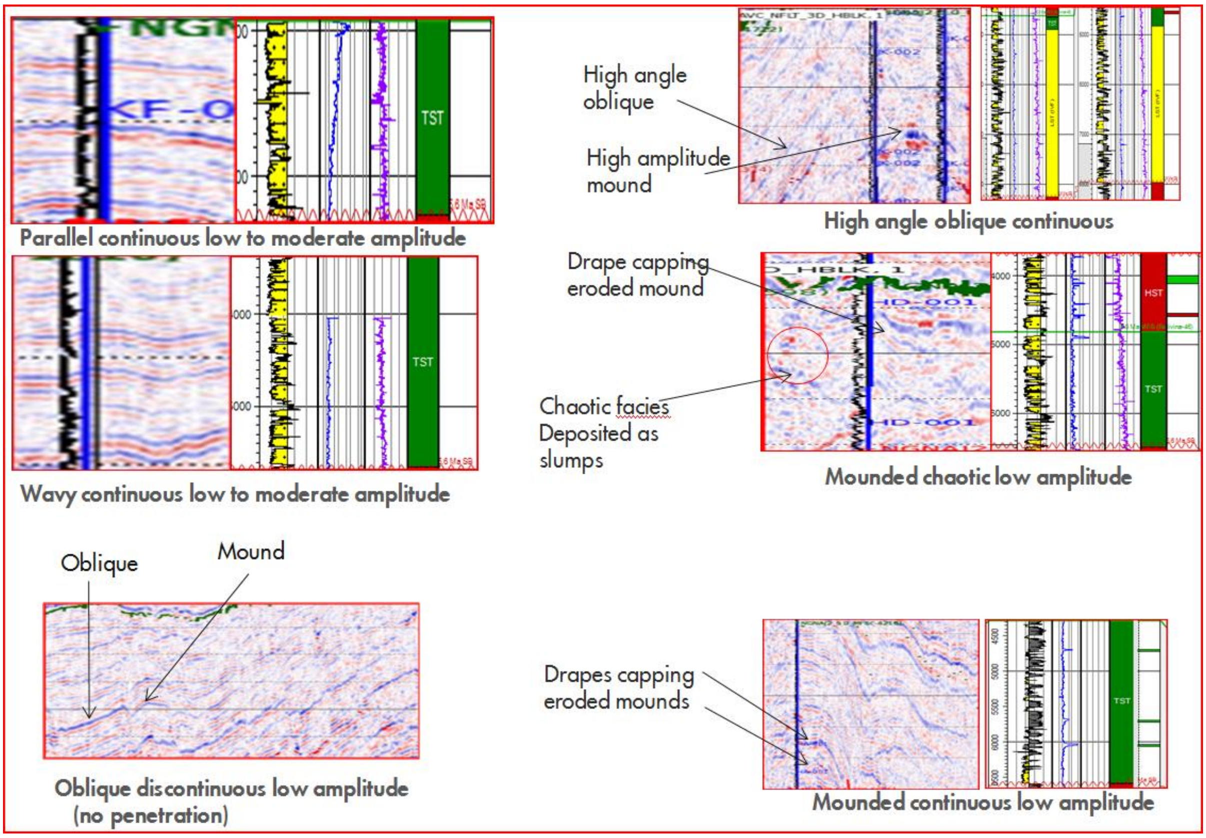

Fig. 3.4.2: Typical reflection attributes used in classifying seismic facies

The parallel, continuous configuration facies suggests uniform sedimentation conditions while wavy, continuous configuration suggests a sequence deposited on top of a subsiding substratum. Well information shows that both parallel and wavy continuous facies are associated with channel sandstone (Fig. 3.4.2). However, both possess poor reservoir-seal pairs and may hold little or no hydrocarbons (see Fig. 3.4.3). The oblique, discontinuous, low amplitude facies was interpreted as shallow marine progradation in a high energy environment.

The mounded chaotic and mounded continuous, low amplitude facies showed good reservoir-seal pairs, which ensured that all the facies contained hydrocarbons (Fig. 3.4.3). These facies are found towards the western portion of the study area within the Ham Block. The mounded, chaotic facies were interpreted to occur at the shelf edge (lower shelf environment) while mounded, continuous facies suggested deposition within the slope. From the positions of the wells, interpreted paleobathymetry and seismic facies (mounded, continuous, low amplitude), the slope deposits appear to have started around HaA-001 well and moved basinward toward the western flank (HaB-001 and Hobo-001 wells).

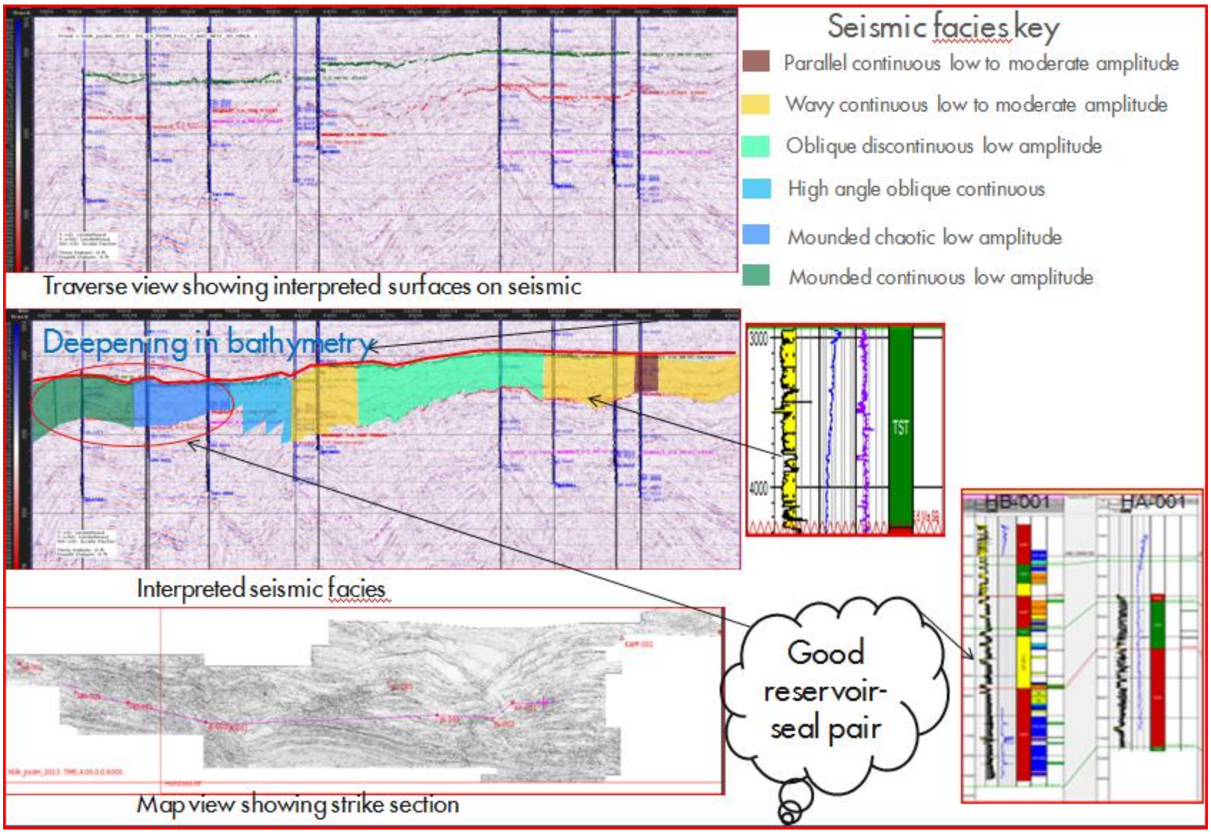

Fig. 3.4.3**:** Seismic facies calibrated with well information showing the facies with good reservoir – seal pair

3.5 Geologic model

A closer look at the geologic model showed that two major down-to-basin faults; one synthetic boundary fault and another counter regional fault (Fig. 3.5) occurred towards the western and eastern portions, which divided the study area into three macrostructures. The regional fault at the western portion is a growth fault showing a listric characteristic (becoming horizontal at the base). These macrostructures have been named fault block I (FB I), fault block II (FB II) and fault block III (FB III). The FB I houses the HaB, Hobobo and HaA fields, the FB II houses the HaB, HaM, HaD and JaK fields while the FB III houses the JaO, JaN and KaF fields.

Further observation from the geologic model showed that sediments within one of the graben bounded by the counter regional fault demarcated FB I and FB II, and stretched to an opposing fault just after HaD field are thicker compared to those in the flanks. These sediments are the hanging wall of the counter regional fault. The implication is that this counter regional fault is the major fault that controlled sediment accumulations in the area. The incised valley fill (IVF) around the JaK field are clearly shown in the model. However, it appears to have extended more in the eastern direction. This could be due to lack of well control between the JaK and JaN fields, which are wide apart. The FB I (Ham Block) is located in the anticlinal structures with an expectation of hydrocarbon accumulation within the structural traps. The mounded, low amplitude seismic facies is equally located within this fault block and well information shows that the FB I fault has good reservoir-seal pair, which will ensure that all the reservoirs probably contain hydrocarbon.

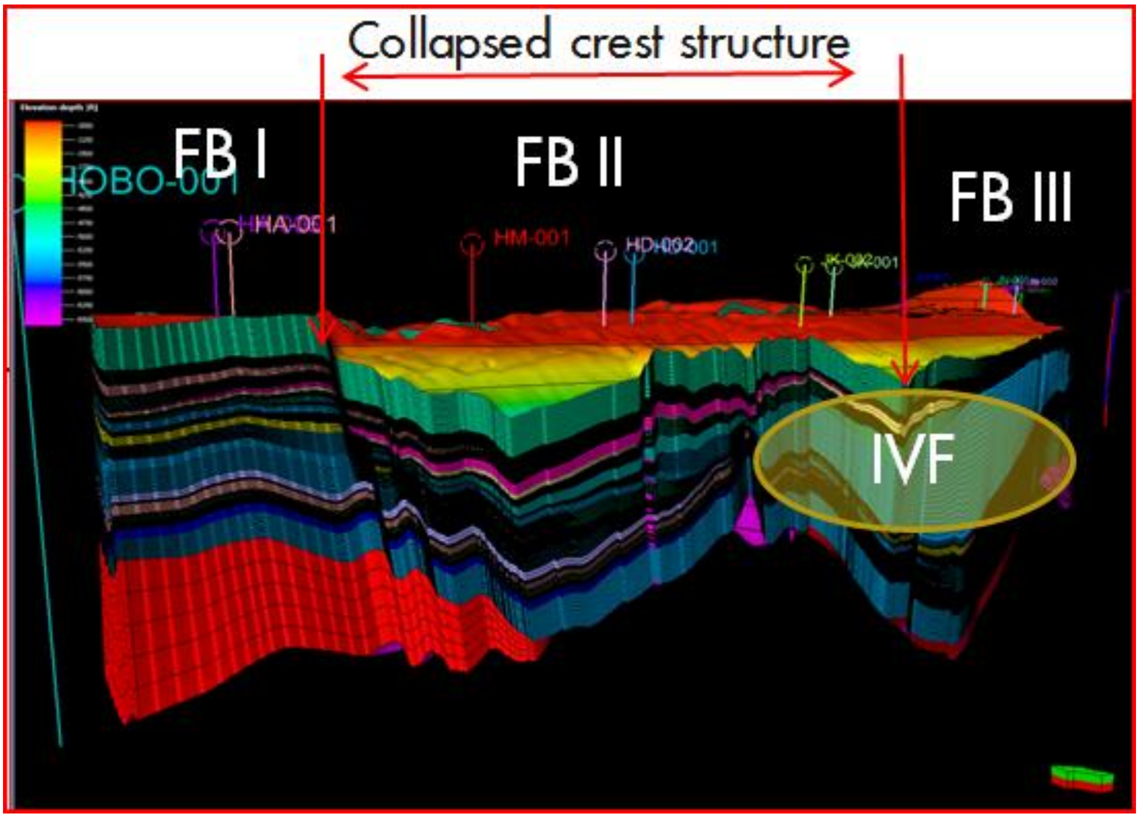

Fig. 13: 3-D geologic model of the entire studied fields, showing FB I, FB II AND FB III fields with their associated wells, an incised valley fill and possible compartmentalization by fault systems

IV. CONCLUSION

The field structural configurations depict a simpler fault architecture that becomes more complex basin-ward as one move from the eastern to the western portion. The structuration varies from a closely spaced flank faults to a complex fault system that has both back – to – back faults forming horst structures to a collapse crest structures.

Three new prospects were identified in the study based on the contour and fault related closures which are mostly located within the anticlinal structures.

The static geologic model help us to demarcate the area into three fault blocks bounded by major regional faults that control sedimentation with the incised valley being identified towards the eastern portion. Integration of seismic facies and 3-D geologic model shows that the depositional environments deepened westward with the eastern portion dominated by channels reservoirs while the western portion is dominated by slope sands. The results from the seismic facies analysis when integrated with well information shoed that the western portion of the study area showed good reservoir-seal pair. This relationship when combined with good structuration enhances hydrocarbon accumulation and retention.

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