

## Intergrated Seismic Stratigraphic and Structural Analysis of the Songo Songo Gas-Field, Shallow Offshore Tanzania, Using Seismic and Well Data

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### Abstract

Seismic stratigraphy and structural analysis of seismic data, when combined with wireline data, provides vital information for hydrocarbon exploration in a prospective basin. These techniques were employed in the Songo Songo shallow coastal basin, southern Tanzania to determine stratigraphic setting, trapping mechanism, reservoirs zones. Suites of well logs from two wells (AA-1 and BB-5) and 2-D seismic data was obtained from TPDC in the study area. Lithologic interpretation and well correlation were carried out using the well log suites. Stratigraphic analysis was carried out with the well logs and 2D seismic data by using principles of sequence stratigraphy while structural interpretation was done with aid of the seismic data to produce polar plots for the different structural trends. The lithology was dominated by sand, shale, and limestone. Five sequence boundaries (SB); SB1 (Albian), SB2 (base of Coniacian-Early Campanian), SB3, (Middle Eocene), SB4 (Late Miocene) and SB5 (Quaternary) and three maximum flooding surfaces (MFS); MFS1-(Early Cretaceous), MFS2, (Late Cretaceous), MFS3-(Early Eocene) were identified. Three main normal faulting systems (Jurassic faults, active during the Jurassic rifting phase of Madagascar, Neogene faults that occurred during Neogene east African rifting and reactivated faults which mostly were Jurassic fault reactivated by east African rifting) of NNW-SSE were recognized in the study area. The structural interpretation reveal that the gas field is dominated by normal faults that occur in the upper and lower part of Songo Songo suggesting two phases of deformation prior to development of the field. The main reservoir is developed in the Neocomian and Albian sandstones, and capped by Jurassic faults and Wami (Formation) overlying rocks. The gas is sourced from Jurassic shale known as Mtumbei Formation and stored at the main reservoir developed in the Lower Cretaceous aged Neocomian sandstone known as Kipatimu Formation, sealed by high pressured shale of upper Cretaceous known as Wami Formation. This study shows that deposition of sediment occurs in the NW – SE direction, with the thinning of sediments thickness towards well BB-5 while the stratigraphic sections show that the horizons are laterally continuous and are being strongly affected by tectonic events.

**Keywords:** Sequence boundaries; Maximum flooding surfaces; Reservoirs zones; Gas field; Songo Songo; Tanzania

### Introduction

The sedimentary basins in Tanzania have been classified into inland (terrestrial) basin, coastal basin, shallow water basin (continental shelf) and deep marine (offshore) basin. The Songo Songo gas field is a shallow offshore Tanzania basin and is believed to have been developed in response to the breakup of Gondwana and have been an active sedimentary basin since Permian with N-S Trend (Figure 1). Several research works have been done on the coastal basin with little attention on Songo Songo gas field which is shallow. Mpanju and Philip, (1994) studied the organic matter and geochemical characterization of bitumen's, surface seeps, rock extracts and condensates from the coastal and part of shallow offshore basins in Tanzania. They described the source rocks to be of type II/III kerogen and analysis of the condensate by gas chromatography showed a typical condensate distribution with traces of n-alkanes up to nC25. The hydrocarbon potential of the deep offshore - off Tanzania coastal basin and few sample oils from Songo Songo gas field shown in studies. Meanwhile work on the extinct and near extinct petroleum systems of the East African coastal basins mentioned of the Songo Songo as being a giant field with 1.1 TCF consisted of play system. It is evident that most research activities have been uneven on the coastal and shallow basins [1-6].

The history of petroleum exploration has shown that there will always be enough possibilities of finding more oil and gas, if accurate exploration technique is employed in the right places. Seismic

sequence stratigraphy and structural integration has turned out to be one of such helpful technique used in petroleum exploration prospects. Therefore, this study will integrate 2D seismic and well data so as to be able to map the sequences boundary, seismic facies, and petroleum reservoirs zones. Furthermore, to define the nature of the structural and stratigraphy settings of the gas field and to identify the type of hydrocarbon trap.

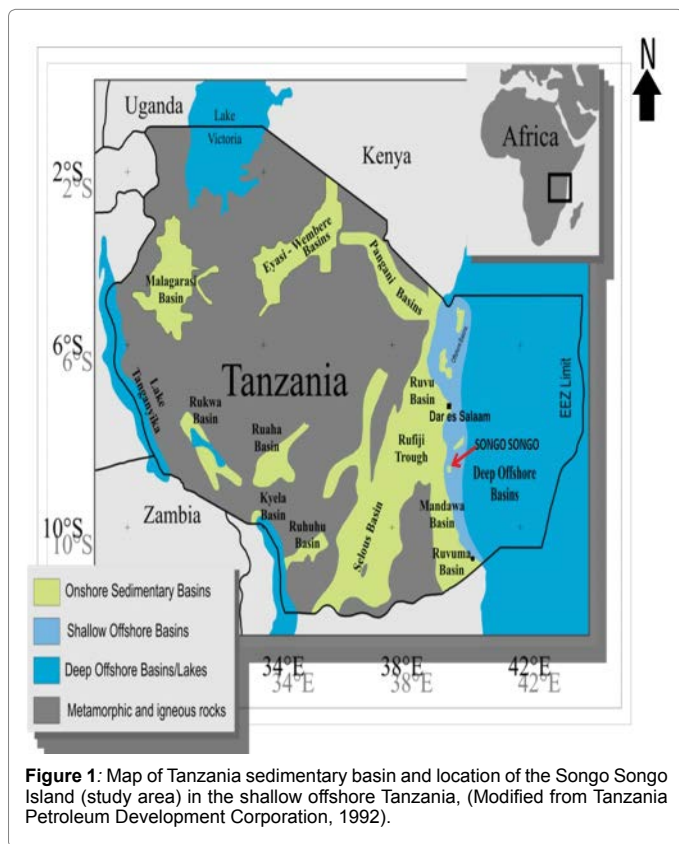
This technique has proven effective with sound success in petroleum province such as those in eastern offshore Niger Delta basin, Nigeria, Northwest Murzuq basin, Libya Arikki Field, Nigeria [7,8]. It is anticipated that this work will convey the understanding of the structure and stratigraphy of the Songo Songo gas field and hence reduce further appraisal and development costs especially in this era of low hydrocarbon costs.

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## Geological Framework

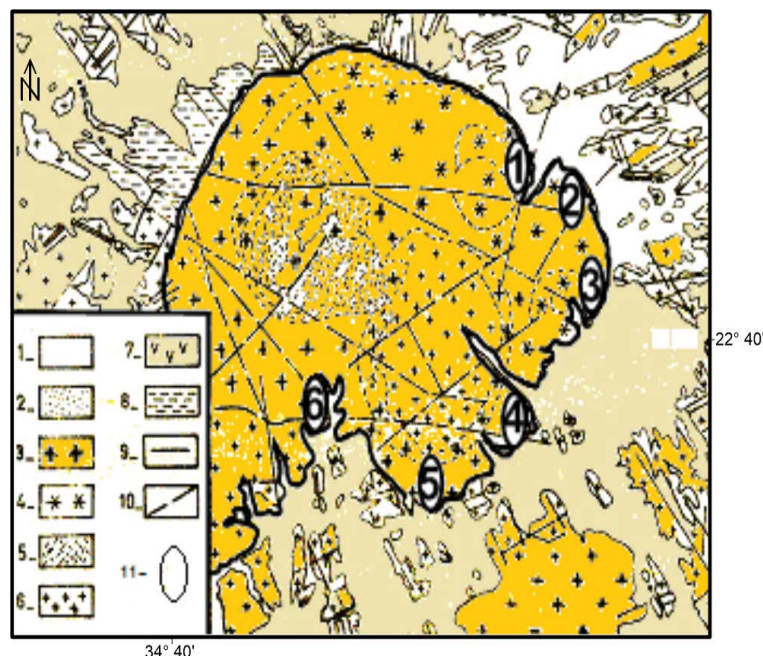
### Geologic and tectonic setting

Songo Songo gas field lies in the southern area of the offshore Tanzania coastal basin. The basin is a seaward thickening sedimentary sequence that may be estimated to be 10 km in thickness although primarily regarded as mainly marine Mesozoic-Cenozoic basin. The Songo Songo Island is part of the roughly N-S trending tectonic belt also containing the islands of Mafia, Zanzibar and Pemba, located within about 20 km offshore from the mainland. This belt is bounded by normal faults on both the eastern and western sides, which trend almost parallel to the present-day coast line. A fault controlled syncline occurs between the mainland and this chain of islands (Figure 2) [9].

Tanzania coastal Basin has undergone three phases of rifting according to (TPDC) (1992) and these includes:

- i) A Carboniferous-Permian Karoo rifting which is associated with the initiation of the breakup of the Gondwana supercontinent and deposition of Karoo super group.
- ii) Break up of Gondwana continent during Triassic and opening of Somali basin in Middle Jurassic (this period was characterized by sea floor spreading and extensive flood basalt in the Somali basin) accompanied with southward movement of Madagascar along the transform fault known as Davie fracture zone (DVZ).
- iii) A Cenozoic rifting, this is associated with the tectonic development of the East African rift system.

These tectonic events have been divided into three faulting events in the coastal basin (Figure 3):



- |                           |                                     |
|---------------------------|-------------------------------------|
| 1- Wadi Alluvium          | 2- Nepheline Syenites               |
| 3- Alkaline Syenites      | 4- Coarse-grained Alkaline Syenites |
| 5- Lavas and Agglomerates | 6- Granites and Gneisses            |
| 7- Metavolcanics          | 8- Schists                          |
| 9- Dykes                  | 10- Faults                          |
|                           | 11- Sites of collected samples      |

**Figure 2:** Geologic map of Songo Songo gas field (modified from Kent et al., 1971).

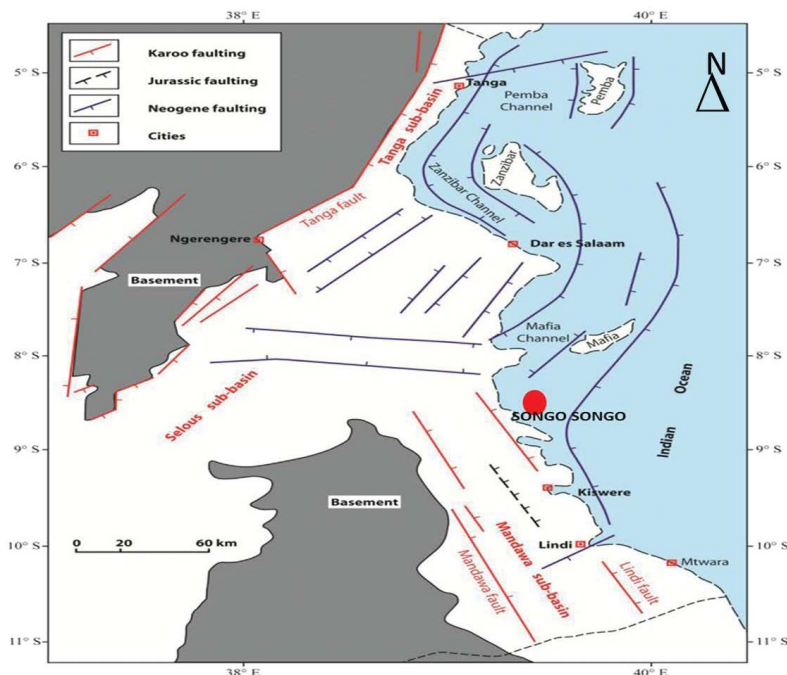


Figure 3: Major structural features of coastal Tanzania with the main faulting zones and ages (adapted from Said et al., 2015).

- i) Karoo faulting associated with Karoo rifting during Permian – Triassic.
- ii) Jurassic faulting associated with the drifting of Madagascar away from the coast of east Africa and opening of Somali basin.
- iii) Neogene faulting associated with East African rifting [10-12].

### Lithostratigraphic setting

The Coastal stratigraphy column is used to explain Songo Songo gas field because this field is referred as part of coastal basin in several. Coastal sedimentary column is characterized by several mega-sequences bounded by major unconformities recognized at base of Pliocene, base Miocene, base Oligocene, base Paleocene, base of Late Cretaceous and base of Jurassic (Figure 4).

Precambrian gneissic basement is uncomfortably overlain by mainly Triassic to Jurassic fluvial sandstones of Karoo, regional unconformity separated the Karoo continental strata from marine Jurassic strata. First marine transgression overlapped the continental Karoo during the Aalenian Bathonian. This period of transgression deposited Mtumbei shale Formation followed by regression in early Cretaceous resulting in clastic sediments deposits of Kipatimu Formation. The Late Cretaceous period was marked by a major transgression

The transgression series which started in the Aptian-Albian continued in the Paleocene. The Paleocene deposited sediments are mostly deep marine, consisting of clay and clay stone with thin bands of fine sandstone.

During Middle Eocene and Oligocene, shale and limestone deposits proves that this period was a transgressive phase that gave rise to Wami shale Formation. The Lower Eocene sediments mainly consist of shale, sandstones and carbonate rocks. The Middle and Late Eocene comprises a sandy deposit transported from the eroded high relief basement areas in the west. It constitutes the gas reservoir in the

Zanzibar, Pemba and Wami. The Oligocene marine regressional strata are of relatively restricted occurrence in the coastal belt of Tanzania and their missing in large area. Neogene is characterized by open-shelf conditions that continued along the East African coast. Oligocene strata are missing in some wells, where by Miocene bed (Mikindani clastic Formation) is present and it is a good reservoir in Mnazibay gas field. These Mikindani bed are overlain by Reef limestone that is observed in large surface part of coastal basin [13-15].

### Data availability and Methodology

#### Data availability

This study was initiated with the collection of data. The data consist of well data from 2 wells (AA-1 and BB-5) and 2D seismic data of 20 lines. The well log suit consists of gamma ray, resistivity, sonic, density and neutron. Check shots and well tops of the Songo Songo AA-1 and BB-5 were also used.

#### Methodology

The seismic section was used for seismic stratigraphic and structural analysis while the wire line logs were used in identifying the lithology and for the performing seismic well tie. The interpretation was done using commercial Petrel software. Figure 5 shows the complete workflow. ARCGIS polar plots were used to display variables, which vary based on the direction and interpreted faults from the seismic section. Lastly, rose plot were used to get the general trend of the faults.

**Seismic interpretation method:** Seismic to well tie wasn't applied due to errors of check-shot data, Formation tops with their two way travel time (TWT) were loaded on a well and projected properly as overlays on interactive seismic displays. These well tops were given based on age of Formation and used as control points for the interpretation (Figure 6).



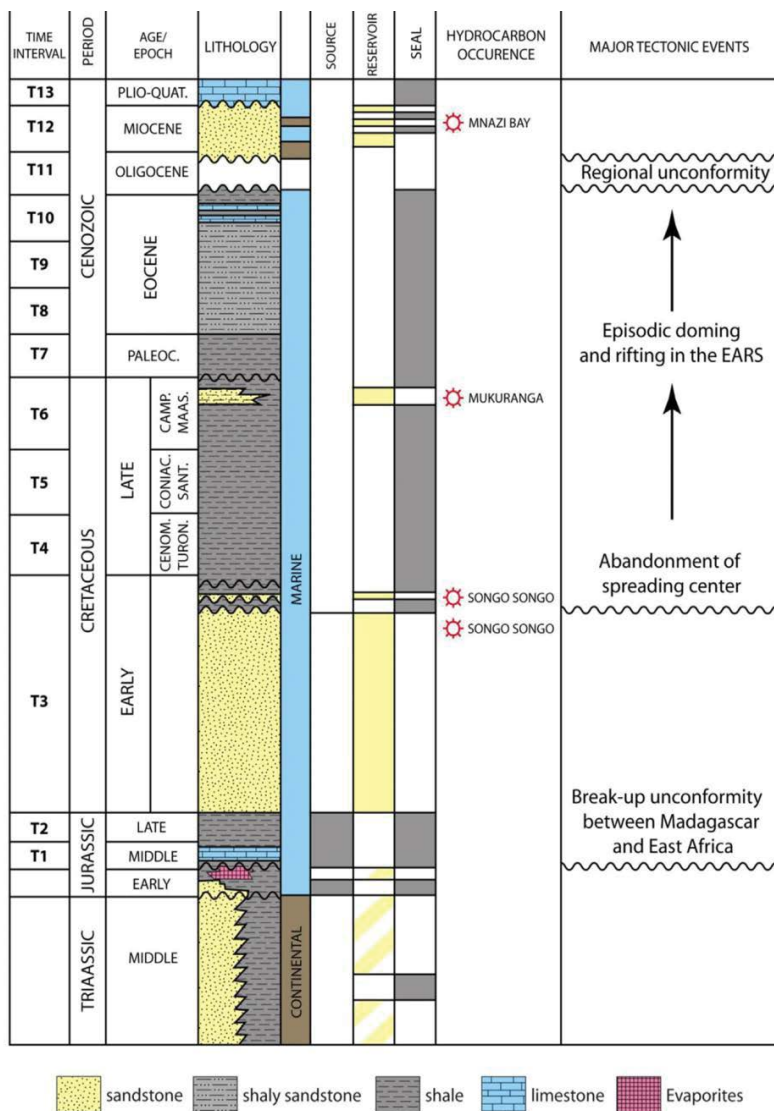


Figure 4: Stratigraphic column of the Tanzania coastal basin (adapted from Said et al., 2015).

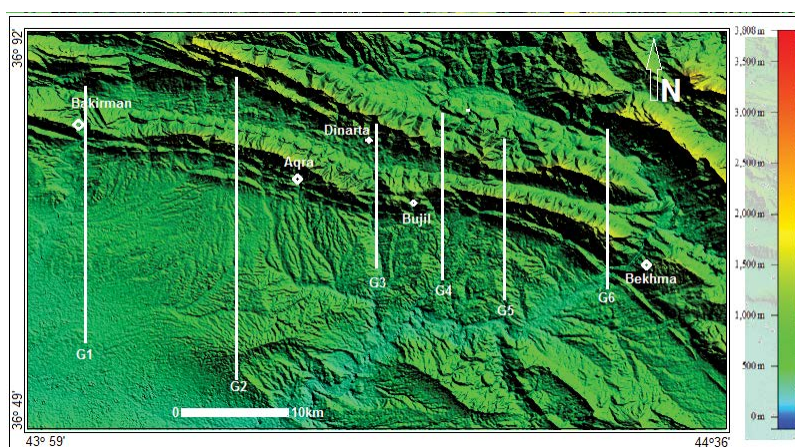


Figure 5: Flow chart of methodology.

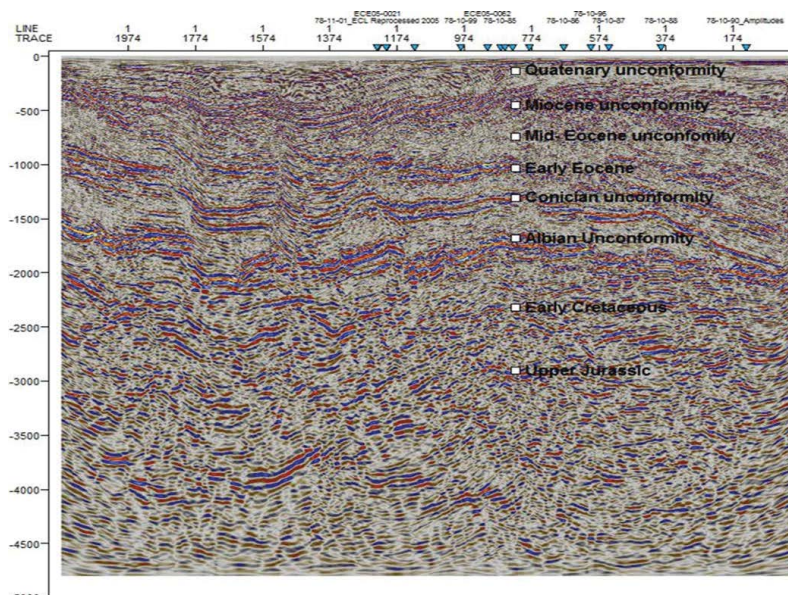


Figure 6: Seismic section with well tops overlay, ECE05-0103, NW-SE.

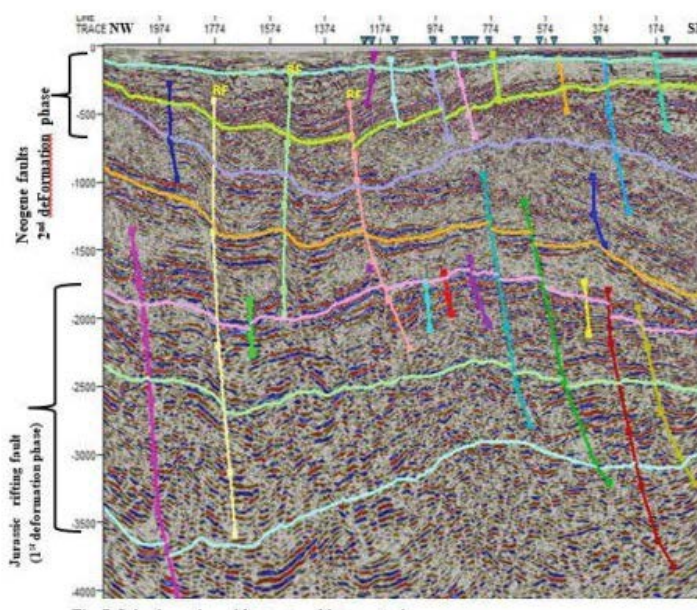


Figure 7: Seismic section with structural interpretation of seismic ECE05-0103, NW-SE.

QSB5: QUATERNARY UNCONFORMITY; MSB4: MIOCENE UNCONFORMITY; MESB3: MID EOCENE UNCONFORMITY; CSB2: CONIACIAN UNCONFORMITY; ASB1: ALBIAN UNCONFORMITY; K: CRETACEOUS BOUNDARY; J: JURASSIC BOUNDARY; RF: REACTIVATED FAULTS

## Results and Discussion

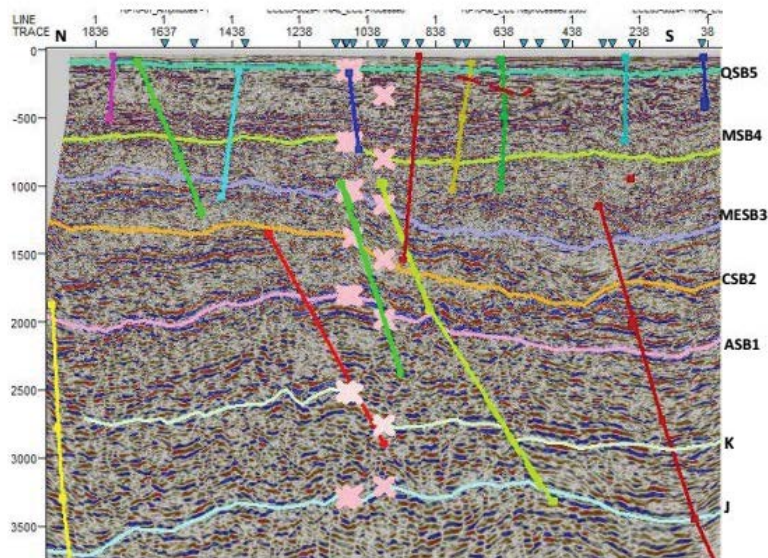
### Seismic structural interpretation

Two major regional faults phase (first and second phase) tectonic activity was recognized (Figure 7). The longest faults shows all the two phase of deformation, these long faults were reactivated during East African rifting. They are characteristics of coastal faults that reactivated during the Neogene and have produced an appreciable throw which has provide migration pathways for hydrocarbon. The horizons studied are laterally continuous lithologic unit and there are variations in the

thickness of units across the seismic section (Figure 8). Faults and unconformities were successfully picked on the seismic sections (NW-SE, N-S, and W-E) and this fault seems to be dominated by normal faults (hanging wall moves down) with series of faults that are observed in the upper and lower part of the section.

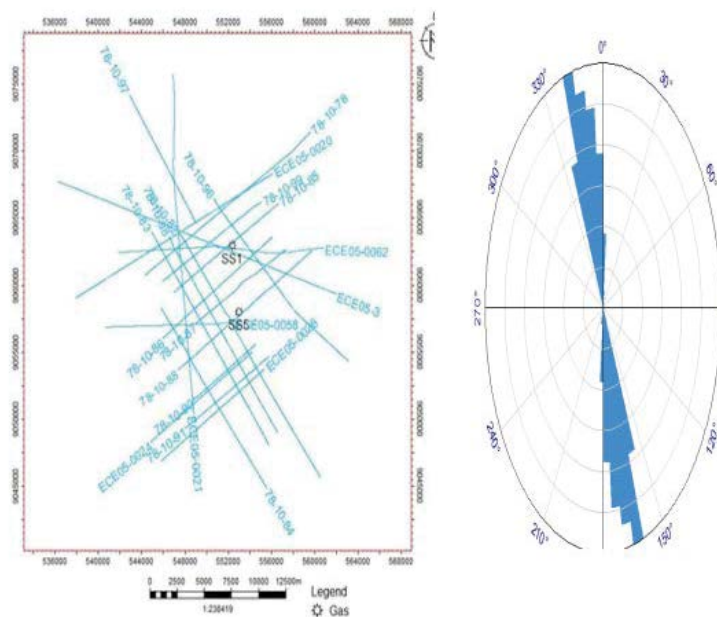
Faulting seems to affect the upper sedimentary sequence and the lower while some faults extends from older sequence to younger, implying that these fault have been reactivated during the Formation of the upper part faults (Figure 7). All these faults show the general trend of NNW-SSE as shown by polar plots and depth structural map (Figures 9-13b).





**Figure 8:** Seismic section to show structural interpretation of seismic line ECE05-00621, N-S.

QSB5: QUATERNARY UNCONFORMITY; MSB4: MIOCENE UNCONFORMITY; MESB3: MID EOCENE UNCONFORMITY; CSB2: CONIACIAN UNCONFORMITY; ASB1: ALBIAN UNCONFORMITY; K: CRETACEOUS BOUNDARY; J: JURASSIC BOUNDARY



**Figure 9:** Base map and trend of faults of line ECE05-0103, NW-SE.

The seismic interpretation reveal that sediments of Jurassic to Cretaceous are separated by series of faults, these faults were formed during Jurassic rifting when Madagascar drifted away from the coast of East Africa and lead to opening of Somali basin. The Early Jurassic faulting led to dislocation of the early erosion surfaces inland, shallow fault are also seen on Neogene to recent sediments mostly dip west. Unconformities provide a record of the timing of structural offset across the faults and patterns of deformation within fault blocks. Stratigraphic surfaces are abruptly lower on eastern sides of faults relative to west sides and are consistent with displacement observed in the seismic cross sections. Surfaces show significantly greater offset across faults

demonstrating syn-depositional movement of faults (Figure 7). This faulting, regional eastward tilting, and rapid Neogene sedimentation created more growth faults which mostly pull down the sealing shales of the upper Cretaceous Wami Formation. The Lower Cretaceous reservoirs are not affected by this later episode of faulting.

Songo Songo is cut by large numbers of strike faults, which in their final development postdate the Miocene beds. The Faults are mostly, or entirely, steeply dipping, indicating control by vertical stresses rather than by major lateral extension movements, the various positive features of the Middle East African coast were progressively developed

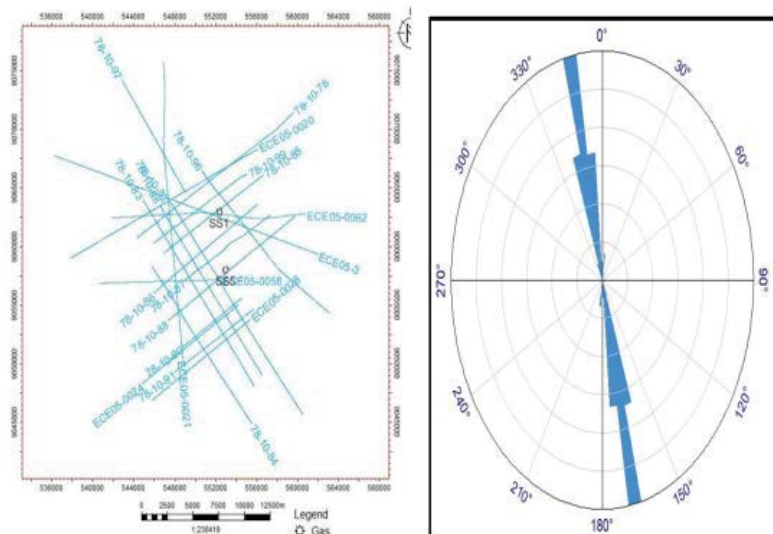


Figure 10: Base map and trend of faults of line, ECE05-00621, N-S.

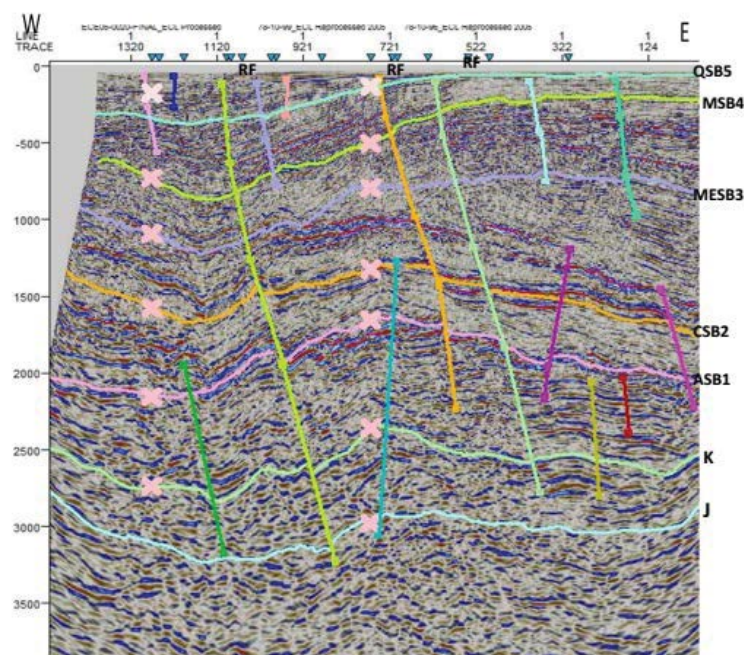


Figure 11: Seismic structural interpretation of seismic line, ECE05-0062, W-E.

QSB5: QUATERNARY UNCONFORMITY; MSB4: MIOCENE UNCONFORMITY; MESB3: MID EOCENE UNCONFORMITY; CSB2: CONIACIAN UNCONFORMITY; ASB1: ALBIAN UNCONFORMITY; K: CRETACEOUS BOUNDARY; J: JURASSIC BOUNDARY; RF: REACTIVATED FAULT

by relative uplift (mostly interrupted by slower subsidence), associated with closely space faulting. The polar plot of depth structural map of all faults showed the NNW-SSE trend of faults, this supports presentation of Songo Songo gas field Tanzania about increasing reserves and expanding gas distribution, she mapped Songo Songo field as a broad N-S to NNW-SSE trending faults (Figure 13b) [16].

#### Seismic facies analysis

**Facies 1 (FS-1), parallel continuous:** Near the surface is marked by continuous parallel reflections, these facies are bounded below by

Quaternary unconformity (QSB5) and the dominant lithology is Reef limestone. They indicate uniform sedimentation in a quite shallow, clear warm marine environment, where organisms capable of forming calcium carbonate shells and skeletons can easily extracts the needed ingredients from ocean water. They are shown by number FS-1 in Figure 14.

**Facies 2 (FS-2), sub parallel discontinuous reflection:** This facies is presented by sub parallel discontinuous reflections where the acoustic impedance contrasts are strong and terminate over the fault. This is

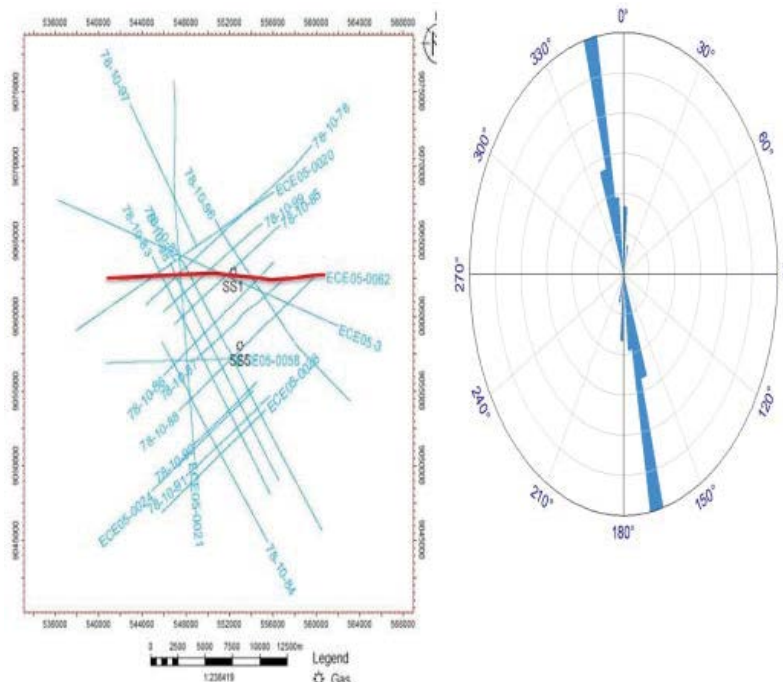


Figure 12: Base map and trend of faults of line, ECE05-0020, W-E.

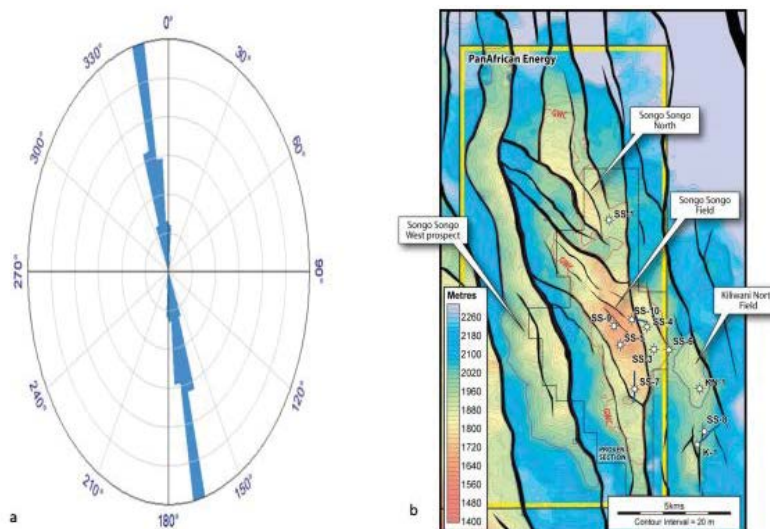


Figure 13 a) Polar plots of interpreted faults b) Depth structural map (adopted from Lucy Williams, 8th PESGB / HGS Conference on African E & P (2009)).

interpreted to be a rather homogenous gross lithology that was affected with tectonic events that cause displacement of these layers; they seem to be deposited on uniform subsiding surface. This discontinuous discordant reflection of low and high amplitude that are in Cretaceous shale is due to the presence of deformed over pressured shale resulting from tectonic deformation that lead to replacement of the strata. They show by number FS-2 in Figure 14.

**Facies 3 (FS-3), chaotic:** The strata of Mtumbei shale and Kipatimu Formation shows disordered arrangement of reflection surfaces, possibly due to rapid sedimentation rate (Figure 14). Kipatimu and Mtumbei sediments had no time for stratification because they have

been deposited immediately after opening of sea floor with the rapid rate of sedimentation. This facie is seen as the first phase of opening of Indian Ocean when Madagascar started drifting and move southwards relative to the African continent. The chaotic pattern shown at the upper part is Mikindani clastic [17-20].

### Well log interpretation and correlation

**Lithology identification:** The broad lithostratigraphic units recognized in Songo Songo southeastern Tanzania are summarized in Figure 15. All lithostratigraphic division made in individual well sections are from well data. For each well, interpretations based on



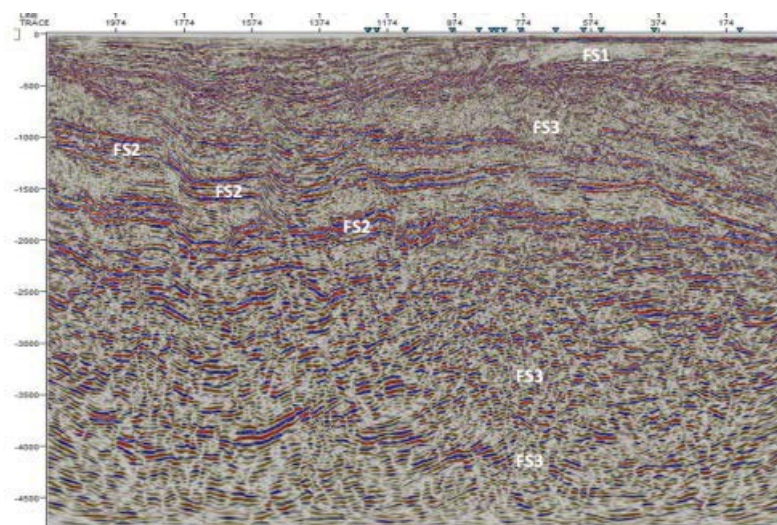


Figure 14: Variable density seismic display with interpreted seismic facies.

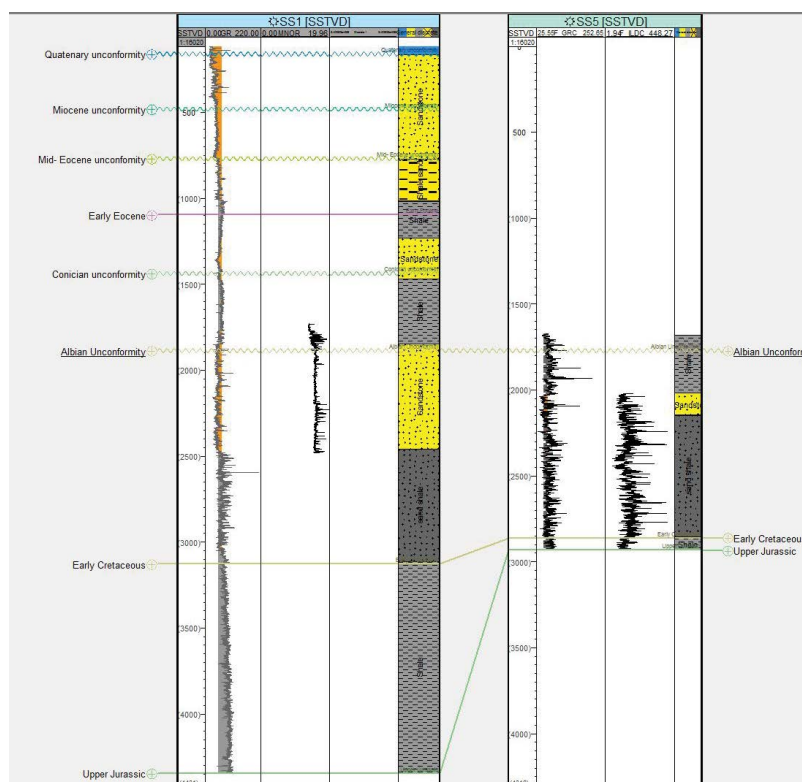


Figure 15: Lithology identified from gamma ray well log.

the individual response of gamma ray log combined into a single stratigraphic summary.

The main lithologies identified from well logs are shale, sand shale, sand, shale sand and limestone. Shale and sandstone are the most dominant lithologies shown by brown and yellow respectively in Figure 16.

AA-1 was also characterized by carbonate rocks in very low quantity and the ones near the surface was easily identified with the help of well tops.

**Jurassic:** The Triassic to Early Jurassic sediments in Songo Songo consists of mainly fluviatile sandstones; they uncomfortably overlie the Precambrian gneissic basement. This indicates that much more extensive transgression occurred in the late Jurassic, a transgression that may have extended far beyond the present coastal basin. Initiation of sea floor spreading in the west Somali basin in the middle Jurassic mark the end of extension rifting and beginning of regional subsidence (The deepening of depositional environments is evidenced by the occurrence of more predatory marine organisms such as ammonites and nautilus (Kapilima, 2003)

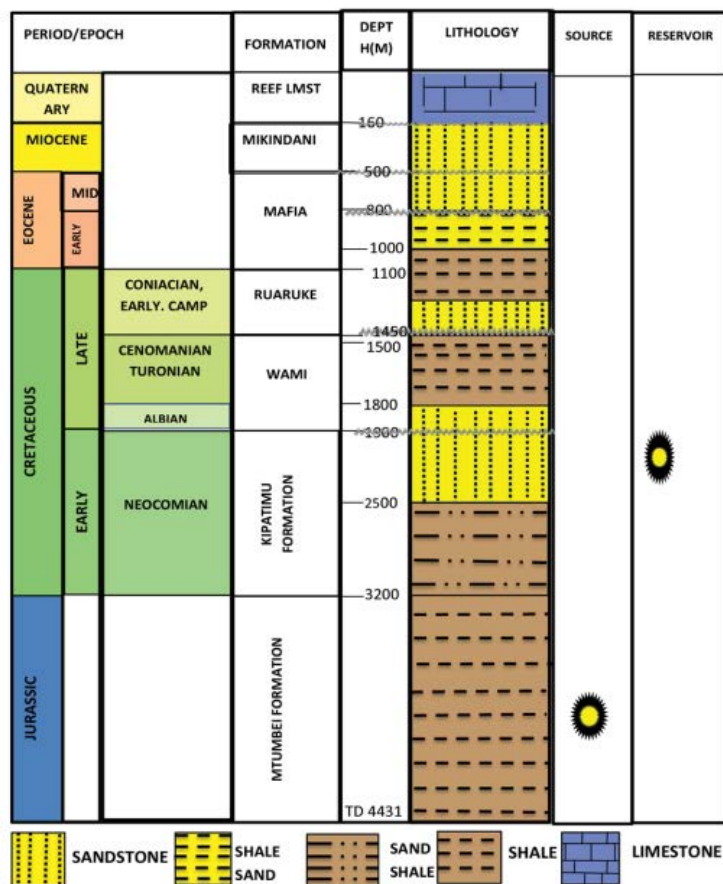


Figure 16: Composite stratigraphic column of Songo Songo gas field.

that led to deposition of Mtumbei Formation with mainly marine shale from depth 4431 m-3200 m, (Figures 15 and 16). During Upper Jurassic-Lower Cretaceous there was nearshore and shelf sedimentation in the area.

**Cretaceous:** Lower Cretaceous in Songo Songo is mainly dominated by sand, with alternation of sand and shale; this proves that it was a period of regression. The main dominant Formations is Kipatimu, lower Cretaceous sandstone with thickness of about 200 m (BB-5) to 700 m (AA-1). This succession of fairly uniform sandstone facies suggests aggradational stacking of shoreline sediments (Neocomian are gas bearing in Songo Songo). The thickness and high sand content observed in the Lower Cretaceous indicates high subsidence rates matched by very high sand supply during the Neocomian in the Songo Songo field.

Middle Cretaceous seems to be a period of wide spread uplift and erosion in eastern Tanzania due to domal uplift. After the unconformity, further domal uplift occurred to the south of Songo Songo Island and resulted in more erosion and deposition of re-worked sands at the base of the overlying upper Cretaceous sequence (Albian Beds). The reworking of the Kipatimu sand deposited shallow marine and deltaic sands with excellent reservoir characteristics. The erosional surface marks the boundary between Kipatimu sand and Wami series sand of Albian.

Late Cretaceous in Songo Songo is dominated by wide spread sequence of over pressured shale, mainly shales of Wami series, By

the late Cretaceous it was a period of rapid subsidence of offshore area led to the widespread deposition of deep water marine clastics (shale) including organic rich shales (Figures 15 and 16) [20-23].

**Paleocene:** Paleocene deposited sediments in Songo Songo are mostly deep marine (shale) known as Mafia Formation. Well logs show a complete succession from the Lower Paleocene to the Middle Eocene, but the Upper Eocene is missing due to erosion or non-deposition. In Songo Songo the Paleocene to Lower Eocene is dominated by shales, but there are significant inter-bedded siltstones and thin-bedded sandstones present in wells identified on well logs as shale sand (depth 1000-800 m). Thickest and cleanest sandstones in the Eocene are seen in AA-1 (800-500 m) (Figures 15 and 16).

**Neogene:** Neogene period is dominated with Miocene sediments. In the Songo Songo region the Early Miocene sits unconformably on the middle Eocene in all wells, it is likely that the upper Eocene to upper Oligocene was removed by erosion associated with the major regression across the region during the early Miocene. In well AA-1 the lower Miocene is unconformably overlain by the Pliocene, indicating another phase of erosion. Still in AA-1 the base of the Miocene is marked by major regression with stacked blocky, fine to coarse-grained sandstones interpreted to represent fairly proximal estuarine channel deposits at 500-160 m, this sandstone is known as Mikindani clastic Formation (Figures 15 and 16).

**Quaternary:** This stratum is mainly made up of Reef limestone and often a tight due to carbonate cementation with probably cave

or fracture porosity it's between 0 to 160 m. The limestone is strong seismic reflector recognized Far East offshore Songo Songo shelf (Figures 15 and 16).

**Sequence stratigraphy:** Well AA-1 has total depth of about 4431 m, its well log response shows the presence of five unconformities. Sequence boundaries (SB) are laterally extensive and conformable in stratigraphic order from the oldest (SB1) to the youngest (SB5). This seismic section with the help of well logs is characterized by several mega sequences bounded by major regional unconformities recognized at base of Quaternary (SB1) at depth 160 m, base Miocene (SB2) at depth 482 m, base Middle Eocene (SB3) at depth 838 m, (base of Coniacian-early Campanian) (SB4) at depth 1506 m and base of Albian (SB5) at depth 1955 m. The sand of Kipatimu seems to be deposited during the period of high stand system tracts (HST) with good reservoir quality (Figure 17).

**SEQUENCE 1** is at depth (4400-1800) m in AA-1 dominated by shale of late Jurassic formed during the period of high sea level (TST) (4400-3200) m, sand shale (3200-2500) m with sandstone at (2500-1800) m of HST during early Cretaceous while BB-5 shale of TST is found below 2850 m followed by sand shale of HST (2850-2200 m) and the LST sandstone is very thin at depth 2000-1800 m and both capped with Albian unconformity SB1 at depth 1800m. Sequence one has two Formation that's Mtumbei and Kipatimu Formation (Figure 17).

**SEQUENCE 2** is at and depth 1800-1158 m. Is dominated with Cenomanian shale of TST started to appear at depth (1800-1500 m) and sandstone of HST (1500-1400 m) capped by erosional surface of Coniacian unconformity (SB2) at 1400 m. Main dominant Formation is Wami series (Figure 17).

**SEQUENCE 3** is at depth (1400-800 m) is dominated with sandstone of LST at 1400-1200 m and TST shale at (1200-1000 m) with shale sand of HST at (1000-800 m) that capped with the Middle Eocene erosional surface SB3 at 800 m. Main dominant Formation is Ruaruke formation (Figure 17).

**SEQUENCE 4** is at 800-460 ms and depth 800-500 m this zone is

dominated with sandstone only (LST), this sandstone is capped with an erosional surface SB4 known as Miocene unconformity at 500 m. Main dominant Formation is Wami Formation (Figure 17).

**SEQUENCE 5** is at depth (500-160) m this zone is dominated with sandstone only (LST), this sandstone is capped with an erosional surface SB5 known as Quaternary unconformity at 160 m. Main dominant Formation is Mikindani Formation (Figure 17).

**SEQUENCE 6** is at depth 160 m and below, this zone is dominated with Reef limestone it shows that after regression nothing happened again, the sea level remained the same and gave roof for coral to flourish. Main dominant Formation is Reef Limestone (Figure 17).

**System Tracts:** The following system tracts were identified:

- **Transgressive system tracts (TST)** are usually sand deficiency and contain abundant fine grained deposits rich in organic matter, they have potential for source, seal and reservoir however source and seal are generally the dominant facies in TST, The transgressive shale of the TST form the source rock for potential reservoirs in the study area sealed by maximum flooding surface (MFS) (Figure 17).
- **Highstand system tract (HST)** are known to make good reservoirs with high porosity and permeability. This good quality reservoir rocks are deposited during this period of decreasing sea level. This deposit area known to hold a great amount of hydrocarbon and they are believed to derive their hydrocarbon from previous sequences of Mtumbei Formation and their often overlain by their next depositional units and capped by SB1 Albian unconformity this massive sand from AA-1 provide good potential reservoirs (Figure 17).
- **Lowstand system tracts (LST)** make excellent reservoirs, this is due to its higher porosity and permeability. The LST of Albian sand also is known to hold great amount of hydrocarbon, however the thickness of sand units is only 50 m (Figure 17).
- **Transgressive system tracts (TST)** of Wami Formation is the

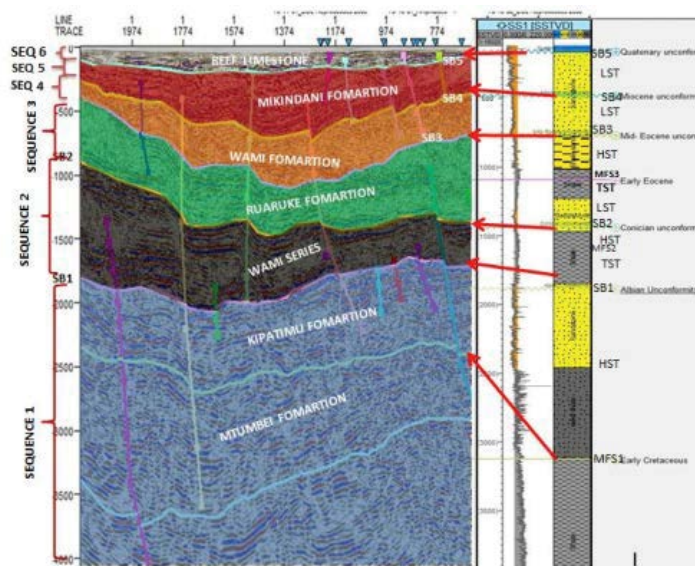


Figure 17: Well log and seismic to show sequences from the wells and its corresponding horizon on seismic section.



caprock for the HST and LST that hold hydrocarbon in Songo Songo field. This TST has thickness of 350 m seen at depth (1500-1850) m (Figure 17).

- The alternation of TST, HST, LST, and TST, shale, sand and shale therefore provide a union of source rock, reservoir and seal rocks that is essential for hydrocarbon generation, accumulation and trapping (Figure 17).

### Well log correlation

The well correlation was done to develop a regional framework of the Songo Songo area (Figure 18). For the regional framework two wells has been used AA-1 and BB-5. These wells are 5 km away from each other with North-South relationship. Lithology interpreted based on the gamma-ray log. The well correlation stretches from the north to south, where the north part is close to River Rufiji that is the main contributor of sediment.

#### Correlation based on age

**Late Jurassic (Mtumbei Formation):** In the Songo Songo field the wells show variable penetration down into the Jurassic, with thick intervals of Late Jurassic present in wells BB-5 and AA-1. The basal contact of the Jurassic sequences was not seen (below TD) and the upper contact of the Jurassic is conformable with Lower Cretaceous in all two wells, the Late Jurassic is developed in marine facies and dominated with marine shales in both AA-1 and BB-5 so the Jurassic shale of AA-1 shows that the shale thickness thins towards well BB-5

this proves that the rate of sediment influx was low and it's from well AA-1 in the north to well BB-2 in the south (Figure 19).

**Early Cretaceous (Kipatimu Formation):** The distribution of Early Cretaceous strata is similar to that of sediments of Late Jurassic age. Early Cretaceous to Albian successions, developed in a fully marine. The early Cretaceous in AA-1 is dominated with sand shale and sandstone correlated with early Cretaceous deposit of BB-5 with dominant sand shale, sandstone and shale (Figure 19).

**Correlation based on lithology:** The two wells (AA-1 and BB-5) studied from the Songo Songo field are penetrating Late Jurassic and early Cretaceous (Neocomian) sections and uniformly exhibit relatively high accumulation/subsidence rates, Jurassic and Cretaceous sediments are well represented within this group of wells. However, many sections exhibit stratigraphic breaks at several levels and of varying duration and sediment accumulation rates varying with location.

The shale in Jurassic succession in Songo Songo BB-5 and AA-1 were correlated. AA-1 shows a very high proportion of shale that thinned as you go to BB-5. The rapid lateral variation in facies development between adjacent wells suggests tectonic control on sedimentation patterns (Figure 20).

The sand shale of AA-1 correlated with the same thickness of shale sand on BB-5 and they showed uniform thickness, while the sandstone of AA-1 thinned towards BB-5, the shale that is in BB-5 at depth 2000

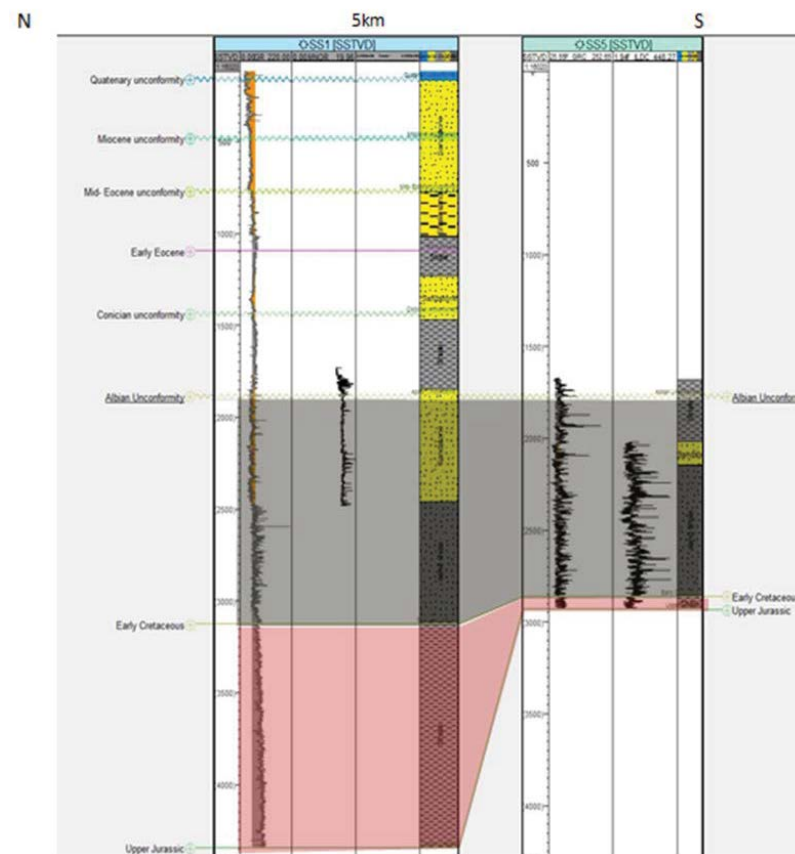


Figure 18: Well AA-1 and BB-5 correlation based age.

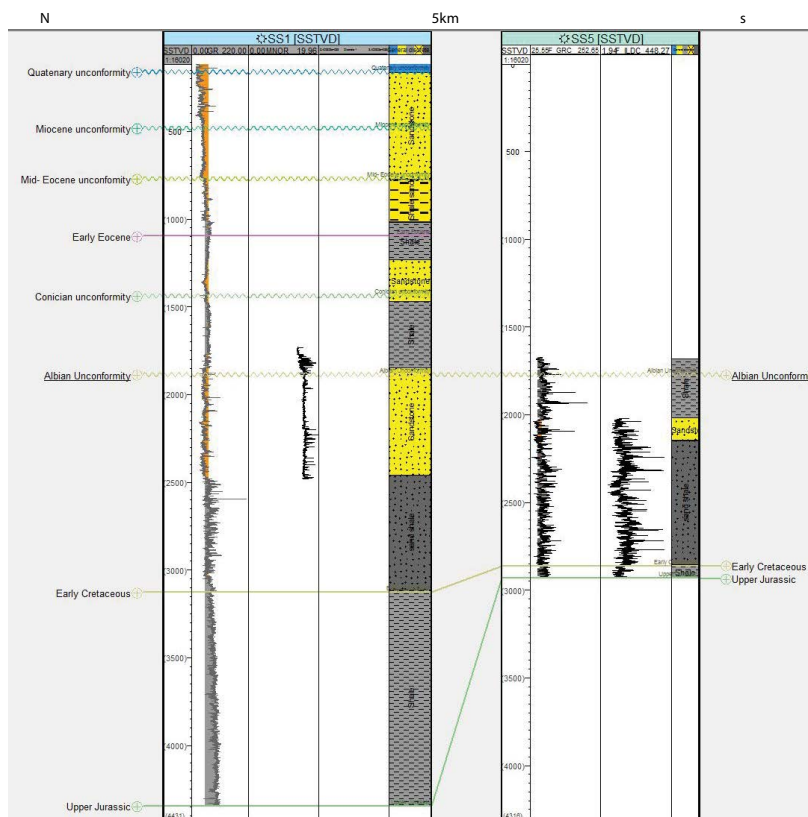


Figure 19: Well AA-1 and BB-5 correlation based lithology.

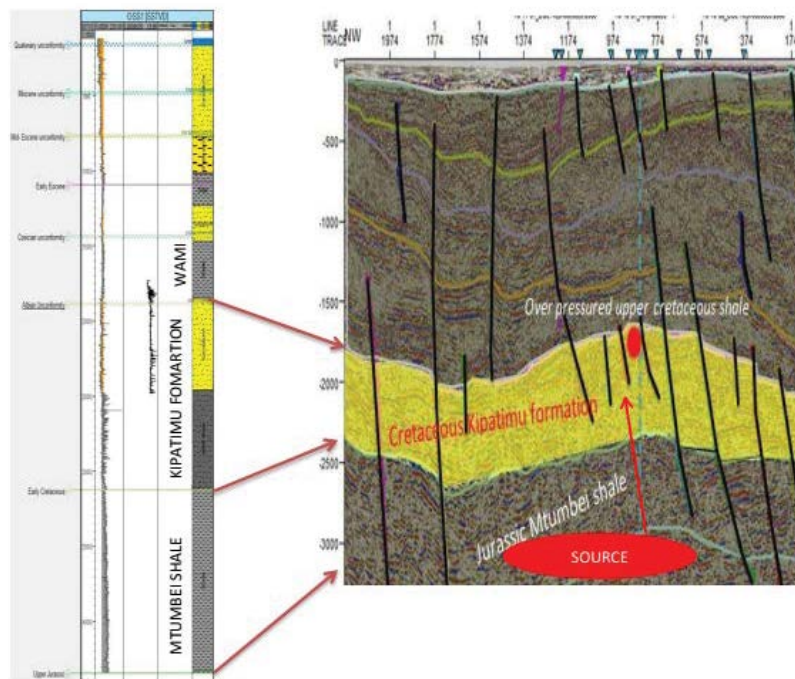


Figure 20: Reservoir and source rock from well log and seismic section.

m seems to be eroded on the AA-1 as the sandstone in AA-1 is capped above by Albian unconformity (Figure 20).

There is a significantly higher proportion of sandstone in AA-1 compared to BB-5, suggesting that AA-1 was located closer to the main feeder systems during the late Neocomian, Well BB-5, in contrast, shows a consistent extremely sand poor trend throughout, and it appears to be located on the footwall terrace which experienced significant uplift and erosion during the late Neocomian (Figure 20) [24-28].

## Conclusion

The structural and stratigraphic framework of Songo Songo field in Tanzania was predicted and determined by careful integration of seismic and well log data with the main aim of using the sequence stratigraphic approach in establishing structural and stratigraphic settings (classifying the sedimentary units, understanding of structural styles and stratigraphic concept) with their tectonic events, define reservoir and trapping mechanism in the study area. Seismic and stratigraphic sequences based on 2D seismic data from Songo Songo gas field helped to depict the different depositional unit from the Jurassic to Quaternary time span, Based on this information, the location of potential reservoirs and the relation of deformation with deposition were established with shale, sandstone and limestone were dominant lithofacies. Six mega sequences bounded by major five unconformities recognized at base Pliocene (SB5) base late Miocene (SB4) base Middle Eocene (SB3), base of Coniacian-early Campanian (SB2) and base of Albian (SB1) with three maximum flooding surfaces (MFS1 in early Cretaceous at depth 3150 m, MFS2 in Cenomanian (Late Cretaceous) at depth 1600 m, and MFS3 in early Eocene at depth 1100m). Seismic facies analysis also reveals that there is a vertical alternation of contrasting lithology (sand/shale) while on the surface we have Reef limestone. Through systems tract assessment of the seismic data and well log the source rocks, reservoir and seal was able to be defined. Source rock recognized at depth (4431-2500) m, reservoir recognized at depth (2500-1800) m and seal recognized at depth (1800-1500) m.

Structural analysis revealed the presence of normal faults that trending NNW-SSE with three faulting systems. Fault systems include Jurassic faulting, Neogene faults and reactivated faults. Faulting events affected the upper sedimentary sequence and the lower with minor evidence of cutting or affecting the Eocene sedimentary sequence, this implies that there is only two tectonic events (deformation phase) that occurred in the Songo Songo area indicating a two phase of faulting event. Presence of reactivated faults indicates the reactivation of Jurassic faults during the east Africa rifting. Reactivation might be the reason why the area has less gas; this reactivated faults possibly acted as the migration pathways for the gas to escape to the surface.

The gas appears to have been sourced from post mature organic material of Jurassic to Early Cretaceous age. The main reservoir is developed in the Lower Cretaceous aged Neocomian to Albian sandstones (Neocomian), while Upper Cretaceous Cenomanian sands provide additional reservoir where developed. Wami Formations that contain shale in Songo Songo gas field form a caprock of lower Cretaceous reservoir. The gas is majorly trapped by Jurassic faults and they seem to be potential compare to Neogene and Reactivated faults, this is due to up dip migration during fault reactivation.

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