PS Gravity-Driven Deep-Water Fold-and-Thrust Belts Along the Passive Continental Margin of East Africa and Their Impact on Petroleum Plays*

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Search and Discovery Article #30631 (2019)**
Posted September 23, 2019

*Adapted from poster presentation given at AAPG 2019 Annual Convention & Exhibition, San Antonio, Texas, May 19-22, 2019
 DOI:10.1306/30631Zhang2019

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Abstract

Passive-margin deep-water fold-and-thrust belts (DWFTBs) are geological structures that have been the focus of many studies in the recent decades, since many oil and gas fields have been discovered in traps associated with DWFTBs. Advance in seismic processing and acquisition of new data sets have revealed two DWFTBs in the offshore Rovuma Basin and (SE Tanzania and NE Mozambique) the offshore Lamu Basin (NE Tanzania and SE Kenya), both of which originated over an shale detachment due to a mainly gravity-spreading mechanism. Recently, a prolific natural gas fairway has been proved to exist in the offshore Rovuma Basin, trapped in a system of gravity-driven, extensional-compressional deep-water fold-and thrust system. However, the petroleum play of the DWFTB in the offshore Lamu Basin receives less attention. In this study, we propose a possible model for the petroleum play in the DWFTB in the offshore Lamu Basin based on an integrated analysis of seismic, geochemical and geology data. Our results indicate that the DWFTB in the offshore Lamu Basin originates over an lower Cretaceous shale detachment and extends for more than 450 kilometers along the continental passive margin, the scale of which is much larger than that in the offshore Rovuma Basin that originates over an Eocene shale detachment and extends for about 120 kilometers. High-quality seismic data, available in depth domains, allows us quantify the evolution of thrust anticlines exhibiting growth using the area-depth-strain method in the DWFTBs in the continental passive margin of East Africa, which indicates that the DWFTB in the offshore Lamu Basin became active as early as the late Cretaceous period to the early Miocene period with a constant sedimentation rate, while the DWFTB in the offshore Rovuma Basin became active during the Oligocene period to the early Miocene period. Organic geochemistry and basin modeling show that the widespread lower Jurassic mudstone is the major source rock in the DWFTBs, and the peaks of oil generation and gas generation are the Cretaceous period and the Cenozoic

period, respectively. Thus, we suggest that oil generated from the source rocks migrated along faults as conduits and accumulated into the Cretaceous traps during late Cretaceous period, and gas migrated and accumulated into the Cenozoic traps during the Cenozoic period. Conversely, oil of the DWFTB in the offshore Rovuma Basin is insufficient due to the absence of the oil migration conduits and traps, since the DWFTB had been initially formed from the Oligocene period instead of the period of the peak of oil generation.

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- As many oil and gas fields have been discovered in traps associated with them, passive-margin deep-water fold-and-thrust belts (DWFTBs) have been the focus of a number of studies in recent decades.

- Nevertheless, the impact of DWFTBs on petroleum plays remains unclear.

- In this study, we developed models for petroleum migration and accumulation in the offshore Rovuma Basin and Lamu Basin DWFTBs (Fig. 1-6) located along the passive continental margin of East Africa based on an integrated analysis of seismic, geochemical and geology data.

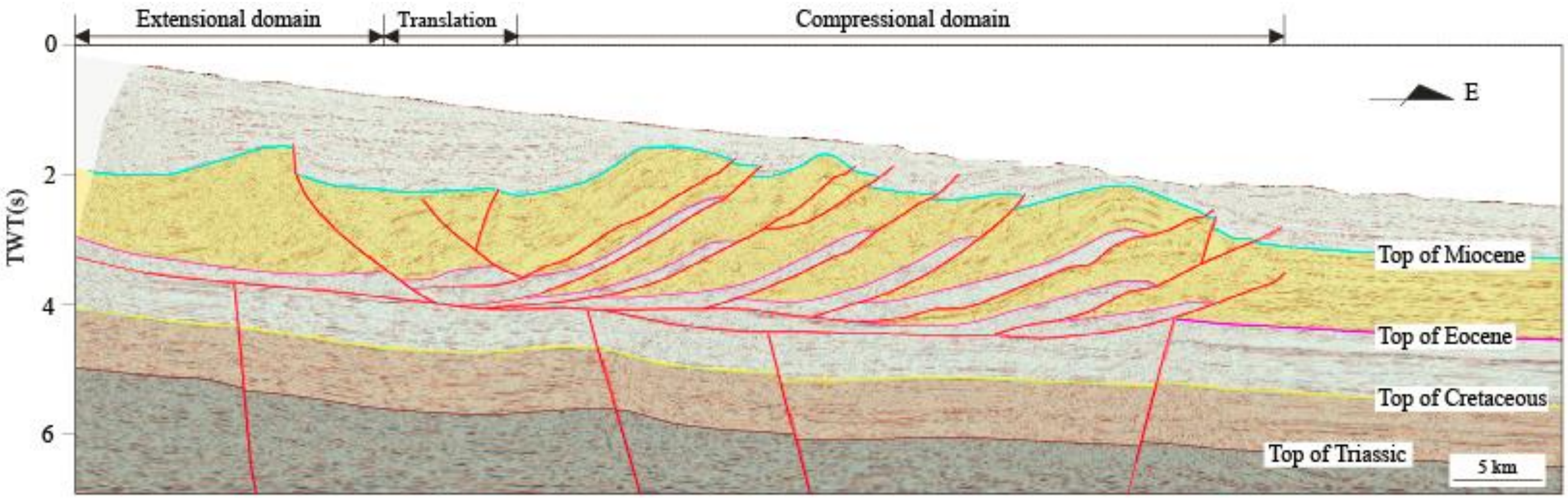

Figure 1. Interpreted seismic section showing the general architecture of the northern Rovuma Basin DWFTB from the extensional to the compressional domains. Structural and stratigraphic interpretation showing basin-ward-dipping listric extensional faults in the west and an evolving counter-regional fault toward the compressional domain TWT = two-way travel time.

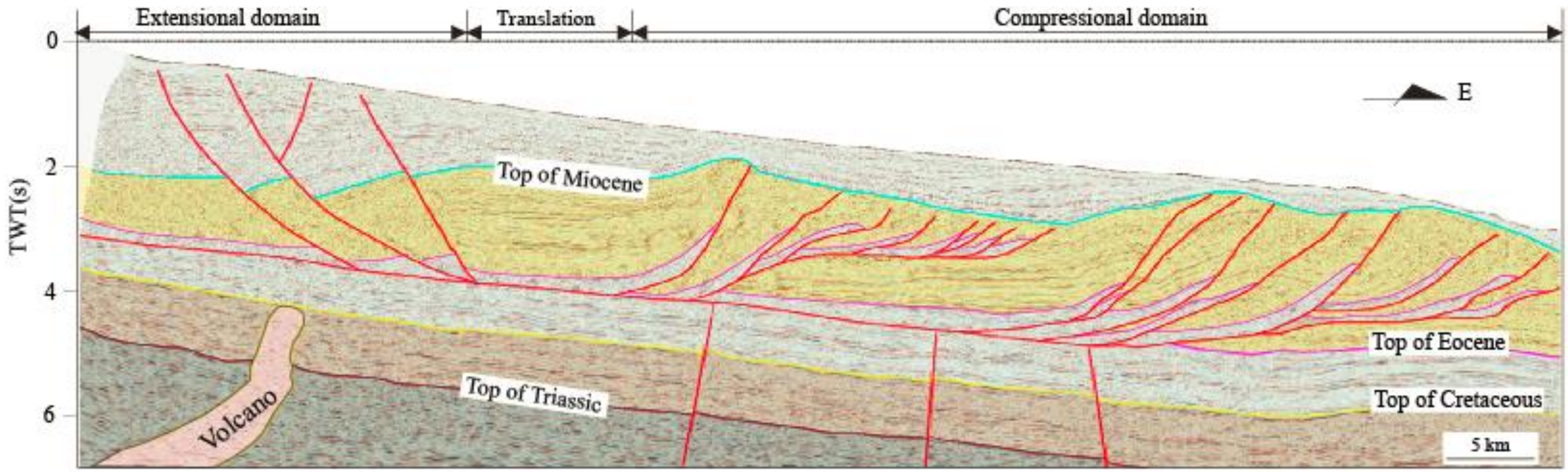

Figure 2. Interpreted seismic section showing the general architecture of the southern Rovuma Basin DWFTB from the extensional to the compressional domains. Structural and stratigraphic interpretation showing basin-ward-dipping listric extensional faults in the west and an evolving counter-regional fault towards the compressional domain. The compressional region is dominated by the DWTFB with partly dual detachment surfaces resulting in thrust duplexes. TWT = two-way travel time.

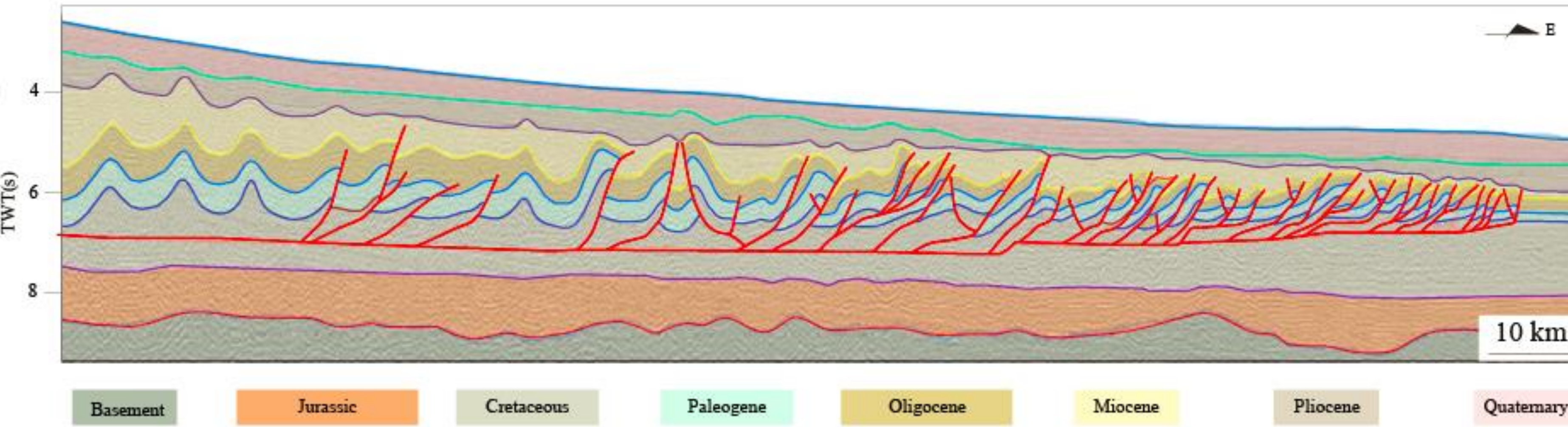

Figure 3. Interpretation of seismic profile P1 across northern portion of DWFTB (see Figure 1 for location), showing four characteristic structural sectors from basin to land. The first structural sector is dominated by basinward verging thrusts, above landward dipping detachment surface. A few back thrusts form pop-up folds. The second structural sector shows series of steep, closely stacked imbricates. The third structural sector, includes basinward verging thrusts and double-verging out-of-syncline thrusts, transporting bowl-shaped, thick piggy-back basins. The fourth structural sector is dominated by set of large symmetrical folds. TWT = two-way travel time.

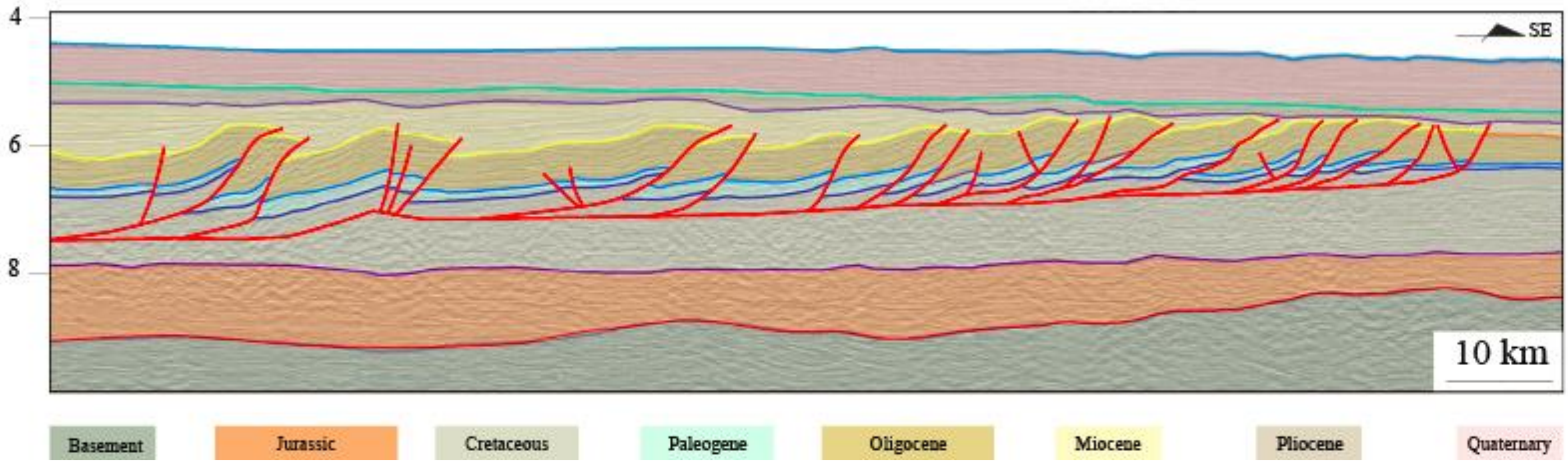

Figure 4. Four sectors from basin to land were identified along this profile, characterized by different structural styles. Theoutermost sector, about 30 km wide, shows imbricate thrusts and thrust-related folds with markedbasinward vergence, with the exception of a few symmetric “pop-up” structures. Landward, the second sector, about 25 km wide, is characterized by a set of steep, closely stacked thrusts. The third sector, about 60 km wide, shows more complex geometry, including basinward stacked thrusts and double-verging out-of-syncline thrusts, transporting bowl-shaped, thick piggy-back basins. The fourth sector, about 65 km wide, is dominated by a set of largesymmetrical detachment folds, resembling diapir-like foldsasins. The fourth structural sector is dominated by set of large symmetrical folds. TWT = two-way travel time.

◆ Using available high-quality seismic data in the depth domain, we were able to quantify the evolution of thrust anticline growth by applying the area-depth-strain (ADS) method. Our results indicate that the offshore Lamu Basin DWFTB was active from the late Cretaceous period to the early Miocene period（Fig. 5), while the offshore Rovuma Basin DWFTB has been active from the Oligocene period）.

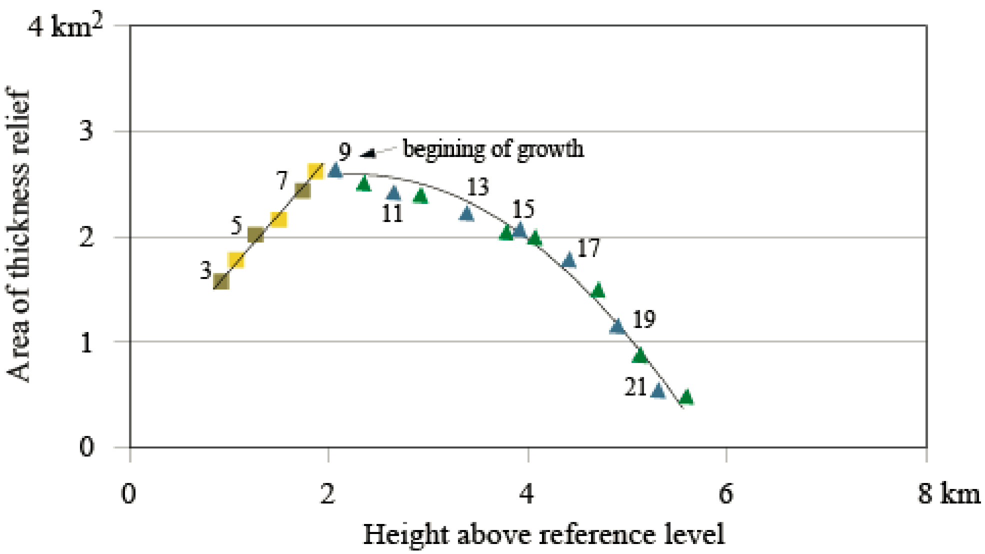

Figure 5. Area of structural relief graph of the detachment fold showing a linear regression between horizons 3 to 8 indicating that detachment has a constant mean shortening. Because the area of relief decreases with height from horizons 9 to 22, we conclude that the detachment fold initiated after horizon 8 was deposited.

- Geochemical parameters and basin modeling show that widespread lower Jurassic mudstone is the dominant source of petroleum resources, with peaks of oil and gas generation in the Cretaceous and Cenozoic periods, respectively.

- Based on this, we suggest that the traps within the offshore Lamu Basin DWFTB contain oil generated from lower Jurassic sources that migrated along faults and accumulated during the late Cretaceous period and gas generated from the same sources during the Cenozoic period.

- Conversely, there is an insufficient amount of oil in the offshore Rovuma Basin DWFTB owing to the absence of oil migration pathways or traps as a result of the DWFTB's more recent formation from the Oligocene period

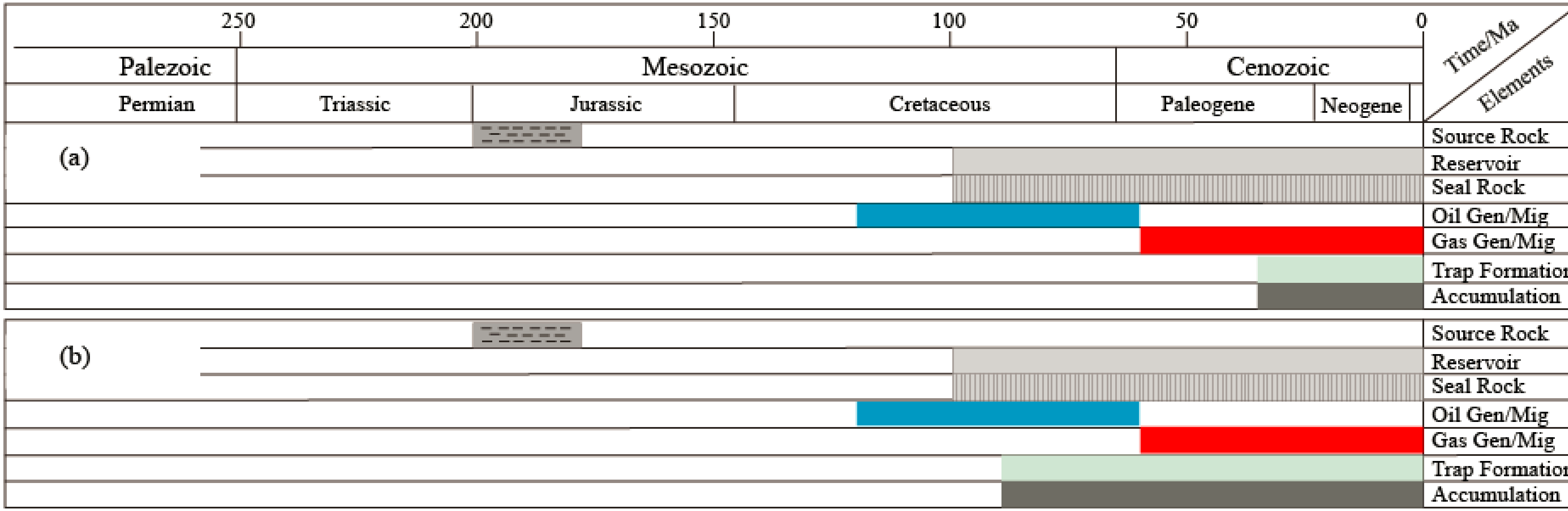

Figure 6. Event charts depicting timing of the petroleum system in the (a) offshore Rovuma Basin and (b) offshore Lamu Basin DWFTBs. Peak oil generation and migration from dominant source rocks occurred during the Cretaceous, while peaks of gas generation and migration from dominant source rocks occurred during the Cenozoic. The event chronology for the offshore Lamu Basin DWFTB (b) indicates a favourable Late Cretaceous timing for the accumulation of oil and a favourable Cenozoic timing for the accumulation of the gas. The event chronology for the offshore Rovuma Basin DWFTB (a) indicates unfavourable timing for oil accumulation but favourable Cenozoic timing for gas accumulation.