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Seismic Chronostratigraphic Illustration of the Tertiary Section in Tano Basin, Southwestern Ghana

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Abstract
In this paper, the principles of sequence stratigraphy were employed to conceptually interpret the geomorphological features on a 2D seismic survey that intersects parts of the Tertiary section, offshore Tano Basin of Ghana. In the Tertiary section, a relatively younger shelf-edge delta and an older depositional sequence were identified and mapped as constrained by reflection termination. The depositional sequence comprises offlapping highstand oblique prograding lobes downlapping on a Maximum Flooding Surface (MFS) and truncated on a normal fault. Three (3) MFSs and two (2) Sequence Boundaries (SB) were distinctly identified on the shelf-edge delta. The Wheeler diagram placed the clinoforms of the shelf-edge delta in their chronostratigraphic framework and the identified system tracts (falling stage, lowstand, transgressive and highstand). Generally, the morphology of the delta is prograding, which developed as a result of relative sea-level fall, supported by a truncating erosional base event. Nevertheless, incorporating more data sets can help understand the mechanism and processes that relates and characterise the shelf-edge delta sedimentation.

Keywords: *Shelf-edge delta; Tano Basin; Depositional sequence; Wheeler diagram; System tracts.*

1. Introduction

Sediment delivery into a sedimentary basin is one of the important factors considered during hydrocarbon exploration, particularly in a clastic depositional environment. According to Magbegbeola [1], successful explorational efforts of hydrocarbon is hinged on proper comprehension of sediments accumulation, preservation and trends within the basin fill. Besides gravity flow, contour currents and pelagic sedimentation, the shelf-edge delta represents a significant sediment entry locus to the deep-water regime [2]. The shelf-edge delta is also referred to as the shelf-margin delta.

Roberts and Bally [3] defined deltas as coastal sediments that amass about a riverine point source of sediment delivery to a standing water body, usually the sea. Hitherto, deltas remain a significant multi-component of fluvial to deep water depositional systems. In the marine domain, deltas are prominent at the shelf-edge region. This region is distinguished as a gradient change from the flat-lying continental shelf to a steep slope regime [4-5]. However, shelf-edge deltas exercise a critical role in deep-water sediment delivery and shelf margin accretion [6]. They contribute a larger amount of coarse sediments to the deep-water slope and basin floor [7-8]. Factors such as relative sea-level fall, high sediment influx and the nature of the shelf-edge regime are regarded as the essential requirements to assist delivering clastics though the shelf-edge to the deep-water [9]. The geomorphological appearance of the shelf-edge delta can be recognized on geophysical data (two-dimensional and three-dimensional seismic data) and outcrop, which have conspicuous dip orientation [6]. The shelf-edge deltas are usually impacted by wave, tidal and fluvial with other oceanographic currents [10]. Most of the reported shelf-edge delta in the world are conventionally part of the Cenozoic Era, particularly on the Quaternary shelves [7].

The present-day Tano Basin is noted for its broad, steep continental shelf and steep nature along its margins. However, the Basin has been noted for its deep-water potentials with abundant hydrocarbon resource [11]. The Tertiary section of the Basin has received little exploration attention, largely due to the void of active source rock and a good trapping system [12]. In the Tano Basin, there is a paucity of information about the relevance of shelf-edge delta to basin sedimentation. An established relationship exists between deep water sedimentation and the presence of shelf-edge delta. Nevertheless, recognizing and the mapping of a shelf-edge delta on seismic survey should not be disregarded. Similarly, studies conducted by Sylvester *et al.* [13] demonstrated that using subsurface data sets; regional architecture and geometry of shelf-edge can be evaluated. Thus, this study aims to examine the shelf-edge delta mapped on a 2D seismic survey that intersects the Tertiary section of the Tano Basin using the wheeler diagram.

2. Geologic setting

Ghana is home to two groups of sedimentary basins. They are the coastal basins (Tano Basin, Saltpond Basin and Keta Basin) and the onshore or inland Basin (Voltaian Basin). Significantly, the Voltaian Basin occupies approximately 40% of the total landmass of Ghana. The referenced Basin of study i.e., the Tano Basin (Fig. 1), is one of the coastal basins in Ghana which is geographically situated in the province of the West African Transform Margin (WATM) suits of Basin.

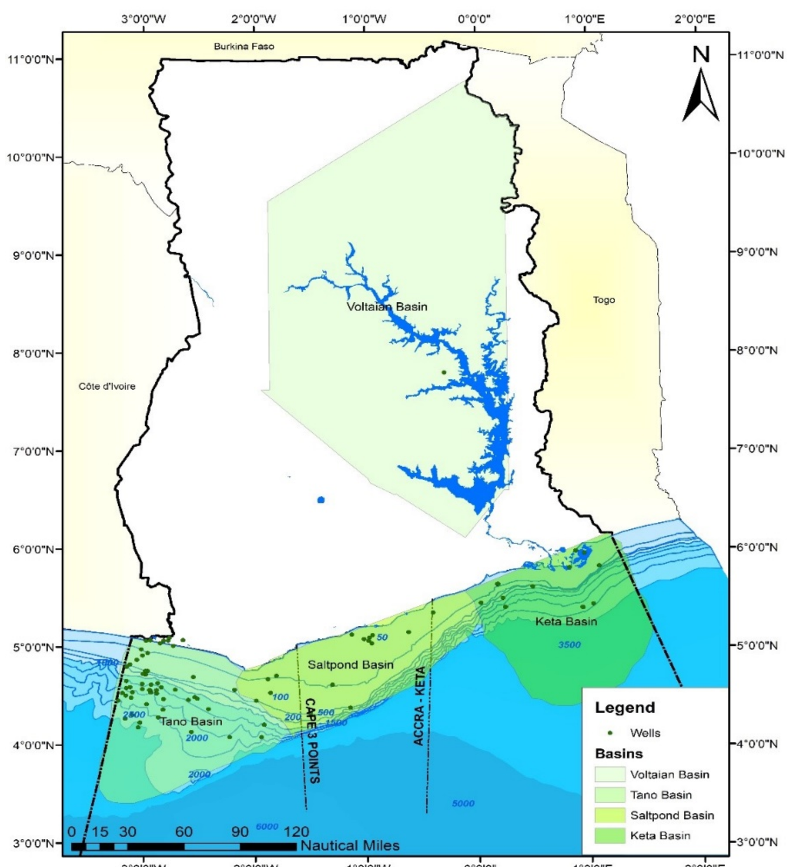

Fig. 1. The geographic location of the Tano Basin in relation to other sedimentary basins of Ghana

More often, the Tano Basin is referred to as the Western Basin, Cape Three Point Basin or the eastern extension of the Cote D'Ivoire Basin. The Tano Basin extends about 500km from the coastal shelf of Cote D'Ivoire to southwestern Ghana, having a relatively smaller portion on the onshore and a larger proportion in the offshore region [14-15]. The Basin originated from a rift system on thinned continental crust followed by extension and subsidence as the South Atlantic Ocean opened up during the separation of the West African and Northern Brazil continental plates. Initially at the end of the Jurassic Epoch, the Tano Basin was a pull-apart basin but it was later altered in the Cretaceous by wrench tectonics. According to Rüpke *et al.* [16] and Nora Herbst *et al.* [17], this cumulative evolutionary alteration is noted as a continental to oceanic rifting accompanied by a grand scale transform faulting.

The lithic fill in the Tano Basin started in the Aptian age as accommodation space was created when the South Atlantic Ocean opened up and deepened. Kesse [18] described this lithic fill to be made up of Cretaceous to Eocene marine sedimentary rocks. Brownfield and Charpentier [19] reported that sedimentary fill within the Tano Basin exceeds 6,000 m. However, a fair portion of the clastics supplied into the Basin were from two major river sources i.e., the Ankobra and Tano Rivers [20]. This Basin fill has been complemented by sedimentation of pelagic, hemipelagic shale and mudstones. Carbonate sediments have also been reported to be deposited in the Tano Basin [21]. With regards to the regional stratigraphy, the Tano Basin contains syn-transform rocks of Early Cretaceous age in both offshore and onshore region [22]. There was continuous graben filling until the middle of the Cenomanian when uplifting of the Basin brought about extensive regional erosion across the Gulf of Guinea Province. Post-transform rocks in the Tano Basin range in age from Campanian to Holocene. The Campanian strata unconformably overlies the Albian syn-transform rocks. The Maastrichtian rocks lay unconformably on the Campanian strata which grades into continental clastic. The Tertiary post-transform rocks unconformably overlie the Maastrichtian rocks. These rocks are separated from the Upper Miocene marine stratal by a major Oligocene-Miocene unconformity. Nevertheless, Davies [23], Ghana National Petroleum Corporation [21] and Dailly *et al.* [24] have given a detailed description of the stratigraphy of the Tano Basin, as the latter took into account the various associated tectonic phases.

The petroleum system of the Cretaceous Tano Basin comprises an active shale source rock (Albian – Cenomanian and Turonian age) whose derivative oil and gas charges the Upper Cretaceous reservoir sands, and confined by a structural and stratigraphic trap and intra-formational seal [25]. Martin *et al.* [26] and Tetteh [27] provided an insight into the Cretaceous play of the Tano Basin discussing the recognized petroleum play, which are; the Albian, Cenomanian, Turonian, Campanian and Maastrichtian play.

3. Data and method

This study made use of a 2D seismic data on which seismic interpretation was done. The 2D seismic survey which extends basinward of the Tano Basin had the following characteristics: recorded in two-way travel time (TWT), processed to zero phases, bears the normal (American) SEG convention and had a good data quality.

The 2D seismic section was examined based on the reflection termination relations such as onlap, down lap and top lap (Fig. 2). Then, the shelf-edge delta was recognized and mapped with other geomorphological features. To place the shelf-edge delta in its chronostratigraphic context, the wheeler diagram [28], a stratigraphic summary and chrono-chart was constructed to show the delineated sequences constrained by their sequence stratigraphic surface, notably the Maximum flooding surface (MFS) and the Sequence boundary (SB). This study made use of the sequence definition according to Sloss [29], as an unconformity-bounded stratigraphic unit. Also, the stratigraphic surface represents system tracts boundaries which marks changes in stratal termination pattern [2]. The sequence boundary (SB) combined the subaerial unconformity (unconformity formed under subaerial condition, up-dip) and the correlative conformity (marine or basinward equivalent or down-dip subaerial unconformity).

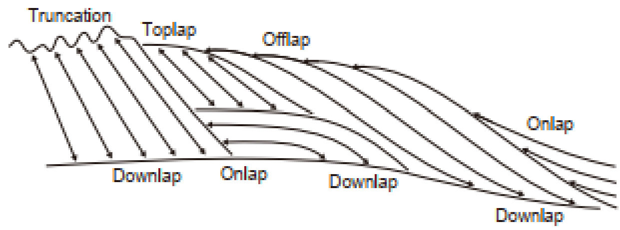

Fig. 2. Types of seismic reflection termination [2]

The systems tracts defined as a linkage of contemporaneous depositional systems which form the subdivision of a sequence according to Brown and Fisher [30] was mapped conceptually based on their position within the sequence and type of bounding sequence stratigraphic surfaces. The systems tracts recognized were the Falling stage system tracts (FSST), Lowstand systems tracts (LST), Transgressive system tracts (TST) and the High stand system tract (HST). A conceptualized hydrocarbon potential of the shelf edge delta concerning the source, reservoir and seal system was then proposed in the context of the identified systems tracts and seismic stratigraphic surfaces.

4. Result and discussions

In the studied section, the examination of the variation and style of the acoustic/reflection character have been employed to delineate seismic stratigraphic sequences within the 2D seismic survey.

The depositional sequence is the oldest in the studied seismic section (Fig. 3). This sequence straddled between 1250 and 1750 milliseconds (TWT) is mapped below the shelf-edge delta. The depositional system is not well developed on the seismic section compared to the mapped shelf-edge delta, perhaps due to the compaction effect by the overburden strata. However, a look at the depositional sequence shows two bounding continuous reflections on the top and bottom. The bottom bounding reflection event is a maximum flooding surface, diagnosed by a high amplitude contrast with lateral continuity which bears downlapping seismic termination on the surface [2, 31]. Overlying the MFS is a set of oblique prograding highstand lobes which downlaps on the MFS and later truncates against a normal fault in the basinward direction. The Base Tertiary, a seismic marker event in the Tano Basin, is a regional surface which differentiates the sedimentation of the Upper Cretaceous Epoch from the Tertiary (Paleogene and Neogene Period). This regional surface is diagnostic of a strong bright acoustic contrast below the MFS (Fig. 3). This assertion of the Base Tertiary surface is according to the regional stratigraphy of the Tano Basin [21]. The identified normal fault on the seismic section is one of the reactivated syn-rift fault system known in the Tano Basin. Most of these reactivated syn-rifts fault systems penetrate the Tertiary section of the Tano Basin.

Sedimentation followed on the depositional sequence as parallel to sub-parallel seismic events which is more evident in the proximal basinward direction. These parallel seismic events indicate the paleo continental shelf deposition [32]. The shelf-edge delta identified and mapped on the seismic section is shown in Figs. 3 and 4. The base of the shelf-edge delta is marked by an extensive Sequence Boundary (SB1) which is characterized by a steep slope erosional base. An examination of the nature of the SB1 surface demonstrates that the shelf was exposed subaerially around the shelf-edge region, this is consistent with [33]. Sedimentation followed after the subaerial exposure to birth the shelf-edge delta. The stratigraphic surfaces mapped two sequence boundaries (SB1 and SB2) and three Maximum Flooding Surfaces (MFS1, MFS2 and MFS3) characterising the shelf-edge delta (Fig. 4). These stratigraphic surfaces constrained the identified system tracts, a representative of sediments succession [34].

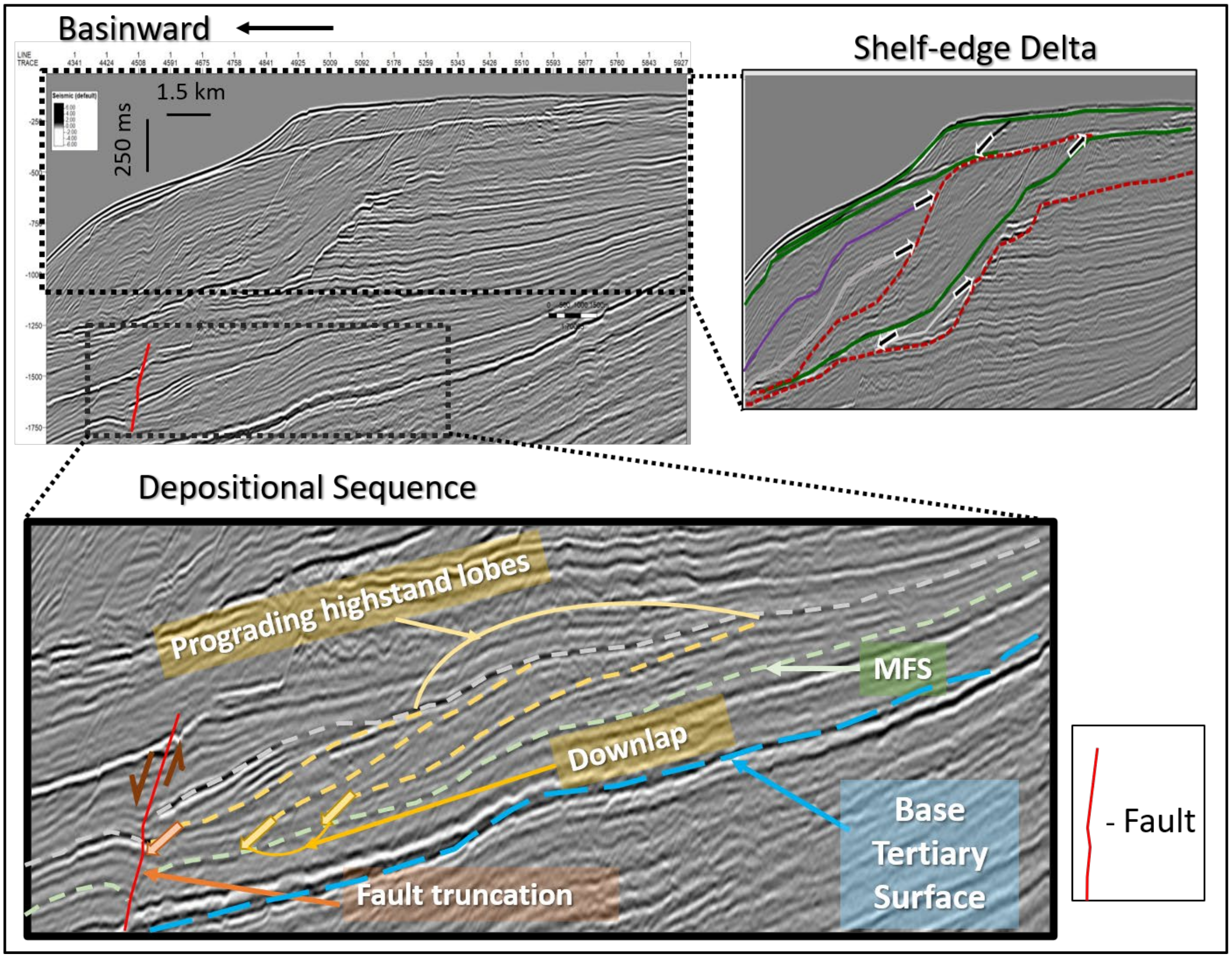

Fig. 3. The seismic section showing the shelf edge delta and the older depositional sequence

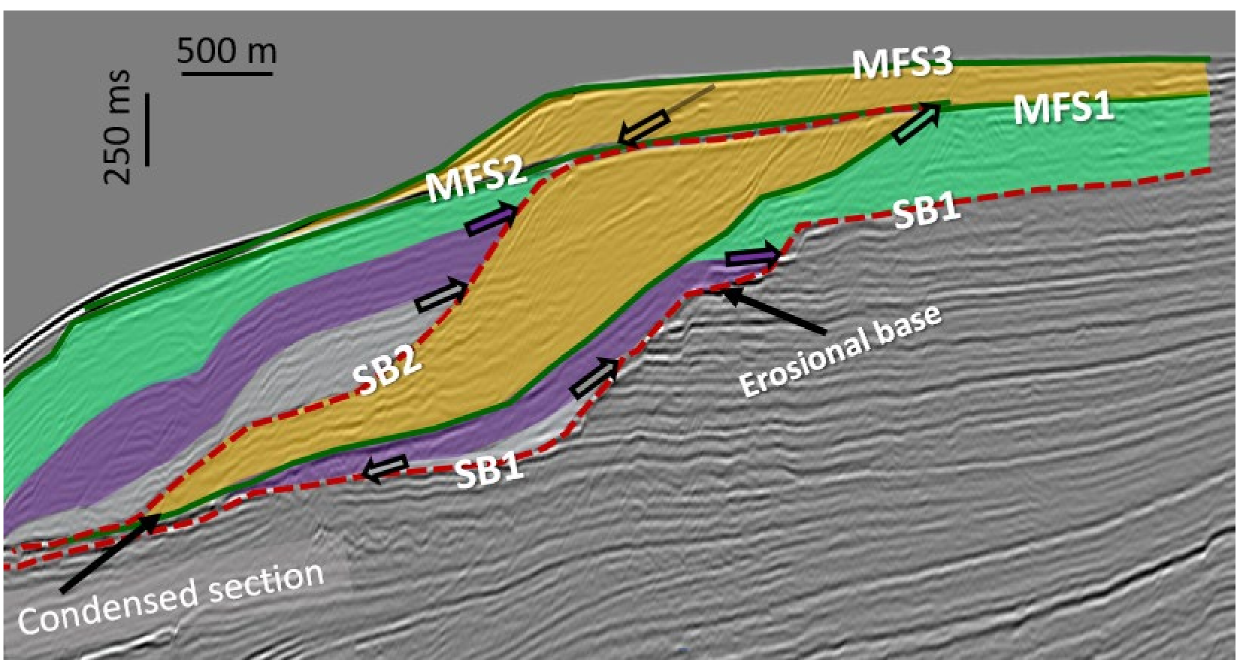

Fig. 4. Seismic mapping of the shelf-edge delta showing the identified stratigraphic surfaces and reflection termination types

The wheeler diagram constructed, placed the system tracts components of the shelf-edge delta in their relative chronostratigraphic spatial relation (Fig. 5). The SB1 formed an extensive unconformity surface cutting into older events. The first FSST followed farther downslope as bypassed sediments away from the eroded continental shelf as relative sea-level fall. Then, the preformed erosional base was filled by the first LST and later by the first TST in the upper slope region. The MFS1 caps the first transgressive system tracts and emerged as a condensed section in the distal basinward direction. Offlapping highstand prograding clinoforms followed and downlaps on the MFS1 with a greater thickness on the paleo shelf which thins out in the basinward direction. This first HST is interpreted to consist of possible normal regression deposits with oblique reflection pattern.

The SB2 was overlain on the first HST. The second FSST was deposited farther down slope as bypassed sediments basinward and steeply onlaps SB2. The second LST aggrades and wedges on the second FSST, indicating a rising sea level, high sedimentation rates and onlapping towards the continental shelf with subtle erosion in the basinward direction. The second TST followed on the second LST as retrogradational pattern of layers of events and was capped by MFS2. The second TST is interpreted to consist of parallel and progressive onlapping reflectors with an aggradational pattern occurrence when relative sea-level rise outpaces sediment supply. The MFS2 is laterally extensive which indicates high sediments influx. The second HST downlaps on the MFS2 as steeply dipping clinoforms with an oblique reflection pattern which indicates a slow relative sea-level rise. The last surface to cap the overall succession is an MFS3 characterized by an extensive bright acoustic contrast.

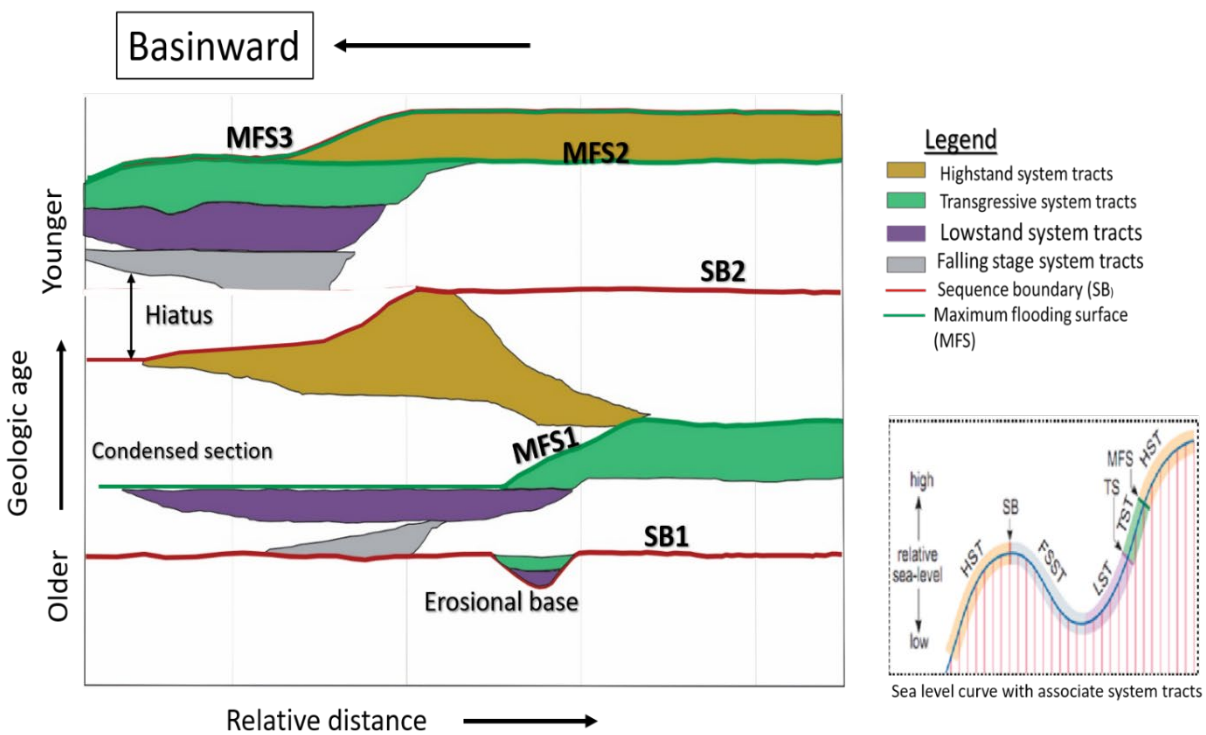

Fig. 5. The chrono-chart of the shelf edge delta showing the system tracts delineated by the stratigraphic surfaces

In general, the seismic reflection signatures of the shelf-edge delta indicate that the delta was formed probably due to a forced regression of the shoreline as marked by prograding lobes with down stepping styles. As stated earlier, the exploration of hydrocarbon in the Tertiary section has not proven prospective, reason been that, the depth of the Tertiary sequences or units are too shallow for deposited source rock within the interval to mature. Also, there is a high susceptibility to biodegradation if hydrocarbons were accumulated at such shallow depths. Furthermore, there is virtually no evidence of migration pathways connecting the deeply buried mature source rock to the Tertiary reservoirs. It is also important to emphasize that the Miocene-Oligocene Unconformity (MOU) is prominent in the Tertiary interval of the Tano Basin and associated with numerous erosional systems [35]. The possibility of these numerous erosional systems to inhibit preservation and subsequent maturity of deposited source rocks in the Tertiary interval cannot be totally ruled out.

Nonetheless, the hydrocarbon potential of this shelf-edge delta cannot be undermined. The MFSs could provide the seal to trap hydrocarbon migration and a good source rock to generate hydrocarbon, provided all favourable conditions are satisfied. Also, the second LST and to some extent the first FSST can be a good reservoir rock if they are sufficiently rich in clastic sands. As a matter of fact, the shelf-edge has been reported to be a common habitat to reservoir sands [36-37].

5. Conclusion

In the absence of well and core data, efforts have been made to illustrate conceptually the chronostratigraphic framework of a shelf-edge delta observed in the Tertiary section on a 2D seismic survey in the Tano Basin using the wheeler diagram. A depositional sequence was also recognized and mapped on the 2D seismic survey. The depositional sequence comprises offlapping highstand oblique prograding lobes which downlaps on a maximum flooding surface and truncated by a normal fault. The stratigraphic surfaces delineated were constrained by the seismic reflection pattern and termination; they are three MFSs and two SBs. The wheeler diagram, also called the chrono-chart showed the spatial relation constrained by the delineated stratigraphic surfaces.

A careful examination of the shelf-edge delta on the seismic section shows that the shelf-edge delta was formed as a result of relative sea-level fall as the paleo shelf was exposed, marked by an underlying extensive erosional truncating base event. Though hydrocarbon exploration campaign in the Tertiary section of the Tano Basin have not proven to be productive, results from this study indicate that some of the mapped systems tracts i.e., the first FSST and the first LST can serve as a good reservoir if sufficient clastic sand accompanied their deposition. However, seismic reflection termination portrays the first and second FSST as bypassed sedimentation. This could improve some of the reservoir properties through sorting.

Nevertheless, further inclusion of more data sets such as core, well logs and a 3D seismic volume will facilitate the comprehension of the mechanism and geologic processes that relate this shelf-edge delta to deep-water sedimentation.

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