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Research Article

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Depositional Structures, Tectonic and Stratigraphic Units and Their Effect on The Reservoir Rock Units of South Lake Albert Basin, Albertine Rift, Uganda.

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Abstract
The study focused on interpretation of three-dimension (3D) seismic and suites of wireline log datasets, to construct and interpret models and facies analysis to assess the depositional structures, tectonic and stratigraphic unit' settings. Challenges and uncertainties of low to moderate reservoir quality parameters attributed to limited understanding of depositional structures, tectonic and stratigraphic units had been identified in previous studies within the study area. From the study undertaken, the study area is structurally complex with compartments and flower structures. The stratigraphic interpretation, realized that sediments were highly intercalated (clay, silt, fine and coarse sands) majorly attributed to the short changes in climatic (wet and dry) conditions. It was further deduced that compartmentalization and intercalations of sediments had a very high effect on the reservoir rock properties which might affect the recovery of the available fluids.

Keywords: SouthLake AlbertBasin, Reservoir Rock Units, Flower Structures, Compartmentalization and Intercalation.

1. Introduction

1.1 Background

South Lake Albert Basin (SLAB), forms part of the Albertine [1]. (Fig. 1), and had been subjected to intensive research and petroleum exploration activities for many years [2-8]. SLAB is composed of Kaiso-Tonya and Kingfisher areas (Fig. 1).

A number of studies conducted in the Albertine graben include basin evolution, sedimentology, stratigraphy, structural, geochemical, core analyses specifically to investigate the depositional systems, depositional environments, reservoir rock types, source rock and general techniques in petroleum exploration among others, however, little emphasis had been put on the detailed understanding of depositional structures, tectonic and stratigraphic units and their effect on the reservoir quality. Successful delineation and understanding of reservoir rock units is guided by depositional structures, tectonic and stratigraphic units' interpretations of the stratigraphic section in a given basin [1-2]. Their interpretation is conducted by tectonic and stratigraphic modelling processes using seismic and wireline datasets. Lithofacies analysis was also conducted to understand the architectural units within a given sedimentary section.

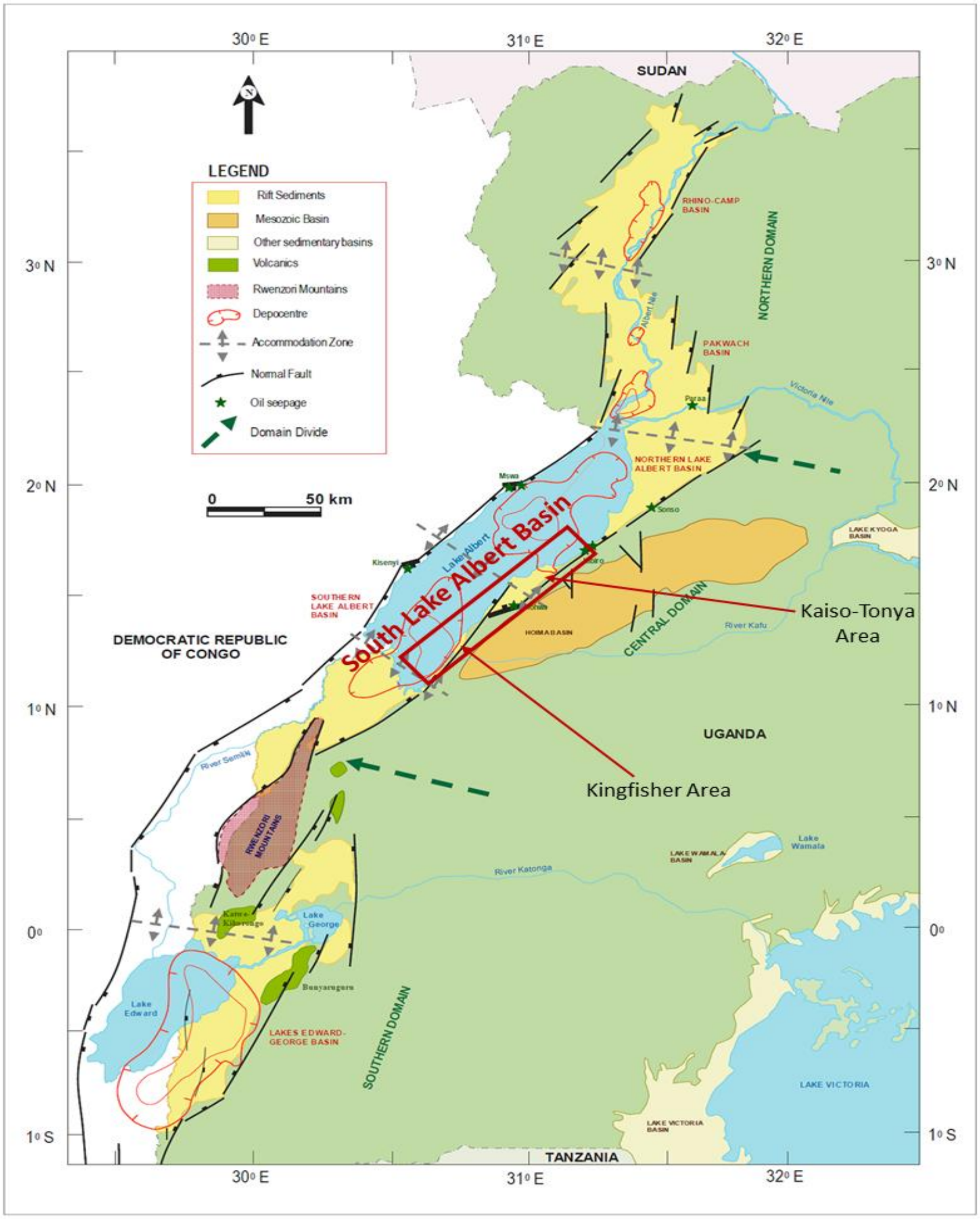


Figure 1: Map showing the Extent of South Lake Albert basin (modified from Abeinomugisha and Njabire, 2012).

According to Wilson et al., (1977) and Martinius et al., (2014), investigating the tectonic and depositional factors guide the understanding of the control and effect on the reservoir quality. Thus, the different studies conducted in SLAB highlighted challenges and uncertainties of low to moderate porosity, permeability and high volume of shale i.e., poor reservoir rock parameters that were attributed to limited understanding of depositional structures, tectonic and stratigraphic units, and its effect on the reservoir quality. These challenges may affect the recovery of petroleum resource volumes within a given field. According to Galloway, (1989), successful interpretation and delineation of depositional systems, and basin-scale facies require the recognition and correlation of stratigraphic packages. Hence, undertaking studies on the depositional structures or tectonic and stratigraphic units and facies analysis will guide the understanding of reservoir quality. In conclusion, the causes of the highlighted challenges and uncertainties of low to moderate porosity, permeability and high volume of shale would be better understood. Thus, this study was aimed at understanding the depositional structures, tectonic and stratigraphic units, and their effect on the reservoir quality.

1.2 Geological Setting

1.2.1 Structure and Evolution of The Albertine Graben

The East African Rift System (EARS) represents the world's best example of an active rift system, although its deep origins remain poorly understood [9]. The Albertine graben forms the northernmost part of the western arm of the East African Rift System and it is a tertiary intra-continental rift developed on the precambrian orogenic belt of the African craton [1-2]. It stretches from the Aswa shear zone at the border between Uganda and South Sudan in the north to Lake Edward in the south, a distance of over 500 km. The graben has an average width of around 45km and runs the entire length of Uganda's western boundary with the Democratic Republic of Congo. The graben is a NW-SE striking trans-tensional pull apart depression [10].

Structurally, the Albertine graben is segmented into a series of asymmetric graben depocenters, or domains, each being separated by trending basement highs most of which are associated with volcanic [1,11-13]. However, comparison of Lake Albert rift with data available in the rifts of both Western and Eastern branches of the EARS showed that most of the sedimentary basins experienced the geometrical evolution from large basins with limited fault control [8].

1.2.2 Geochronology and Sedimentology of The Albertine Graben

A number of formations had been identified within the SLAB (Tables 1&2). Claystones in lower parts of the Nkondo formation in the subsurface contained isolated thin sandstone stringers which provided the main oil reservoirs in the area and conflicting mid-miocene age and late pliocene age had been suggested from cuttings of Mputa-1 and Waraga-1 wells on the basis of palynomorphs [14,15] This formation was deposited in the marginal lacustrine to deltaic deposits, and dominated areas towards the lake shores [16]. Whereas coarser alluvial fan and fluvial deposits were more common towards the graben's marginal escarpment [17,15]. Nyaweiga formation was suggested to be of mid-miocene and late pliocene to early Pleistocene on the basis of Mputa Formation was of mid-miocene age and had been suggested in the Mputa-1 and Waraga-1 wells on the basis of palynomorphs, whereas RPS Energy suggested a late Pliocene age and the Formation's sandstones represent deltaic to fluvial sequences.

Kisegi Formation was interpreted as the best potential reservoir rock and Kasande Formation was interpreted to be a very good potential source rock [18]. Kosgei Formation was generally composed of thick, channeled and cross bedded sandstones with thin beds of suspected tuff, bleached silts and clays, and had conflicting ages of early miocene to early miocene. This was conducted using sediments from Turaco wells by polymorphs and it was further suggested to be pre-dominantly fluvial environment in a relatively quiescent tectonic regime, with low energy small-scale channel systems. In the Kasande Formation, transgression led to the development of mud flats with meandering channels, interfingering with near-shore lacustrine deposits, replacing the totally sand-dominated alluvial deposits of Kisegi Formation [3,18,6].

SN	Age	Formation
1	G7 – 0.5 Ma	Absent in Kaiso-Tonya
2	G6 – 1.8 Ma	Absent in Kaiso-Tonya
3	GX – 2.3 Ma	Kaiso Village
4	GX - 2.6 Ma	Hohwa
5	G5 – 3 Ma	Kyehoro
6	G4c – 3.4 Ma	Upper Warwire (above Kyampanga Tuff)
7	G4b – 3.7 Ma	Middle Warwire (Sebugoro)
8	G4a - 4.5 Ma	Lower Warwire
9	----------------	Extinction event
10	G3b – 4.9 Ma	Uppermost Nkondo (Nyaweiga Member)
11	G3a – 6.5 Ma	Upper Nkondo shaley member
12	G2b – 7 Ma	Not exposed
8	G2a – 8 Ma	Not exposed
9	G1 – 12-9 Ma	Not exposed
10	G0 – 13 Ma	Not exposed

Table 1: Kaiso exposures display only 10 of the complete succession of molluscan associations known in the Albertine Rift, for reasons to be discussed herein (Gautier 1970; Pickford et al., 1993; Senut & Pickford., 1994; Van Damme & Pickford., 1995, 1999, 2003, 2010).

SN	Age	Formation
1	G7 -0.5 Ma	Rwebishengo Beds
2	G6 -2-1.5 Ma	Nyabusosi Fm
3	GX -2.3 Ma	Absent in Kis-Nyab area
4	GX -2.6 Ma	Absent in Kis-Nyab area
5	G5 -3 Ma	Nyakabingo Fm
6	G4 -3.5 Ma	Upper Nyaburogo Fm
7	G3b -4.9 Ma	Lower Nyaburogo Fm
8	G3a -6.2 Ma	Upper Oluka Fm
9	G2b -7.1 Ma	Lower Oluka Fm
10	G2a -8 Ma	In Congo
11	G1 -12-9 Ma	Kakara Fm
12	G0 -13 Ma	Kisegi Fm (upper part)

Table 2: Semliki exposures display the most complete succession of molluscan associations known in the Albertine Rift, but three associations (shown in blue) are absent (based on Gautier, 1970; Pickford et al., 1993; Senut & Pickford 1994; Van Damme & Pickford, 1993, 1995, 2003, 2010).

2. Material and Methods

Available data used for this project was acquired from Ugandan exploration areas 2 and 3A in the SLAB that covers the Kaiso-Tonya and Kingfisher area situated under the Coordinate Reference System (CRS); WGS 84 UTM84 – zone 36 North (Fig. 2). Datasets included; 350 and 230sq.km of 3D seismic data from Kingfisher and Kaiso-Tonya areas respectively, and suites of wire logs. Two softwares were used during this study, that is Petrel and Techlog. According to Ali et al., (2021), the integrated study using multidisciplinary datasets (3D seismic and wireline logs) to understand the structural, stratigraphic, depositional and facies characteristics can be used to investigate the complex geometry of any basin. That is why these datasets were identified to be used in this study.

Within the two (Kaiso-Tonya and Kingfisher) surveys, wells with density, sonic velocity and Vertical Seismic Profile (VSP) data were used to run seismic-well tie thus creating a well time depth relationship (TDR) between the seismic volumes and the corresponding wells. During seismic well-tie process, density and sonic logs were multiplied to get acoustic impedance as per the equation below; $z=\rho v$, *z-Acoustic Impendence*, ρ *-density*. $v=\sqrt{(E/\rho)}$, *v-Sound wave velocity, E=Elastic modulus*, ρ *-density*. The obtained acoustic impedance across two formations of different densities and sonic velocity were convolved with a selected wavelet in petrel thus generating a synthetic seismogram. The generated seismograms for Mputa 5 and Kingfisher 1A wells were used in picking formations on the two 3D seismic volumes (Kaiso-Tonya and Kingfisher areas respectively). Correlation of different wells was also conducted to identify formations. It was conducted on the Kaiso Tonya wells using, Nzizi-1, Nzizi-2, Mputa-1, Mputa-2, Mputa-4 and Mputa-5 wells to identifying the different formations i.e., Base Nkondo, Base Mputa and Base Nyaweiga, the identified reservoir rock units (Fig. 3).

Faults were interpreted on the two 3D seismic volumes. Fault interpretation was enhanced using structural seismic volume attributes such as structural smoothing, anti-tracking and variance (edge detection). During horizon mapping, to define the area of interest, a boundary polygon was generated by digitizing on the survey map and all data within this boundary was modelled and mapped. The interpreted horizon interpretations and faults were used as input in generating structural maps defined by the boundary polygon. The generation of these structural maps involved the use of convergent interpolation algorithm using seismic lines with high density.

A velocity model was created using surfaces as inputs and this velocity model was used for depth conversion. The surfaces were used to define the value at each xy location and covered the whole area of the velocity zone. The velocity model used was; $v = vo + kZ$, $v = vo = vint$ *(assuming k=0)*, Where v -calculated velocity at xy location in zone, vo = *Velocity at datum (SRD)*, v_{int} = *Interval Velocity* (all these were generated using seismic well-tie process). z-Acoustic Impendence and k- Instantaneous velocity gradient.

Horizon and fault interpretations were depth converted using the calibrated seismic velocity cube modelling method and then used in structural modeling. To build a structural model, a fault framework was first generated under structural frame work modeling method. The depth converted horizon and fault frame work were then modelled using Volume Based Modelling (VBM) method thus creating zoned model.

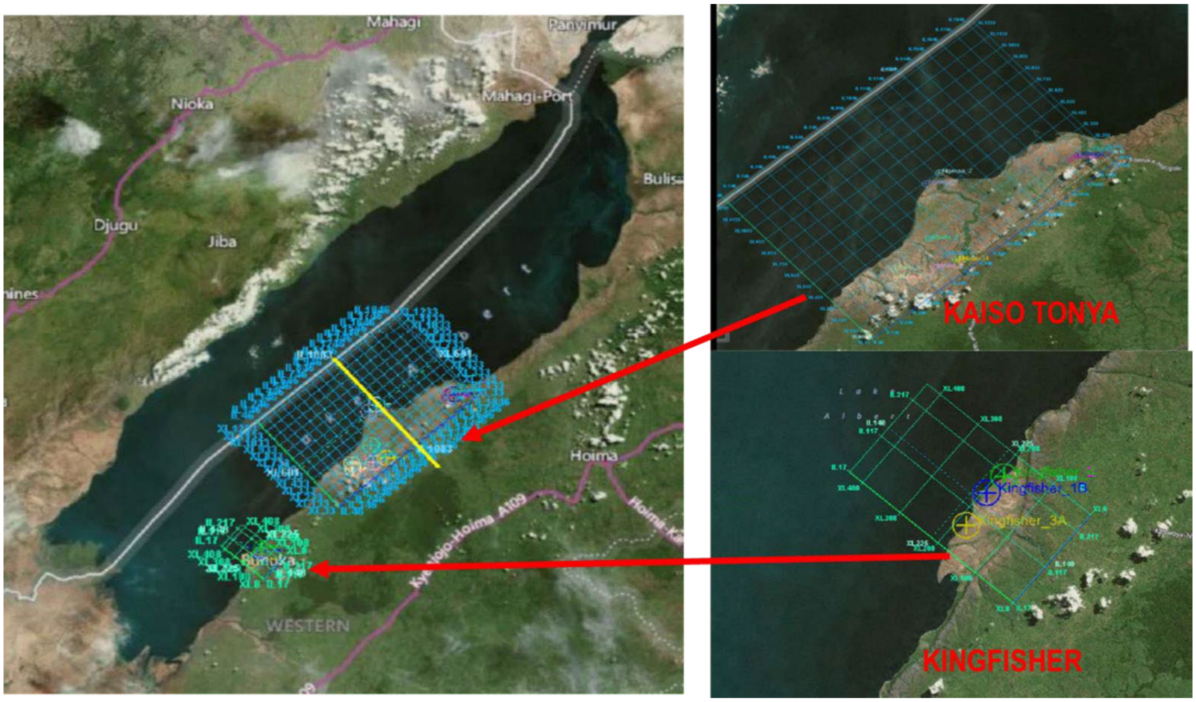


Figure 2: Seismic and Well data coverage in South Lake Albert basin.

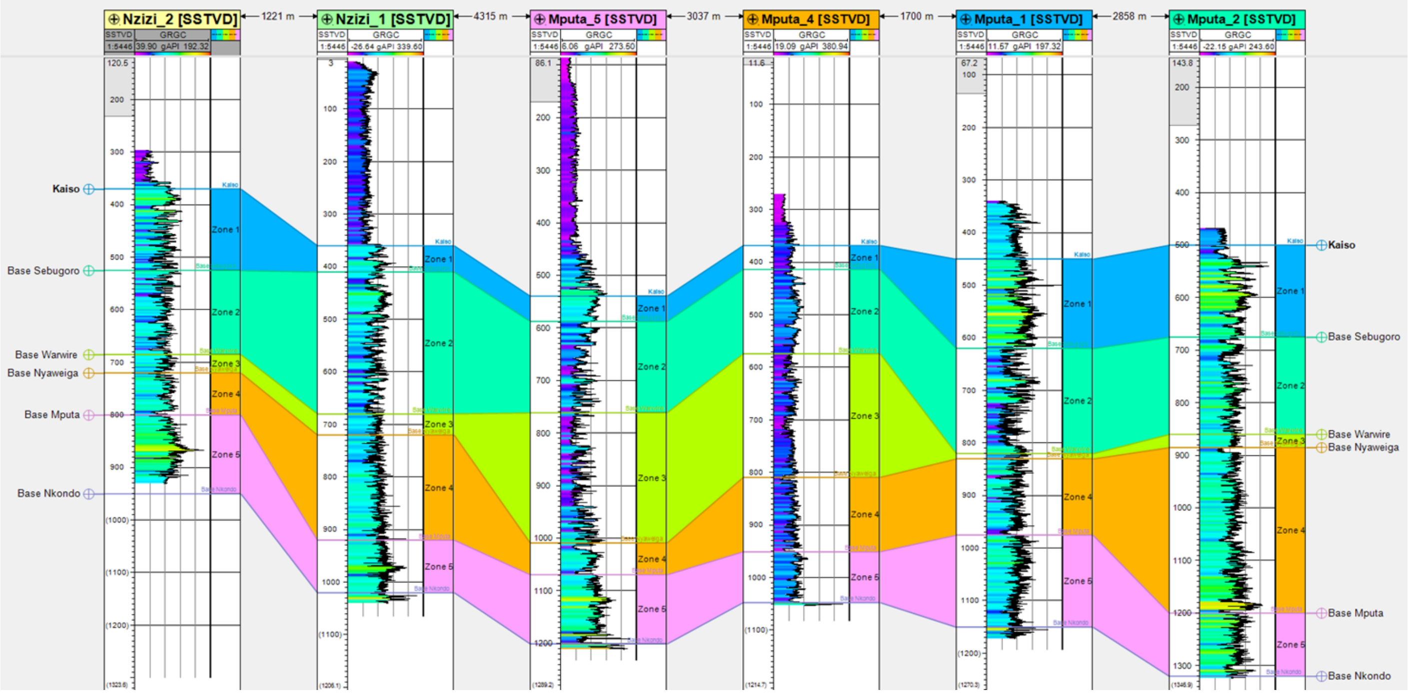


Figure 3: Well Correlation for Kaiso Tonya wells using, Nzizi-2, Nzizi-1, Mputa-3, Mputa-4, Mputa-1, Mputa-2 wells, identifying the different formations, with Base Nkondo at 1320m, Base Mputa at 1200m and Base Nyaweiga at 885m all were picked using measured depth (mD). Base Nkondo, Base Mputa and Base Nyaweiga zones were observed to have majorly sand and taken as potential reservoir rock.

Velocity Model Building (VMB) is the platform that helps convert seismic volumes, lines and/or events from seismic time to depth. There are different methods of building velocity models depending on the available data (Abrahamsen, 1993). Some of the available techniques include; calibrated seismic velocity cube, polynomial method and the vo -K (Instantaneous Velocity-Gradient) Function [19,20]. VMB involves creating a meshed volume then computing a stratigraphy property within the meshed volume in order to calculate relative age of the geological layers. As constraint, iso-values of the stratigraphy property would go through data points.

The stratigraphy property was then used to subdivide the volume into layers. The structural grid was then built from the volume subdivisions. A depth structural grid was finally generated under structural gridding process in petrel with different formations and depth maps. Facies were generated from their respective upscaled logs from facies modelling processes in petrel and finally the property maps were created through an average method run based on a particular zone hence a zone-based property map. These property maps were used to identify the different facies that were used in this study. Depositional setting analysis was conducted using Root Mean Square (RMS) amplitude attribute in Kaiso Tonya area and variance in Kingfisher area. These attributes of petrel were varied and appropriate shapes were obtained for sediments in the study area and thereafter, the sediment depositional settings were generated.

3. Results

3.1 Formation Mapping

From uninterpreted datasets of seismic data (Fig. 4), and after interpretation, different formations were mapped on seismic dataset as indicated in Figs. 5&6. From the studied section in the Kaiso Tonya area. The stratigraphic profile started with basement at the bottom, followed by Base Nkondo, Base Mputa, Base Nyaweiga, Base Warwire Formations in this order. Base Nyaweiga, Base Mputa and Base Nkondo Formations were mapped out to be potential reservoir rock units from the correlation that was made during this study (Fig.3). From the study that was conducted within Kingfisher area, the basement was followed by Base Kisegi, Base Kasande, Base Kakara and Base Oluka Formations in that sequence. Base Kisegi, Base Kakara and Base Oluka Formations were identified as reservoir rock units. It was further realized that the mapped Formations were not very continuous as they were affected by the different fault regimes within the basin. Thus, their lateral extent was affected by the faulting regime within the study area.

3.2 Facies modelling and analysis

Facies were generated using upscaled logs from facies modelling processes in petrel and finally the property maps were created through an average method run based on a particular zone hence a zone-based property map. Then, these property maps were used to identify the different facies on the formations that were mapped.

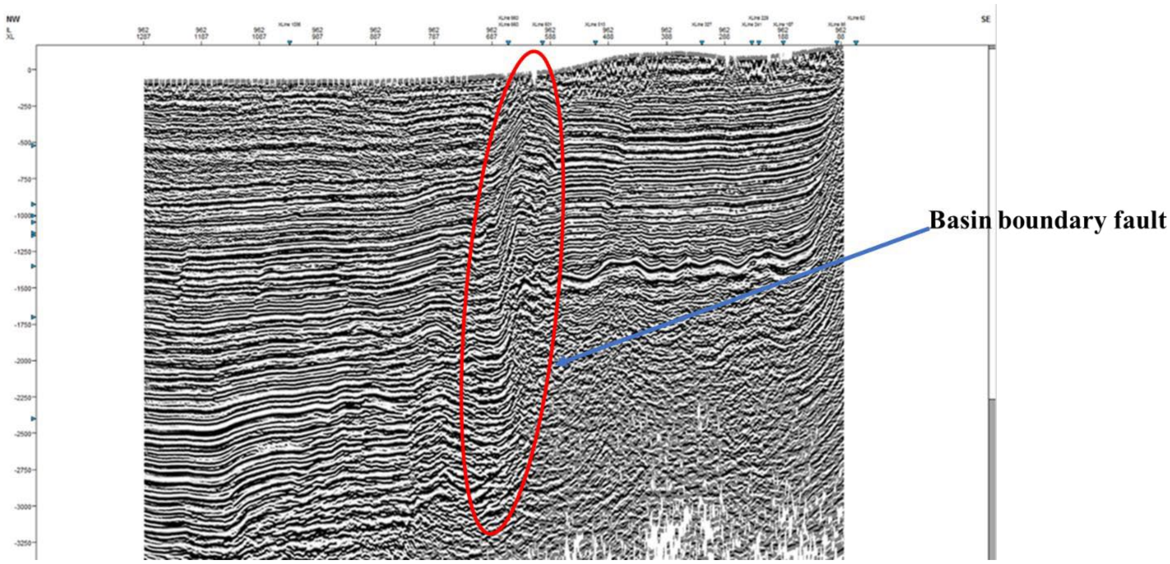


Figure 4: Raw seismic data for basin bounding fault in Kaiso Tonya area.

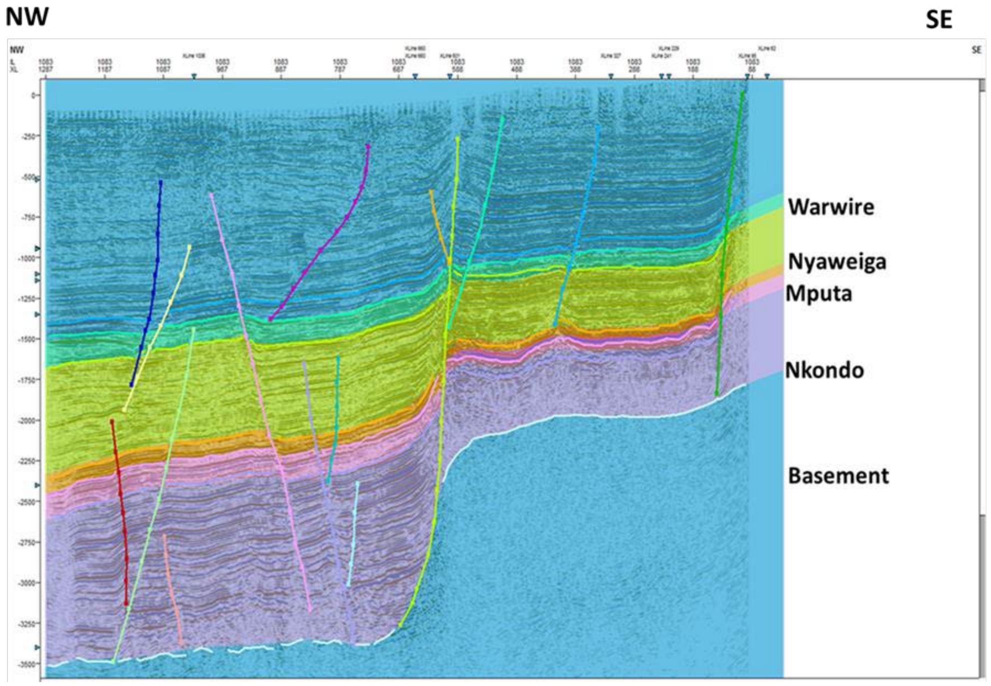


Figure 5: Formation tops mapped from Seismic data using Root Mean Square (RMS) Amplitude attribute in Kaiso Tonya area showing Base Nkondo (purple), Base Mputa (Red), Base Nyaweiga (yellow) and Base Warwire (light green).

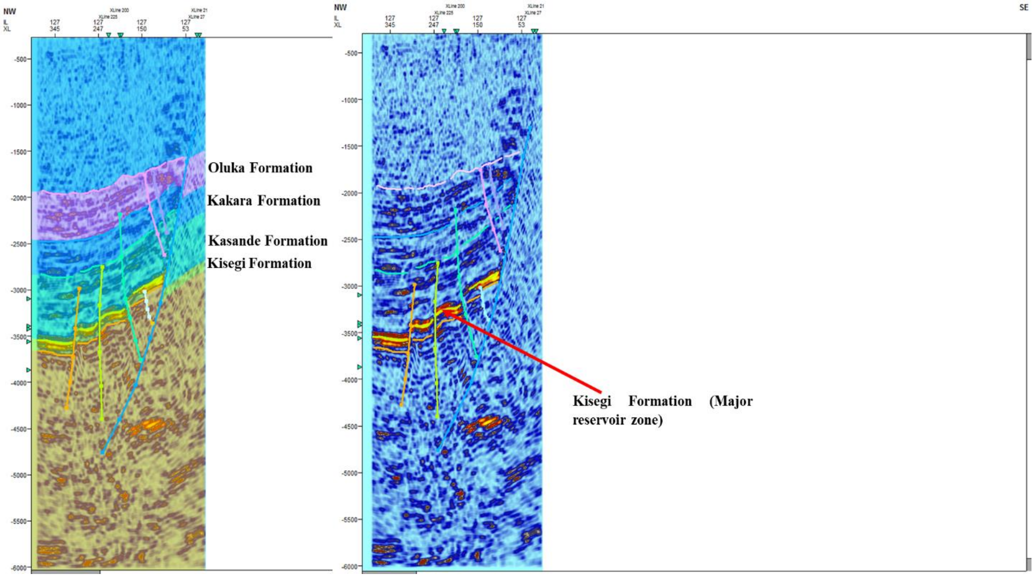


Figure 6: Formations mapped from Seismic data using Root Mean Square (RMS) Amplitude attribute in Kingfisher area, showing Base Kisegi (yellow), Base Kasande (light green), Base Kakara (blue) and Base Oluka (purple).

In the Base Nyaweiga Formation, it was observed that Mputa field was composed of fine sands with pockets of silt, Nzizi field had fine sands with silts, Waraga field was composed of majorly fine sands, Ngassa field had coarse sands, silt and clay, and the section under Lake Albert had coarse sands, silt and fine sands (Fig. 7).Base Mputa Formation was also present in the Mputa-2, 3, 4 and 5, Waraga-1 and Nzizi-1 and 2 wells. In the Base Mputa Formation, Mputa field was composed of silt, pockets of fine sands and coarse sands, Nzizi field had silt and pockets of coarse sands, Waraga field was composed of coarse sands, Ngassa field had fine and coarse sands, and the section under Lake Albert was composed of fine sands with pockets of silt, coarse sand and clay (Fig. 7).From Base Nkondo Formation, Mputa field was composed of fine sands and silts, Nzizi field was composed of fine sands and pockets of silt.Waraga field was composed of fine and coarse sands.Ngassa field was composed of fine sands and pockets of clay and the section under Lake Albert had fine sands with pockets of coarse sands, silt and clay (Fig. 7).

From the cross section through Ngassa field and section under Lake Albert i.e., section parallel to the basin bounding fault, it could be interpreted that sediment deposition in Kaiso-Tonya area was highly intercalated (interbeds of different facies i.e., there were thin lithofacies with different interbedded lithologies (clay, silt, fine and coarse sands) deposited at very shorter intervals (Fig. 8). It was also interpreted that the deposition was influenced by the short changes in climatic conditions that happened over time during the sediment deposition processes.

Base Kakara Formation was composed of silts towards the basin boundary fault, fine sands and coarse sands towards the Lake Albert (Fig. 9). Base Oluka Formation had fine sands, pockets of coarse sands and silt. Base Kasande Formation had coarse sands towards the basin boundary fault, clay towards the bottom of Lake Albert, pockets of fine sands in the south and east direction (Fig. 10). It should also be noted that Base Kisegi Formation could not be modeled due to the poor distribution of facies in wireline logs of the existing wells in the study area.

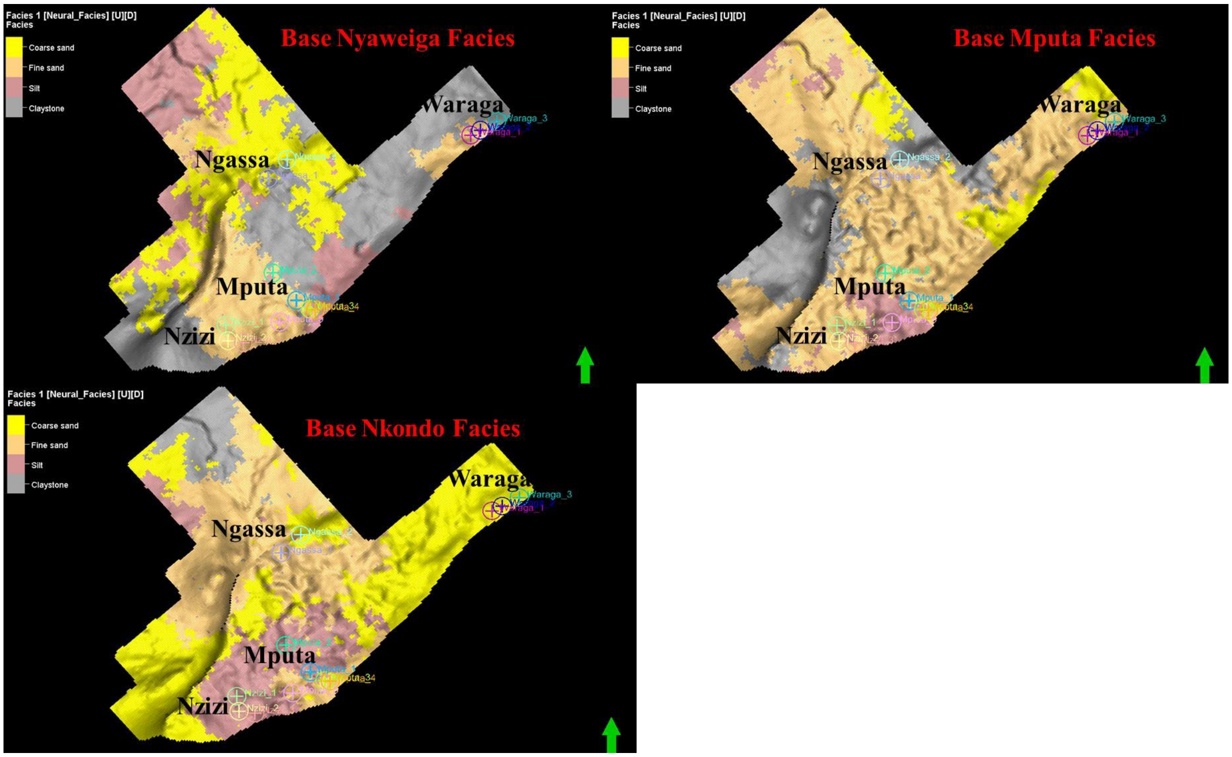


Figure 7: Facies maps for Base Nyaweiga, Base Mputa and Base Nkondo formations of Kaiso Tonya area.

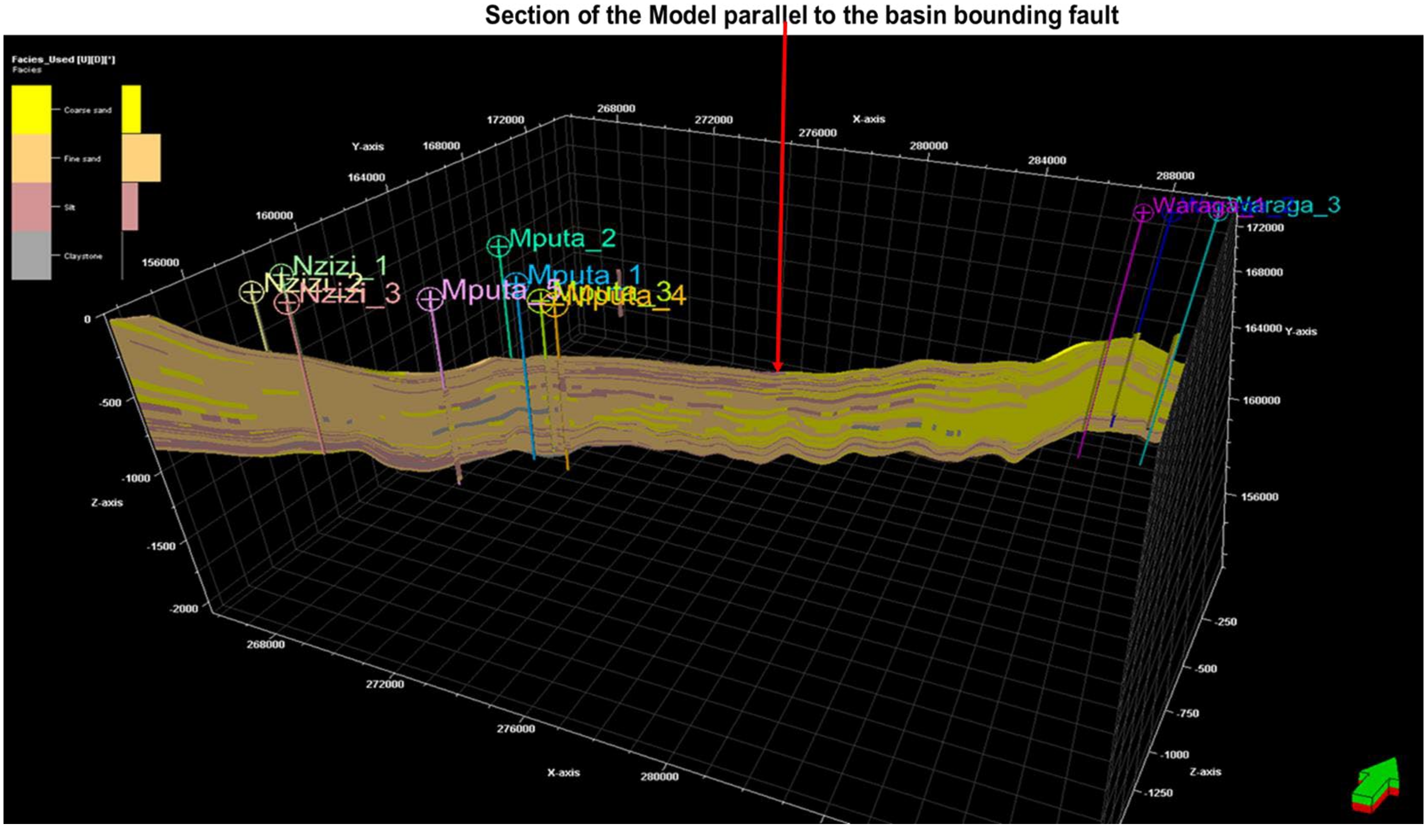


Figure 8: Cross section through different sections using imaginary lines through the facies model of Kaiso Tonya area.

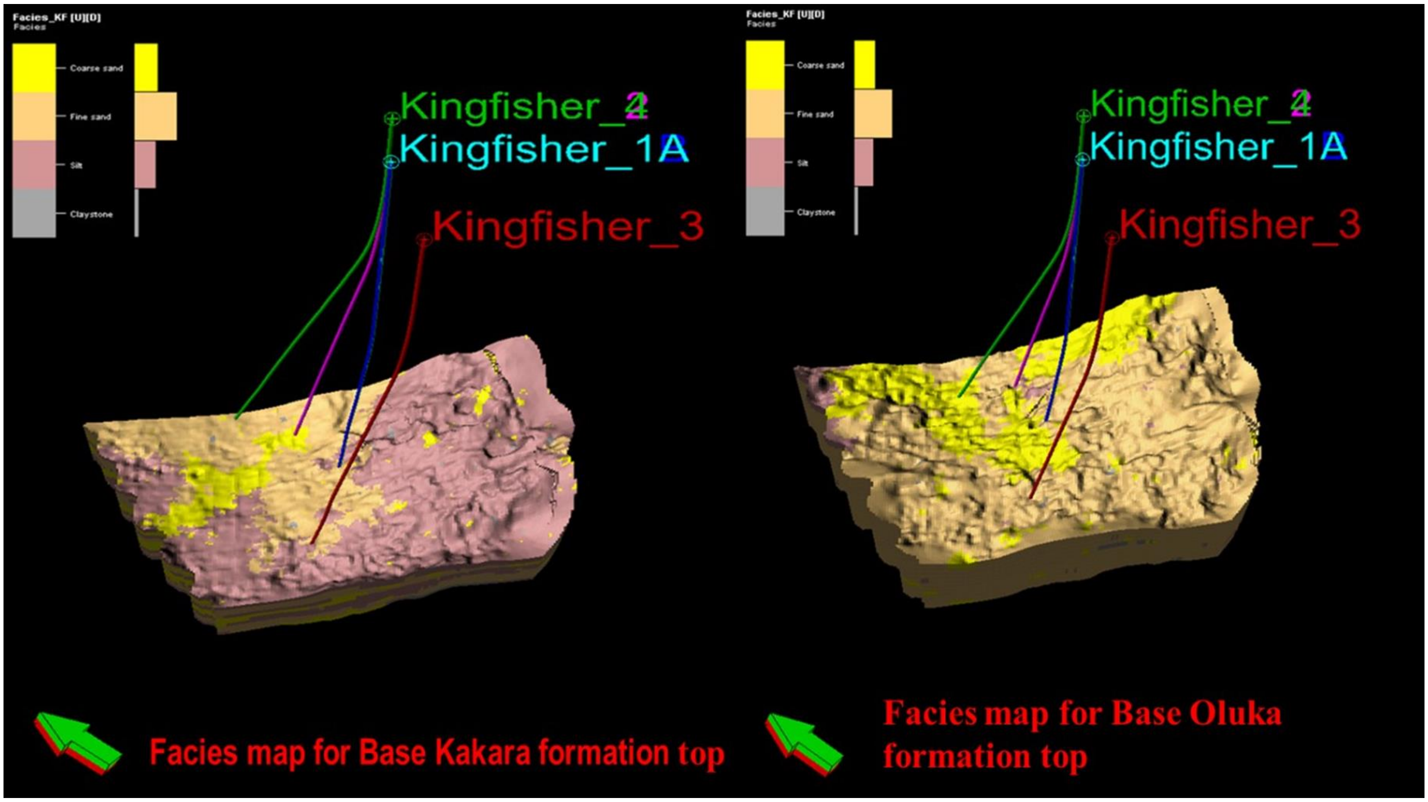


Figure 9: Facies map for Base Kakara and Oluka formations of Kingfisher area indicated the facies distributions within the model as coarse sand (yellow), fine sand (brown), silt (pink) and clay (grey).

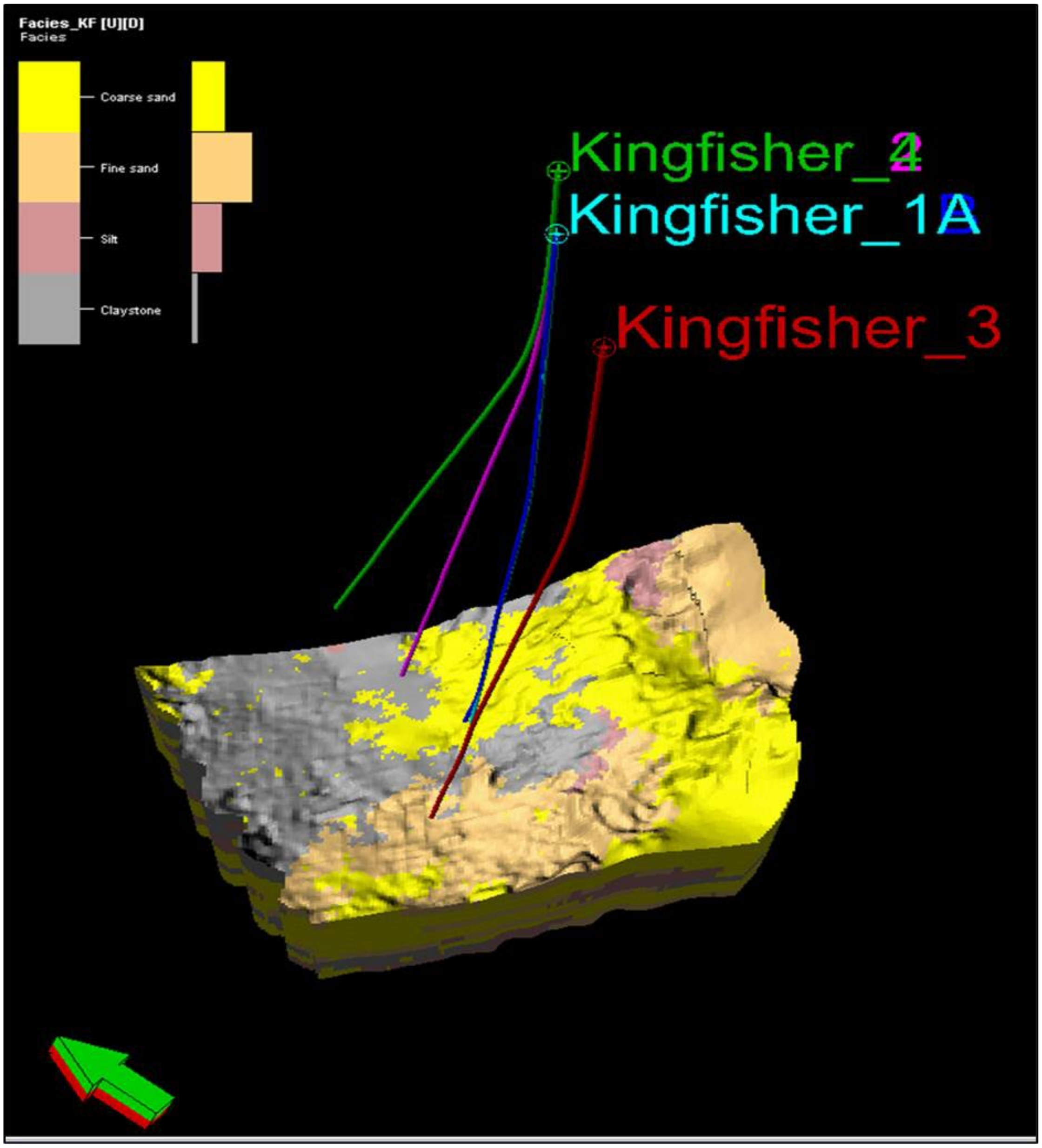


Figure 10: Facies map for Base Kasande formation of Kingfisher area indicated facies distributions within the model as coarse sand (yellow), fine sand (brown), silt (pink) and clay (grey).

3.3 Structural Analysis and Mapping

A cross section through the model of Kaiso Tonya area was made through Mputa-5, Mputa-1, Mputa-2 and Ngassa-2 wells northwards using an imaginary line from NW-SE direction (Fig. 11). From this cross section, it was observed that, Kaiso Tonya area had different compartments separated by different normal faults and was highly compartmentalized. It was also realized that different wells were drilled within different compartments and Kaiso Tonya area had a major fault that makes a terrace around Ngassa field (Fig.5) with faults within the basin that were identified as flower structure (Fig.12).Formations were also mapped from Seismic data using Root Mean Square (RMS) amplitude attribute in Kaiso Tonya area showing Nkondo as purple, Mputa as Red, Nyaweiga as yellow and Warwire as light green (Fig.5).

3.4 Depositional Setting Analysis

Using Root mean square (RMS) amplitude attribute, within the Mputa Formation, a distinctive channel (distributary fluvial deposits) was mapped around the Mputa and Nzizi fields, alluvial deposits were mapped around the Waraga field and deltaic and lacustrine deposits were identified around the Ngassa field and the section under Lake Albert (Figs. 13 and 14). Using variance attribute, within Kisegi Formation, a channel (fluvial deposits) was mapped on 3D seismic dataset in the Kingfisher area originating from the basin boundary fault, towards the Lake Albert and distinctive deltaic deposits were interpreted at a point where sediments interface with Lake Albert sediments (Fig. 15).

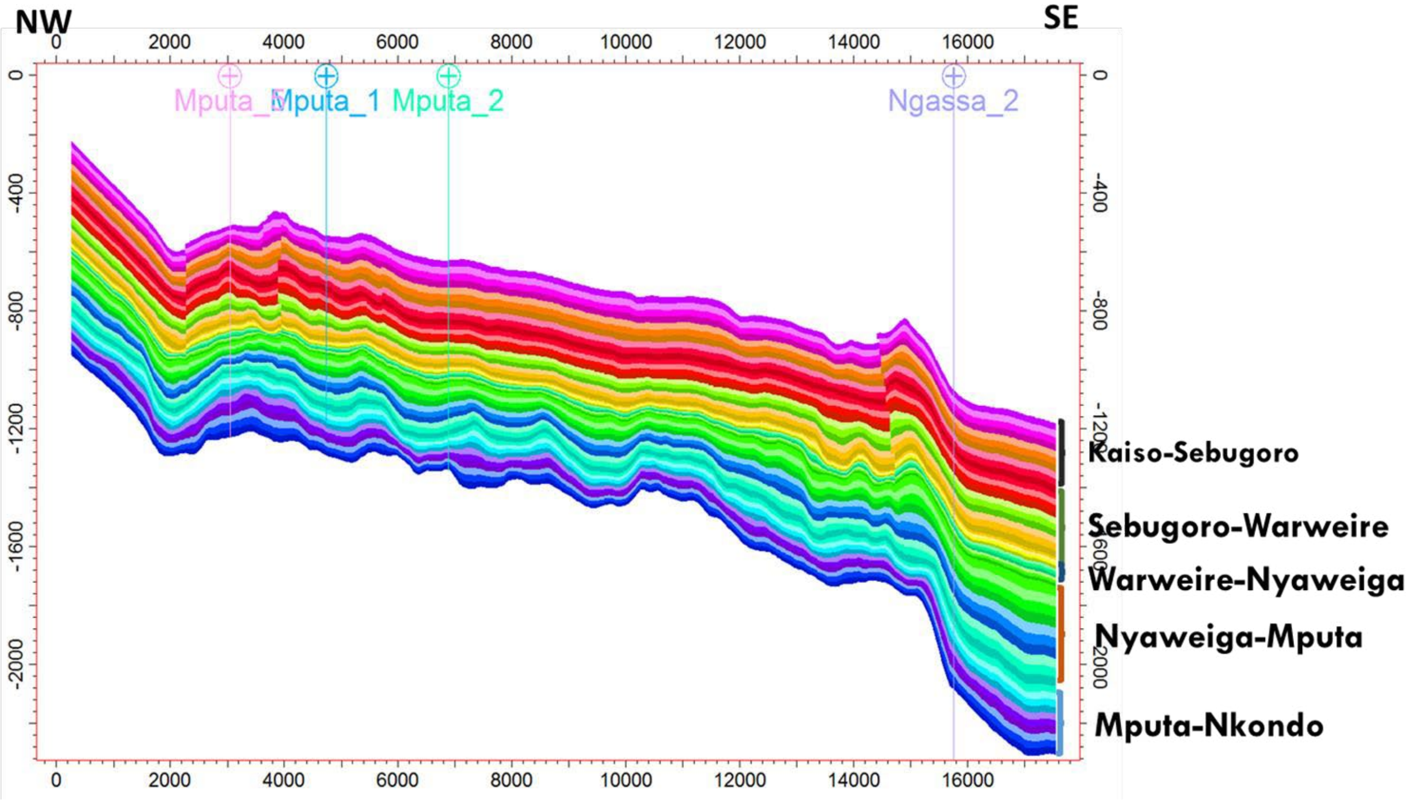


Figure 11: Cross section through formations using an imaginary line in the NW-SE direction for Kaiso Tonya area.

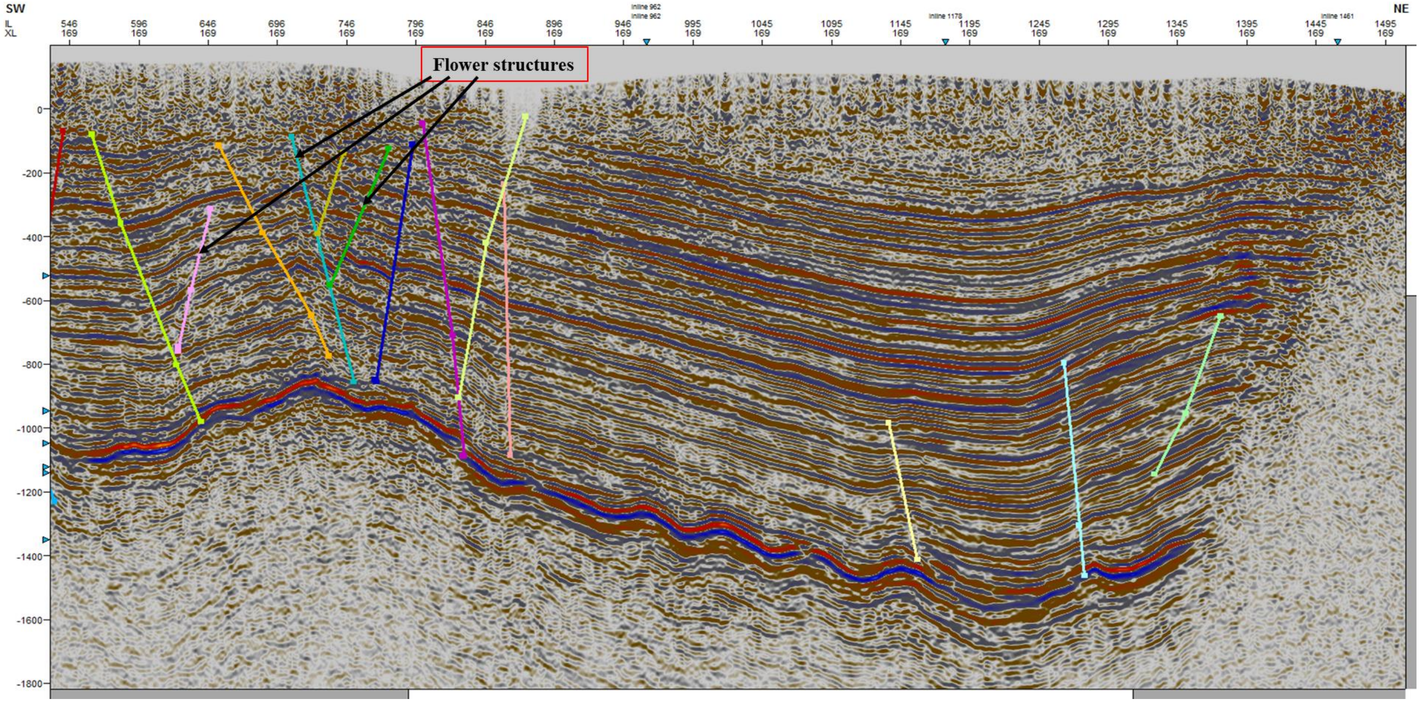


Figure 12: Seismic section showing positive flower structure-like faults persisting up to the top of the section, indicating a recent compressional episode in Kaiso Tonya area.

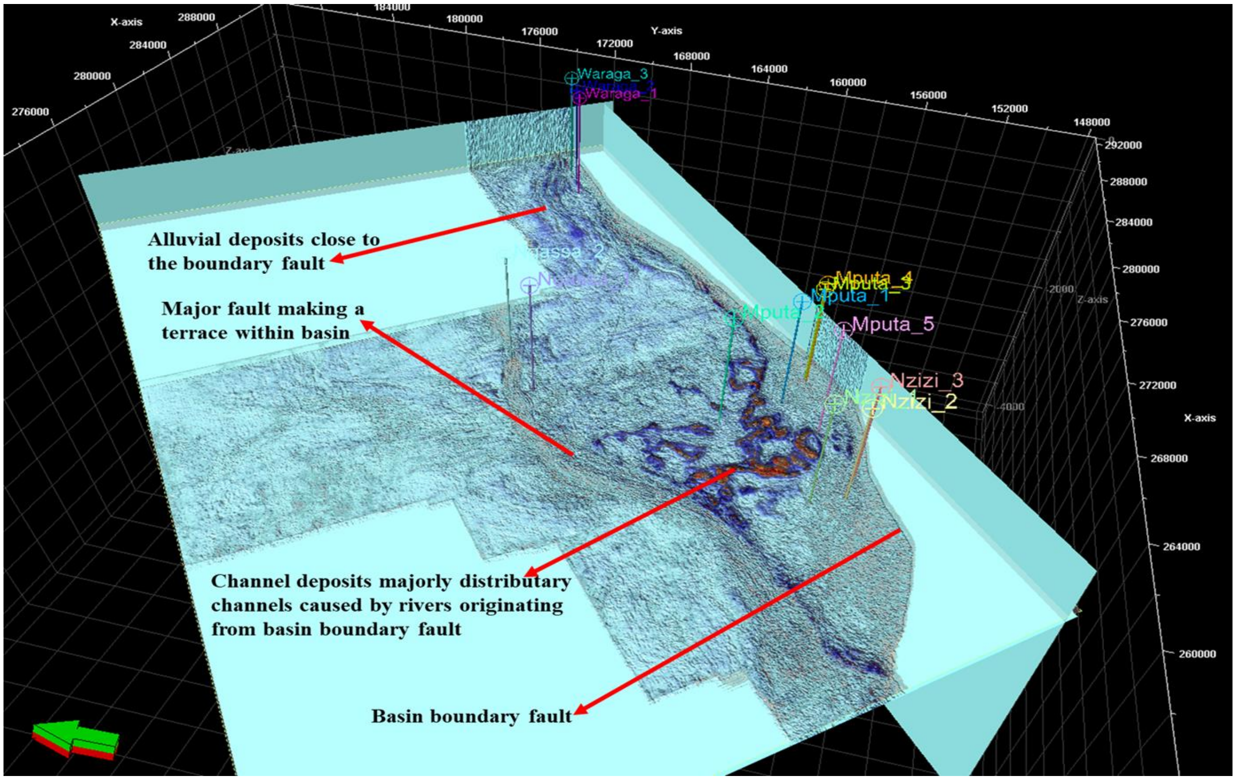


Figure 13: Depositional setting analysis in the Mputa formation using Root Mean Square (RMS) Amplitude attribute in Kaiso Tonya area within Mputa, Nzizi and Waraga fields. Alluvial deposits are deposited close to the basin boundary fault and the channel/fluvial deposits are deposited within the basin by the river (s) originating from the basin boundary fault.

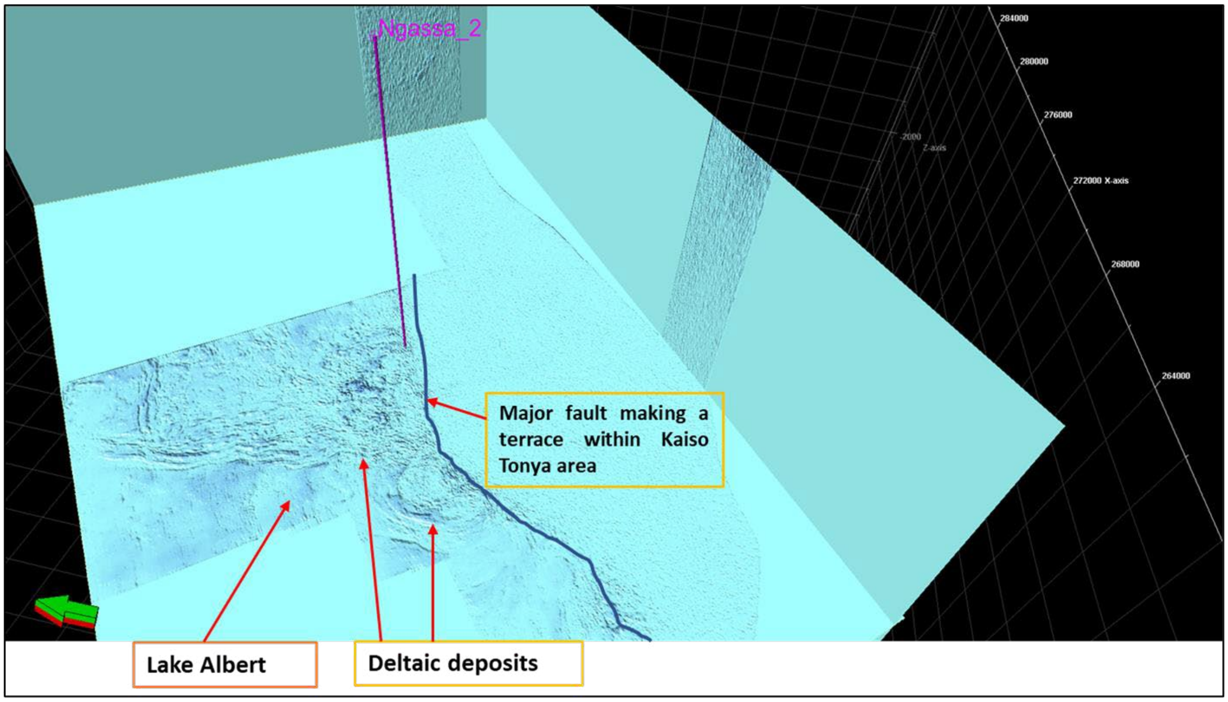
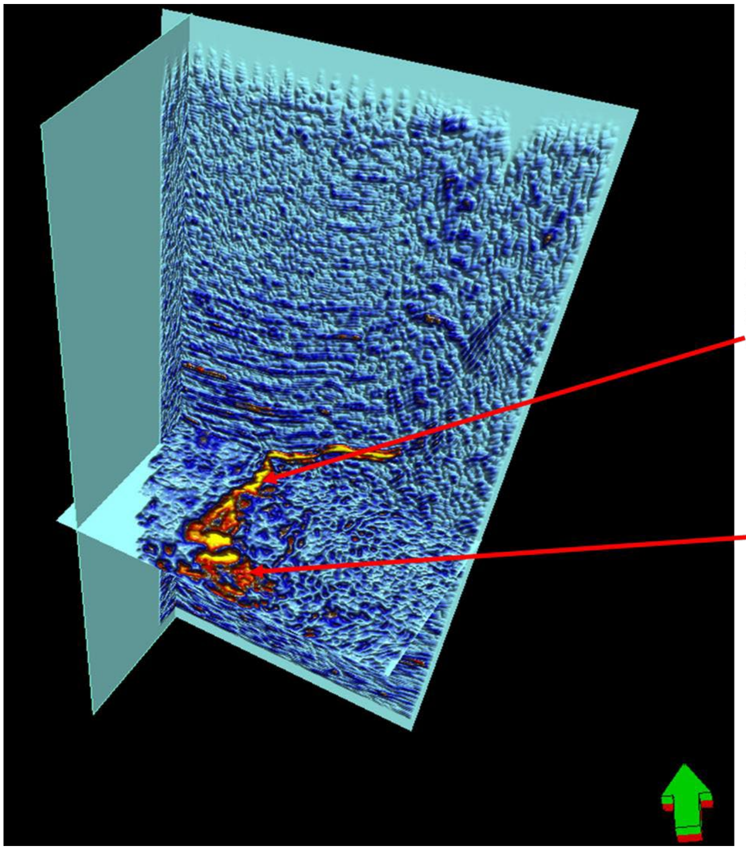


Figure 14: Depositional setting analysis in Mputa formation top using Root Mean Square (RMS) Amplitude attribute in Kaiso Tonya area within the Ngassa field and section under the Lake Albert. Deltaic deposits are identified near the fault that makes a terrace as it gets in contact with Lake Albert water.



Channel deposits by river (s) from the basin boundary fault that are majorly yellow in colour possibly due to high sand composition.

Deltaic deposits which are varying color possibly due to deposition, sand, clay or sits.

Figure 15: Depositional setting analysis in the Kisegi formation using variance attribute in Kingfisher area. Channel/fluvial deposits are deposited within the basin by the river/rivers originating from the basin boundary fault and deltaic deposits are identified at section where basin sediments get in contact with Lake Albert water.

4. Discussion

From the previous studies, SLAB encountered low to moderate porosity, permeability and high volume of shale i.e., poor reservoir parameters that were attributed to limited understanding of depositional structures, tectonic and stratigraphic units, [12,13,15]. This study realized that the different wells were drilled within different compartments, and Kaiso Tonya area has a major fault that makes a terrace towards the lake and the area gets deeper towards the lake. It was also deduced that the study area was comprised of alluvial, fluvial, lacustrine, and deltaic deposits, and all make the reservoir rock units.

According to Nur et al., (2017), deltas are major sites of sand and mud deposition and contain significant volumes of hydrocarbons worldwide, and these include; the Niger Delta in West Africa, the Mahakam Delta in Borneo, the Caspian Sea, and the Maracaibo Basin in Venezuela. Fluvial deposits are sediments that are transported and deposited by rivers in a continental environment and are major reservoir units in sedimentary basins. Furthermore, the contribution of lacustrine environment as the hydrocarbon reservoir has been widely known. Alluvial deposits consist of silt, sand, clay, and gravel, as well as much organic matter, fluvial deposits consist of sand and gravel grain size and mud in floodplain deposits of meandering systems, and they have moderate to poor sorting and deltaic deposits are thick, expanded sections of predominantly clastic sedimentary facies [21]. This study also discovered that sediments in the sections close to the basin boundary fault are mainly composed of fluvial and alluvial deposits, and the sediments close to the lake margins are comprised of deltaic and lacustrine deposits.

This study further deduced that tectonically, SLAB is structurally complex with normal faults that make compartments and flower structure. These structural features might have a serious effect on the connectivity and fluid saturation within the different compartments thus affecting the fluid flow from one compartment to another. If this is the case, this will have a big effect on the recovery of the petroleum resource volumes from fields within the study area. According to Moore and Wade, (2013), in the petroleum industry, it has been hard to identify and predict the effect of reservoir compartmentalization on fluid flow through a field and currently, forensic level of reservoir analysis coupled with use of dynamic signals from production is being used to understand the fluid flow from one compartment to another. However, this may be very difficult to undertake in this study since no petroleum production has been undertaken in the study area. Thus, another study can be undertaken when petroleum production commences that is anticipated in the near future.

From facies interpretation, it was realized that sediment deposition in Kaiso Tonya area was highly intercalated (interbeds of different lithofacies i.e., there were thin lithofacies with different interbedded lithologies (clay, silt, fine and coarse sands) or in some cases stacked i.e., deposited at shorter intervals. This attribute influences the reservoir characteristics [22,23]. Hence, stratigraphically, the study area had different lithologies that were deposited at very short intervals or stacked deposits, and was interpreted to have been caused by the short changes in climatic conditions (wet and dry) that happened over time during sedimentation processes.

According to Martinius et al., (2014), investigating tectonic and stratigraphic features guide the understanding of the control and effect on the reservoir quality. It was deduced therefore that sediments/basins with compartmentalization, flower structure (tectonic features), and those that are highly intercalated (stratigraphic features) generally presented low to moderate reservoir quality parameters. Secondly, the quantity of clay matrix in the sediment sample affects the reservoir rock properties i.e., sediments with high clay matrix have low or poor porosities and permeabilities, and sediments with low clay matrix high or good porosities and permeabilities. All these factors have adverse effect on the recovery of petroleum resource volumes during production phase. Thus, investigating the structural and sedimentological settings, and stratigraphic orientation has identified the causes of the challenges of the reservoir rock properties that were originally identified by the different studies.

In addition, it was further deduced that when sediments are subjected to intensive tectonic activity, climatic changes, with availability of accommodation space, sediment supply and base level changes, there is a likelihood of creating compartmentalization, flower structure-like faults (due to compression at later stages of sedimentation) and sediment intercalations (majorly due to short climatic changes during sedimentation process). These factors may result into reduced connectivity (reduced permeability), reduced or compaction/cementation of pore spaces (reduced porosity) and increased clay matrix (increased Vshale) within sediments. This entire process may lead to low to moderate reservoir quality parameters, thus affecting the recovery of available fluid in particular sediments. This derivative provides for a predictive reservoir quality model that can be used in future studies where similar sedimentological and structural settings have been identified [24-42].

5. Conclusions

The tectonic and stratigraphy of the study area realized a number of compartments and flower structure and sediments were highly intercalated (interbeds of different lithofacies i.e., there were thin lithofacies with different interbedded lithologies (clay, silt, fine and coarse sands) or in some cases stacked deposited at shorter intervals majorly caused by short changes in climatic conditions (wet and dry) that happened over time during the sedimentation processes. These factors might have an effect on the reservoir quality of sediments. The study also realized that well dataset in Kingfisher area was not of good quality. This was attributed to a scenario where the Kisegi formation could not be modelled majorly due to the poor facies' distributions in wireline data from existing wells.

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