A Review of the Tectonics of the Deep Water offshore Trinidad/Tobago; Implications for Hydrocarbon Potential
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Introduction:

Historically, the deep waters offshore Trinidad and Tobago have remained under explored due to a variety of constraints (but not limited to): geologic complexity, distance from onshore / near shore infrastructure and activities, astronomic costs of deep water operations, tight fiscal regimes and legal framework (geared for shallower water) and the availability of antecedent good quality reconnaissance seismic data.

This paper demonstrates how improvements in image technology and seismic processing workflow design permitted better constraints upon extrapolating shallow water exploration potential seaward towards the ultra-deep. Under a Speculative Agreement, a recently reprocessed vintage data set acquired in the ultra deep water to the East and North East of Trinidad/Tobago has improved the industry understanding of this hydrocarbon province. We expect that renewed understanding of the geologic opportunities now observed when combined with favorable government fiscal terms should encourage renewed industry interest in this hydrocarbon province.

Seismic data:

The Trinidad and Tobago Deep Atlantic Area 2D Survey (TTDA 2D) used in the analysis presented here was originally acquired in 2002 to support a future licensing round (Figure 1). The seismic vessel SR/V New Venture (Veritas) used a 6000 meter cable programmed for 240 channels at 25m group intervals with a total record length of 9 seconds.

Based upon exploration interest in the area, Spectrum has revisited the original data processing using more modern seismic techniques and a geologically driven imaging workflow. Given the high quality of the raw data, reprocessing has proven successful in imaging deep structures down to 6 seconds. While the original processing sequence was limited to time imaging, the newly re-processed data includes both Kirchhoff pre-stack time and Kirchhoff pre-stack depth imaging products.

Geologic Driven Seismic imaging:

The re-imaging effort applied by Spectrum is based upon a geologically driven workflow described in Stieglitz (2011). The geologic driven model building of complex structures involves imaging in stages where imaging and model building are conjugate pairs. The modern seismic processing workflow often includes several iterations of analysis to build the smooth base-line stacking velocity field. Care is required to correlate geologic features with seismic reflectivity in order to capture lateral base-line variations, predicated upon known geology and log analysis (where available).

In preparing the data for the geologic driven world, we seek amplitude friendly operators to remove undesired coherent and incoherent signal such as swell noise and cable strum. Although there is no such thing as “true amplitude” processing, we can begin with relative processing operators which preserve the overall bulk properties of the local seismic reflectivity.
The derived background velocity trend is then used as the guiding function for more detailed depth imaging analysis. Restraint must be applied to resolving faults, erosional surfaces, or even sequence boundaries using guide horizons where a local grid based solution is desired. Many false starts may be necessary before a proper solution is found which satisfies regional and sub-regional geologic trends. The geologic driven approach applied to the Trinidad data relies on the seismic data itself to dictate the spatial and temporal limitations imposed by the field acquisition operator.

In expanding the regional time-RMS based velocity trend to a more local tomographic driven depth-interval model, care must be applied to ensure that the imaging operator used to generate the input ensembles for tomography match the operator employed for the simultaneous inversion. More often than not, casual assumptions are made to account for differences between the imaging and model building operators. For example, the operator employed in the tomography may be based on isotropic Kirchhoff theory, while the imaging may be based upon reverse time migration (RTM). Such incongruities between model building and imaging may be overcome with a priori care in establishing good ground rules for data resolution expectations.

Figures 2a and 2b provide an example of the original imaging and an example of the improved imaging by Spectrum/GeoServe.

Two major geological differences influenced the revised Spectrum workflow. The presence of mud or shale diapirism in Trinidad is the inverse for salt diapirism in Gulf of Mexico. While both shale and salt tend to be less dense and forced to shallower layers tectonically, their seismic velocity properties are opposite. Where salt velocity is fast, the seismic velocity through shale and mud is much slower. In particular, the kinematic properties of fluidic shale sediments are extremely effective at attenuating energy; the soft internal impedance boundaries generate an appearance of “lightened” reflectivity as seen on the right of figure 2a. In terms of imaging, low impedance shales typically are much slower than surrounding sands and carbonates; deeper, the velocity trend will speed up closer to proto rift sequences and oceanic basalt. These regional perturbations in the seismic velocity trend were introduced in the updated Spectrum imaging flow in order to minimize over migration of seismic events.

Figure 2b demonstrates the uplift of the “geologically driven” imaging workflow combined with improved pre-processing. The SRME and Radon demultiple techniques applied in the near and far offset data respectively helped to reduce the water bottom and inter-bed multiple events. The final imaging result is a cleaner product with higher frequencies and a greater bandwidth. There is an especially noticeable improvement in some of the deeper reflectors which are now more continuous. The improved reflectivity of the imaging supports easier interpretation of prism structures, stratigraphic plays and three way dip closures. Especially interesting are some near perfect four way dip traps which are seen in the anticlinal part of the shear fault bend folds between mini-basin complexes.
Regional Tectonic Discussion

The geology of the Trinidad and Tobago region is rendered complicated as it lies at the juncture between the North/South American and Caribbean plates. This complex region has experienced multiple episodes of extensional, compressional and transtensional stresses, (Figure 3). Care must be taken in deconstructing the seismic images on a regional basis to draw macro-scale conclusions about the tectonic history and basin evolution.
To understand the geologic history of the offshore Trinidad and Tobago region it is important to place the motions of the plates within a mantle framework (Figure 4). This is accomplished by locating geologic evidence of hotspot activity through time and fixing those positions on the map. The result illustrates that the westward dipping Lesser Antilles subducting slab is fixed by the mantle as the North/South American plate translate rapidly around it. This created an accretionary prism at the leading edge of the Caribbean Plate and an extensional regime which caused the formation of backarc basins and other trans-tensional features to the west of the leading edge.
The basement of the Trinidad and Venezuela region was initially formed during the rifting North America and Africa in the Triassic (Figure 5). At this time the continental crust beneath Cuba formed a part of the North American craton and was located offshore Trinidad and eastern Venezuela. The northern margin of Trinidad was a strike-slip margin that accommodated the northward movement of North America and Cuba. Onshore, arkosic quartz arenites and conglomeratic limestones were deposited along the coast. Contemporaneously 200 to 5000 feet of shale was deposited on the attenuated continental crust and newly formed oceanic crust.
This continued until the Mid-Cretaceous when the mid-Atlantic spreading center passed by the margin forming the original oceanic crust in the region. Sedimentation during this period was characterized by low siliciclastic influx on the margins with small localized marly layers. Offshore, during anoxic conditions thick source rocks formed during the Coniacian-Santonian (Gautier Fm), and Maastrichtian (Guayaguaire Fm.).
More than 1500 kilometers away in the Pacific, the eastern margin of the Caribbean Plate was forming a westerly dipping subduction zone. The associated calc-alkaline volcanism formed the early stages of the Lesser Antilles (Tobago and Barbados) island arc system. The southern margin of this arc formed a transtensional strike-slip contact with the South American craton. Occasionally, during lowstands of sealevel the southern margin of the arc system received continental derived arkosic sandstones in the form of turbidite deposits shed off the South American craton. This continental derived sediment was deposited in forearc basins and in the trench of the accretionary prism.

During the Late Paleocene-Eocene-Oligocene-Miocene east-west striking thrust faults developed in the Trinidad region as North America and South America began to converge. To the south of the Lesser Antilles arc system, South America was sliding passed at approximately the margin of Colombia at a modest rate of 10 mm/yr. Erosion and sedimentation was relatively slow, developing a progradational shoreface with some carbonate bank development. By the late Miocene the region of Trinidad was passing by the southern end of the Lesser Antilles arc system.

Beginning approximately 10 Ma the African plate became relatively fixed with respect to the mantle when it could not move closer to Europe. All of the spreading occurring along the mid-Atlantic ridge had to be accommodated along the Pacific/Nazca/Caribbean and North America/South America plate boundaries. A doubling of the westward velocity (to 20 mm/yr) of South America and North America forced the South American plate to ride on top of the Nazca Plate in the Pacific. This caused the Andean mountain range to uplift. By 4 million years ago a dramatic increase in the siliciclastic sediment influx rate occurred in the Trinidad region as large volumes of sediment from the newly uplifted highlands was transported down the Orinoco and Amazon Rivers. This created rapidly filling basins with overpressured shale (Figure 6). This overpressured shale may have been generated in part as the prolific Albian source rock (Gautier Formation in Trinidad, equivalent to the La Luna in Venezuela and Colombia) passed through the oil window and into the gas window. The overpressured shale became mobile forming diapirs, and mud volcanoes (many of which expulse hydrocarbons). This recent sediment influx has driven burial and maturation of the source rock in the region, which has lead to the expulsion and trapping of the majority of more than 13 tcf of gas and 600 mmbo of oil in the basin discovered in the basin. The core of the accretionary prism became highly deformed and intruded with shale diapirs during this time.

![Regional Seismic Line through the accretionary prism, Diapir - Mud-Volcano Province, and Subsiding Province.](image-url)
At present, the North/South American Plates are moving 20 mm/year in a westerly direction, whereas the Caribbean Plate is stable with respect to the mantle. The southern boundary of the Caribbean Plate (Figure 7) is in contact with the South American Plate and accommodates this motion by a system of dextral shear parallel to the Central Range Fault in Trinidad, and the El Pilar Fault in Venezuela. Extensional detachments are also present south of these faults in onshore Venezuela and offshore Trinidad.

The eastern boundary of the Caribbean Plate is an accretionary prism that is accumulating above the subducting oceanic crust of the North/South American Plate (Figure 5). This plate is subducting into stationary mantle creating a dominantly tensional environment on the west side of the subduction zone. As the North/South American plate slid westward, the Caribbean Plate experienced distributed extension, and volcanic thickening. Locally, much of this extension is present in the trans-tensional structures of the Columbus Basin, backarc spreading and the formation of the Grenada Island Arc. The trench of the Lesser Antilles subduction zone became a deepwater repository for much of this sediment influx as it localized the Orinoco Submarine Fan. The accretionary prism above the subducting slab was also shortening and thickening at twice the rate since the beginning of the Pliocene.
Conclusions

The re-imaging and interpretation of the vintage data described here has permitted an expanded understanding of the underlying tectonic forces that have shaped the evolution of the deep water structures offshore Trinidad/Tobago. We believe that this tectonic discussion on the evolution of the Eastern Caribbean is very timely given the new industry interest in developing the pan-Atlantic conjugate margin petroleum system.

It was through the efforts of the Government of the Republic of Trinidad and Tobago and Spectrum that a Multi-Client initiative was successfully executed and immediately brought renewed interest in the Deep Waters. The importance of this project was incalculable and was and is used as a default workflow in de-risking the TTDAA defined blocks by many existing and potential clients.

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References