Fluvial-Estuarine and Deltaic Reservoirs, Shelf Margin Delta and Slope Reservoir Characteristics

Philip Sedore 2015

Introduction

The offshore Columbus Basin and the onshore Southern Basin of Trinidad are filled with various sequences of fluvial-estuarine, deltaic, shelf and slope sediments. These sediments form possible hydrocarbon reservoirs, and understanding their features is important in characterizing a petroleum system. Both the Southern and Columbus Basin have proven hydrocarbon occurrences that can be associated to these sediment deposits. Tectonism initiated formation of the basins, which in turn controlled the depositional environments and finally the structural features that allow for hydrocarbon migration. For that reason, the tectonic history of the basins is discussed further, as well as the stratigraphy, the depositional environments, and the hydrocarbon reservoirs. Similarities to the Scotian Basin's ancient deltas are also discussed in the hopes that this will provide a familiar analogue.

Evolution of the Columbus and Southern Basin

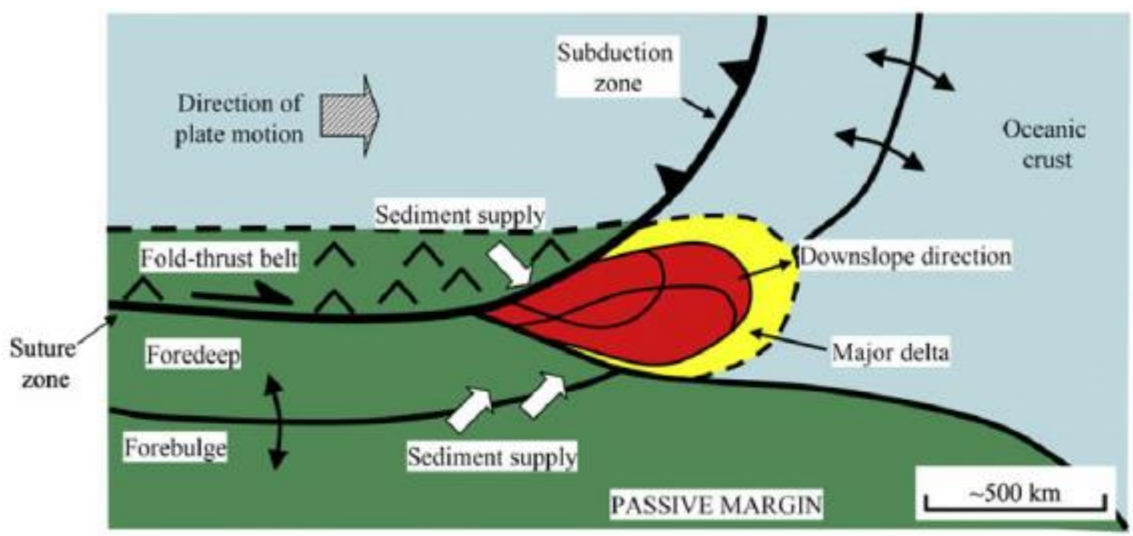

Figure 1. Formation of the foreland basin by oblique plate convergence. The suture zone, suture axis, and the delta lobes are depicted in this schematic diagram (Garciacaro et al. 2011).

The Columbus Basin is defined as the easternmost section of the Eastern Venezuela Basin, and is situated offshore southeastern Trinidad. The Southern Basin forms the southern section of onshore Trinidad. After separation from the African plate, the Northern edge of the South American plate became a passive margin, much like present-day Eastern North America (Garc5eiacaro (B) et al. 2011). Beginning during the latest Oligocene, the obliquely colliding Caribbean plate and the passive South American plate created a foreland basin in which the Columbus and Southern Basin formed (fig. 1). Foreland basin formation is caused by lithospheric loading through crustal thrusting, which results in faulted basement rocks and accommodation space for sediment deposition (fig. 2). The oblique nature of this collision formed a migrating zone of maximum subsidence that is located ahead of the two suturing plates. Migrating from west to east, this evolving depocentre allowed for constant accumulation of sediments derived from both the thrust induced highlands, and the subsequent forebulge (Garciacaro (B) et al. 2011). Syn-tectonic delta sediments in the trace of the migrating foreland basin are uplifted and eroded to provide additional sediments to the coastal delta. The Southern Basin is an example of this uplift, and makes up southern onshore Trinidad today. The two basins are linked through once laterally continuous sediments, which are offset today due to the eastern migration of the suture axis (Garciacaro (B) et al. 2011).

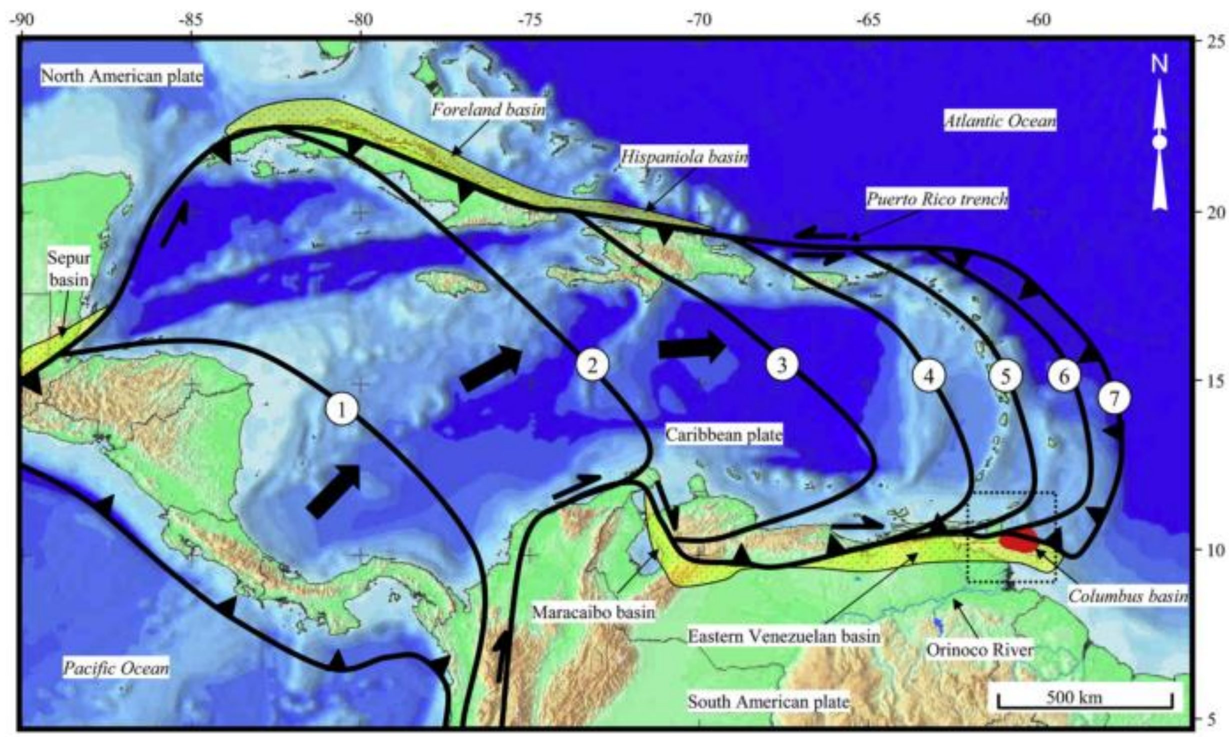

Figure 2. Reconstruction of the Caribbean plate moving eastward relative to the North American and South American plates. The suture zone is shown by the thrust fault to the south, and the trace of the suture axis is shown (Garciacaro (B) et al. 2011)

Stratigraphy

The Columbus Basin and the Southern Basin received upwards of 12-15 km of sediment over their formation, leading to burial and extensive formations across both basins (fig. 3). The same source rocks and deltaic sediments are present in both the Columbus and Southern Basins. (Figure) The difference is that the Southern Basin is exceedingly deformed compare to the Columbus Basin, and the Southern Basin is onshore, providing an analogue to the offshore Columbus Basin stratigraphic units. The formations of these basins have been divided into three main tectonic sequences (S1, S2, and S3) (Garciacaro (A) et al. 2011).

Passive margin sediments of the Cretaceous – Paleogene northern South America make up tectonic sequence one (S1). There is a clearly defined retrogradation sequence during the subsidence of the passive margin. (Figure.) Postulated Cretaceous evaporates govern the base of the sequence with limestones, siltstones and organic-rich shales following. The Naparima Hill and the Gautier Formations, an organic-rich clay and bedded sandstone and siltstone, respectively, make up the source rock for the Columbus and Southern Basins (Garciacaro (A) et al. 2011).

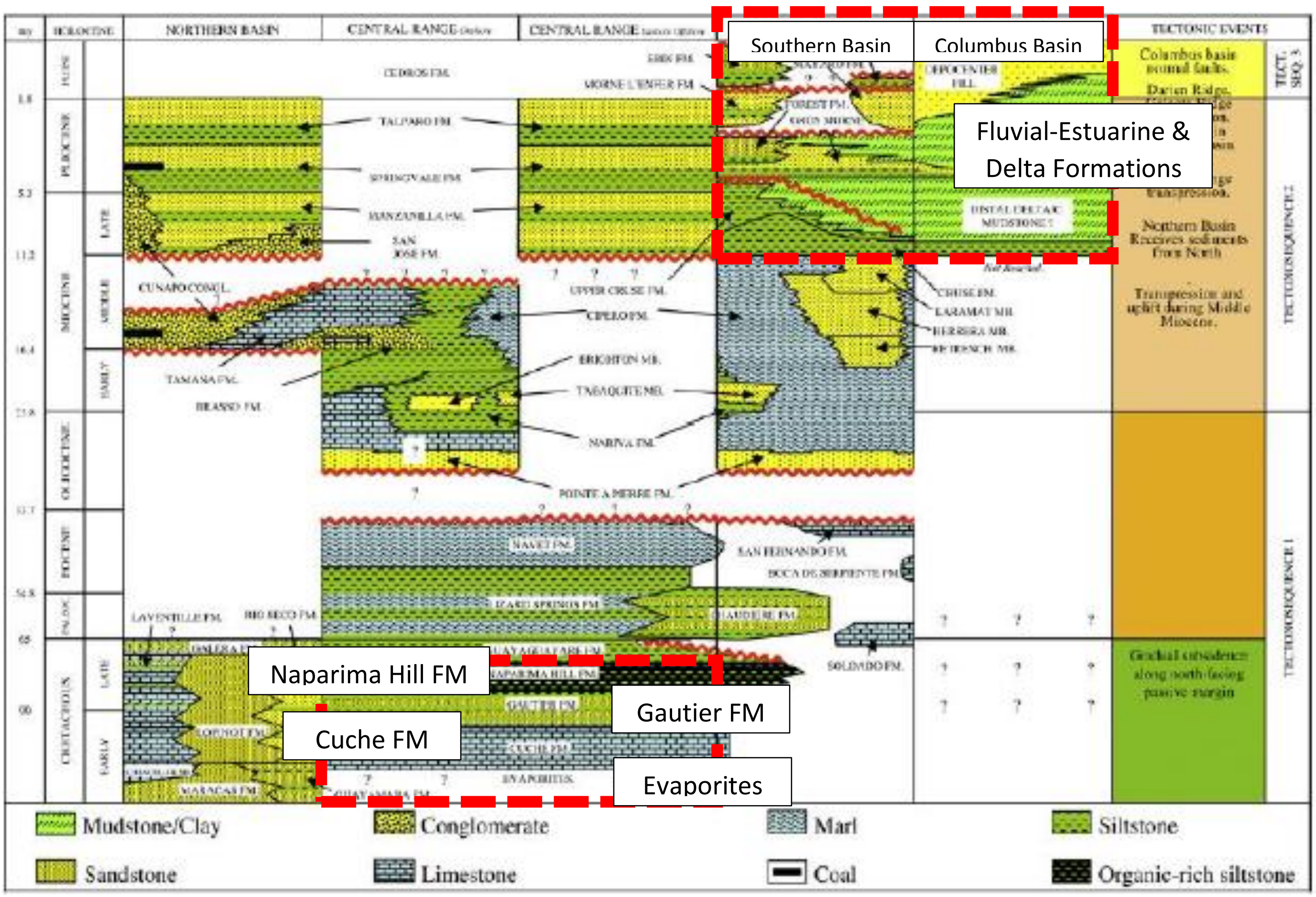

Figure 3. Stratigraphy of the Southern and Columbus Basins. The Cretaceous source rocks, and the delta sediments are highlighted by the red dashed lines (Garciacaro (A) et al. 2011).

Basin fill sedimentation during the Miocene to Early Pliocene are defined as tectonic sequence two (S2). Transpression, which refers to oblique compression, commenced uplift in the Middle Miocene, leading to a change in sedimentation and the formation of the main reservoirs for both the Columbus and Southern Basin. In stratigraphic order, these reservoirs are identified as the Cruse, Gros Morne, Morne L'Enfer and Forest Formations. The Cruse Formation lays unconformably on deformed marine clays of the

Lengua Formation, that were folded and thrusted prior to deltaic sedimentation. Commencement of the paleo-Orinoco delta formation is suggested to have been recorded through the clay-rich sediments of the Cruse Formation (Garciacaro (A) et al. 2011).

Quaternary basin fill describes tectonic sequence three (S3). The Mayaro Formation represents progradation of paleo-Orinoco deltaic sediments into the Columbus Basin. Present day uplift of the Southern Basin commenced in the Pleistocene, due to the eastward migration of the suture axis, and has exposed the shallow marine and deltaic facies of the Gros Morne and Mayaro Formation in the south of Trinidad (Garciacaro (A) et al. 2011).

Depositional Environments

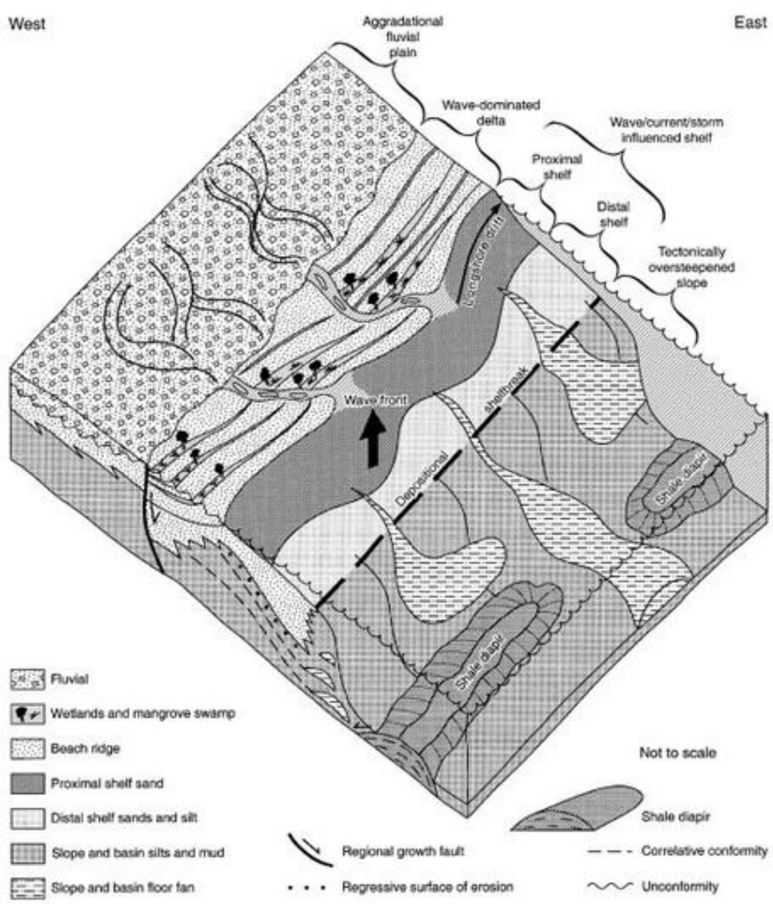

Figure 1. Paleogeography of the lowstand paleo-Orinoco Delta in the Pliocene and Pleistocene. Fluvial, sub-aerial, delta, shelf, slope and distal depositional environments are depicted (Wood, 2000).

Throughout the late Neogene, the wave dominated paleo-Orinoco Delta prograded onto a shelf that was influenced by storms and currents. Throughout the Neogene and Quaternary, the Orinoco Delta migrated eastward, with the uplift of western regions. Aggradation of deltaic sediments dominated as accommodation increased in the basins (fig. 4). The upper six kilometres of the Columbus Basins sediments are characterized by fluvial and deltaic deposits. These depositional facies record mass transport distributary and leveed channel sediments which allows for quality hydrocarbon reservoirs to form (Garciacaro (A) et al. 2011).

Fluvial and estuarine depositional environments consist of either tidally influenced sediments or subaerially. Depositional features in these environments include: flood plains, swamps, sand bars, lagoons, beaches, marshes, and tidal flats (fig. 4). Sediments from these deposits usually vary up section, transitioning from fine silts to sandier units, as their deposition is controlled by the sea level and position of the coast. These contribute to complex reservoir deposits that effect the movement of hydrocarbons and effect the efficiency of reservoirs (Wood 2000).

The deep-water slope is characterized by five main structural elements. The northern edge Darian Ridge fold-thrust belt confines the deep-water basin, the mud-volcanoes create bathymetric highs that divert sedimentation into confined channels, anticlines caused by faulting create increased relief on the seafloor, minor shelf-ward half-grabens create depositional areas, and finally normal counter slope faulting that allows for further subsidence. These structures control the accumulation of sediments and the slope deposition features (Wood 2000).

Reservoirs of the Columbus and Southern Basins

Deltas of the past are studied extensively due to their frequent creation of various parts of petroleum systems. High volumes of sand and silt sedimentation in deltaic depositional environments leads to the formation of potential reservoir rocks (Wescott 1992). This large amount of sediment inputted into the basin is transported away from the delta face by marine processes, which greatly impacts exploration of basin-ward and adjacent facies. Deltas are linked to large accumulations of organic matter, resulting in a possible source rock component of both a conventional and unconventional petroleum system. The sub-aerial portion of a deltaic system, of swamps and/or marshes, may accumulate high volumes of terrestrial organic matter. These can then be preserved as “peats, lignites, [or] coals” (Wescott 1992). These high organic matter intervals can produce substantial gas sources with sufficient maturation. The sub-aqueous portion of a delta may also be a significant source of organic production. The delta front includes deposition of fine sediment, while also encouraging a build-up of plankton from the mixing of fresh and saline waters. These are two important factors in the deposition of a source rock. Gradational and abrupt changes in sediment types lead to favourable conditions for the formation of a petroleum system. The large amount of sediment that accumulates and the high subsidence rates at deltaic sites lead to possible faulting and movement of underlying units which create migration pathways that are needed for a reservoir to accumulate hydrocarbons (Wescott 1992; Sedore 2014).

Approximately one and a half billion barrels of oil have come from the Southern Basin, with another one billion barrels of oil and ten trillion cubic feet of gas coming from the Columbus Basin. Hydrocarbon migration pathways in the Columbus Basin are thought to be caused by at large basinal normal faults. (Wood, 2000). Miocene and Pliocene reservoirs of the Southern Basin are accessed through faulted Miocene stratigraphy. These reservoirs are made up of immature litharenites. These are characterized by subrounded, fine to lower medium grains that show evidence of sediment recycling. They deltaic sediments are a part of a proven hydrocarbon system in both the Columbus and Southern Basins (fig. 5). The deep water reservoirs of the Columbus Basin include distributary channel, leveed channel, and confined channel complexes (Gibson 2003).

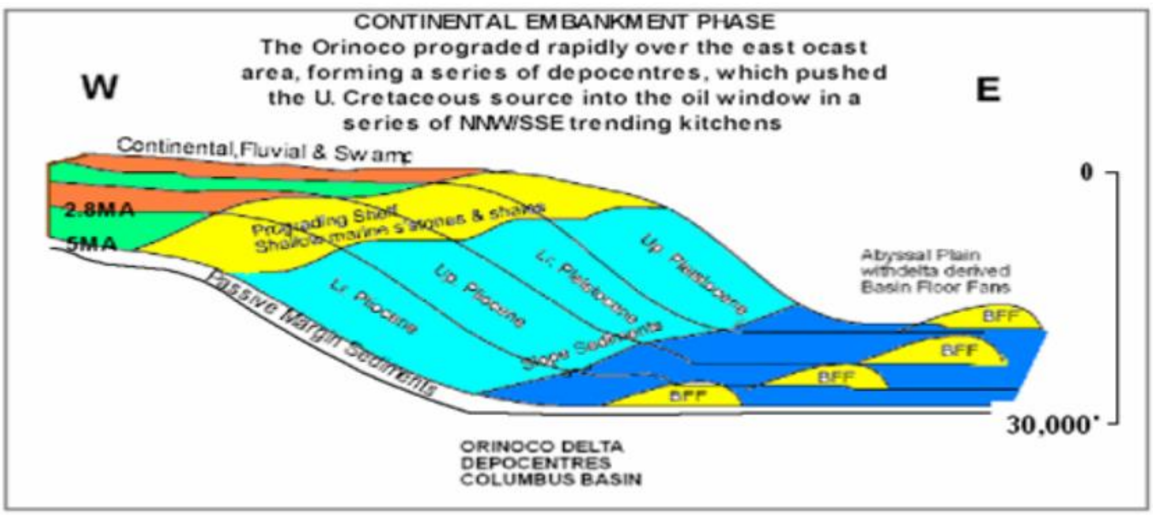

Figure 5. A schematic diagram of the paleo-Orinoco Delta prograding over the east coast shelf, forming depocentres, which pushed the upper Cretaceous source into the oil window (Ritson, 2014).

Wach and Vincent provide a detailed analysis of an onshore exposure of the Upper Morne L'Enfer Formation. This is used as an analogue to sub-surface deltaic facies of the Columbus and Southern Basins. There are proven heavy oil and oil sand occurrences in these outcrops which can be used to determine the grade of heterogeneity and how it effects hydrocarbon migration and compartmentalization (Wach, 2008). The Morne L'Enfer Formation represents late stage deltaic, shallow water sedimentation. The five member Formation overlies the Forest and Cruse Formations. The five memebrs include: Upper Forest clay, Morne L'Enfer silt, Lower Morne L'Enfer sandstone, Lot 7 silt, and the Upper Morne L'Enfer sandstone. These members, being either permeable or impermeable, effect the transmission of fluids through the reservoir and the effectiveness of any present seals (Wach, 2008).

Scotian Basin Comparison

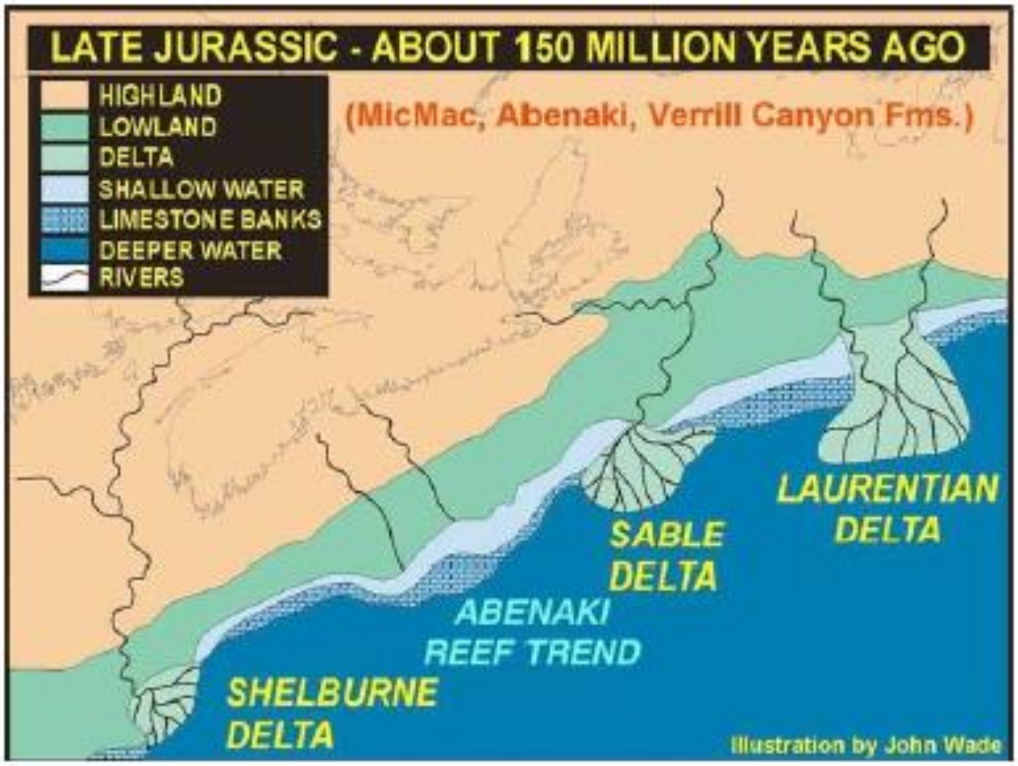

Figure 6. A depiction of the Late-Jurassic in the Scotian Basin. The three main, Shelburne, Sable, and Laurentian Deltas are seen overwhelming the Abenaki Formation (CNSOPB 2014)

The Scotian Basin petroleum systems were formed during the opening of the Atlantic Ocean. The reservoirs of these systems are also deltaic in origin, and have many similarities. The tectonic sequences that initiated basin formation are distinctly different, but the importance of delta systems remains. The basal red beds of the Scotian Basin and evaporates of Trinidad were both formed as the continents subsided in response to increased tectonism (Garciacao, 2011; CNSOPB, 2014). Retrogradational sedimentary sequences followed these deposits, and include both clastic sediments, organic-rich shales and shallow water to deep water limestones. The paleo-Orinoco Delta distributed sediment in a similar way as the Shelburne, Sable and Laurentian Delta leading to similar hydrocarbon reservoirs (fig. 6). Ancient deltas of the Scotian Basin were widespread and drained the western highlands that formed through westward extensional divergence of the North American plate. Comparable seaward formations formed in both the Columbus, Southern and Scotian basins. These are made up of shales that are interbedded with siltstones, limestones, and sandstones. Although they formed under differing tectonic regimes, the deltas of the Scotian Basin and the paleo-Orinoco Delta have analogous features that contribute to both being hydrocarbon reservoir forming deposits (Garciacao, 2011; CNSOPB, 2014).

Conclusion

Oblique collision of the Caribbean plate with the northern edge of the South American Plate lead to an eastward migration of a foreland basin that initiated fluvial-estuarine and deltaic sedimentation along the coast. Formation of a foreland bulge and lithostatic loading of sediments added to accommodation space in the basins, which allowed for further subsidence and accumulation of more than 12 km of sediment. The paleo-Orinoco Delta deposited laterally continuous sediments in the Columbus and Southern Basins. These deltaic deposits form the reservoirs of petroleum systems in the region, and accumulate hydrocarbons from source rock through migration along faulting in the marine sediments. The deltas of the paleo-Scotian Basin are comparable through depositional environments and sediment type, although the formation of the basins are quite dissimilar and consequently differing effects on delta migration and sedimentation follow.

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