Hydrocarbon potential of source rocks from Trinidad to Guyana: An application of Ultimate Expellable Potential (UEP) acme modeling

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Summary

In this study, we model the Ultimate Expellable Potential (UEP) of million-year intervals (acmes) of Cretaceous source rock in the hydrocarbon-rich area of Trinidad and Guyana (Fig. 1). Previous approaches to source rock modeling have focused on applying a single organic parameter, such as Total Organic Carbon (TOC) or Organic Carbon (C_{org}), to a lumped lithostratigraphic formation (Cooles et al, 1985). This is problematic for the source rocks in this area, like the middle to Late Cretaceous Naparima Hill, Gautier, or Canje Formations, whose geographic extent and geochemical composition vary both laterally and vertically (Erlich and Keens-Dumas, 2007).

The updated UEP modeling methodology takes into account both variations in the organic content of the source rock and the total thickness of the source rock section. The back-calculated TOC, Hydrogen Index (HI), and thickness of individual acmes is used to calculate the UEP of intervals that compose the entire source rock.

Regional tectonics and basin development in Trinidad and the Guyana-Suriname Basin likely explain the similarities and slight differences between the source rock potential in the two regions. Both areas formed along a single Jurassic-Cretaceous rifted-passive margin during the opening of the Central Atlantic Ocean. The outer areas of Guyana margin also experienced shearing related to the early Cretaceous opening of the Equatorial Atlantic Ocean and the Trinidad area experienced middle Miocene to recent deformation associated with the eastward migration of the Caribbean Plate (Fig. 1).

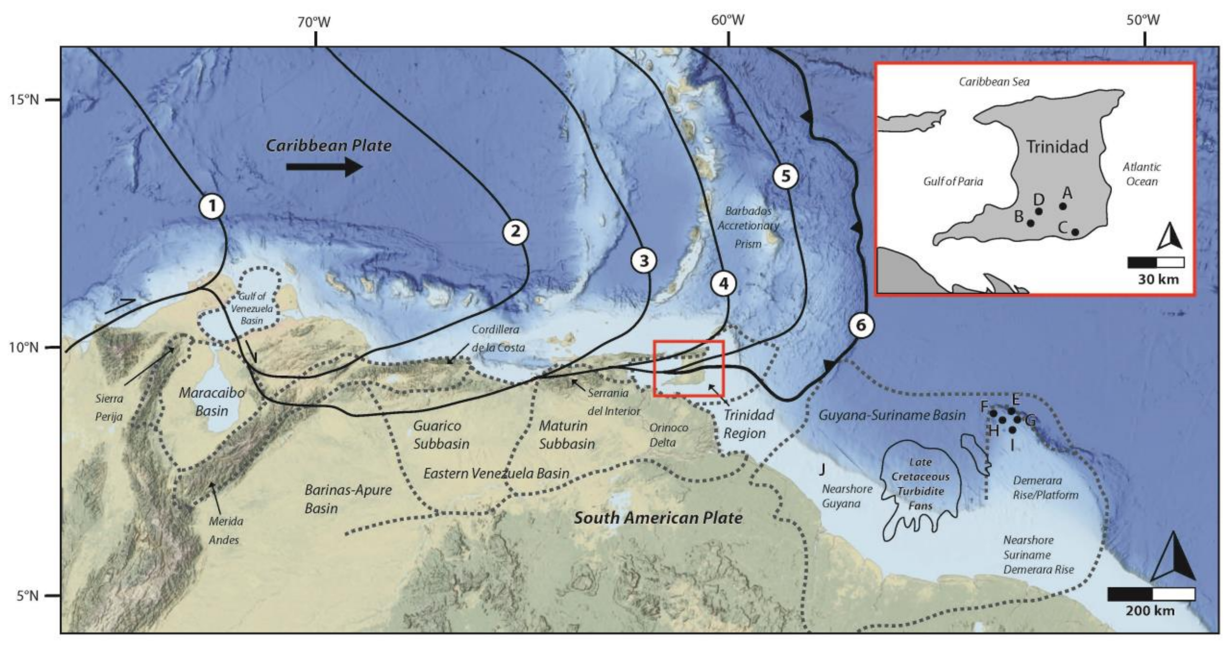

Figure 1: Plate boundaries and basin names in the study area of Trinidad, Guyana, Suriname, and the Demerara Rise. The white, circled numbers 1-6 show the leading edge of the eastwardly-moving Caribbean plate at these time intervals based on Escalona and Mann (2011): 1) Paleocene; (2) middle Eocene; 3) Oligocene; 4) middle Miocene; 5) Pliocene; and 6) Present-day. The wells used for UEP modeling are labeled A-J and include: A) Marac-1; B) Morne-Diablo-34; C) Moruga East-15; and D) Moruga West-45 in the Trinidad region and E) IODP 1257, (F) IODP 1258, (G) IODP 1259, (H) IODP 1260, (I) IODP 1261, and (J) 'Well 1' in the Guyana Basin and on the Demerara Rise.

Methods

A hybrid litho- and chronostratigraphic column was constructed across the Trinidad-Guyana area using local stratigraphic columns, well log data, and paleoenvironmental information (Fig. 2). All sources of stratigraphic data are provided in the caption for Figure 2.

The term 'acme' refers to a moment of maximum deposition, while the 'acme time interval', equivalent to one million years, is defined as the interval which encompasses each acme. The UEP approach begins with the descriptions of type localities of individual source rock deposition and a correlation with age-equivalent rocks.

The next step was to collect TOC, HI, and the thickness of intervals (secondarily defined by age) throughout the study area. The well data and UEP modeled in the Guyana margin were modified from data provided by This !s Petroleum Systems, LLC. UEP modeling in the Trinidad region was based on results from Requejo et al. (1994).

In order to identify acmes which represent significant organic deposition and preservation, the measured TOC and HI values for each sample were used to back-calculate the original TOC and HI at deposition. Inorganic parameters, such as S and Al_2O_3, were also used to differentiate organofacies of the source rock kerogen. The Standard Thermal Stress (STS) was calculated for each individual sample to evaluate overall thermal stress specific to organofacies classification (Pepper and Corvi, 1995). The final step was to model the preliminary UEP – or 'areal yield expelled' - of each age interval using Kinex Software (Zetaware).

Results

The results of UEP modeling completed from ten individual wells in the Trinidad-Guyana-Suriname area show that the eight Late Cretaceous geologic intervals exhibit variable hydrocarbon potential (Fig. 3). As we are presently working to access samples that will allow a high resolution evaluation of the Trinidad region, an assumption is made that the geochemical quality of the rocks is held constant throughout each geologic age. This assumption allows a preliminary, qualitative comparison between the Trinidad region and the Guyana Basin (additional explanation can be found in the Fig. 3 caption):

1) **Maastrichtian section (70.6-65.5 Ma)** in the Southern Basin (Trinidad) shows measurable UEP in the Morne Diablo-34 well. This interval cannot be compared to Guyana because of the lack of data from this same time interval.
2) **Campanian section (83.5-70.6 Ma)** shows UEP values in the Marac-1 and Moruga East-15 wells in Trinidad but cannot be compared to the wells in Guyana because of the lack of data from this same time interval.
3) **Santonian section (85.8-83.5 Ma)** shows no significant hydrocarbon potential in Trinidad with the exception of the Marac-1 well and shows a high UEP in a single well (IODP 1261) on the Demerara Rise.
4) **Coniacian section (89.3-85.8 Ma)** shows UEP values at all well locations in both Trinidad and Guyana with the exception of Moruga West-45 in the Southern Basin of Trinidad. A direct comparison of this area with the Coniacian section in IODP 1258 on the Demerara Rise cannot be made because the same geochemical parameters were not recorded from IODP 1258. However, all remaining wells in the Guyana Basin indicate significant UEP during the Coniacian.

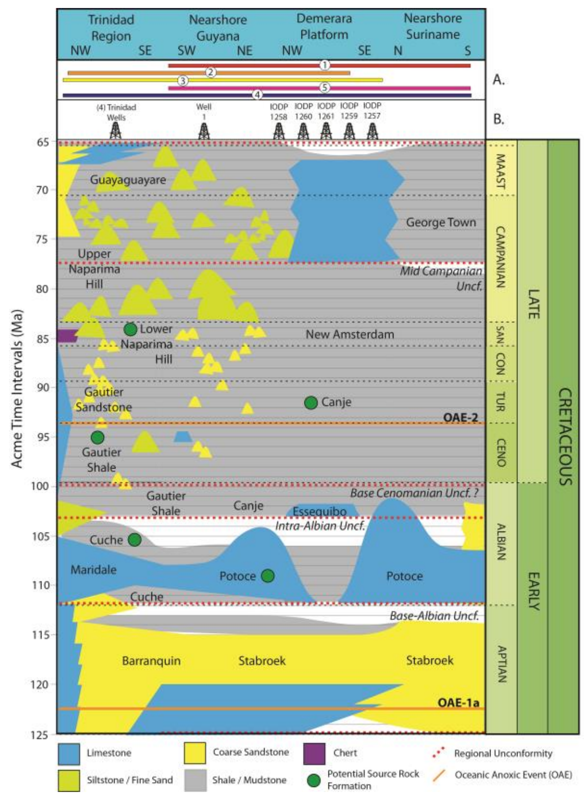

Figure 2: Hybrid litho- and chronostratigraphic column for the areas of the Southern Basin of Trinidad, nearshore Guyana, Demerara Platform, and nearshore Suriname as shown in map view on Figure 1. The most widely accepted source rocks from previous studies are shown by the green circles. The green circles identify source rock formations but do not denote the specific acme time intervals which show significant potential for the generation of hydrocarbons. The lateral extent of the data sources used to create the chart are shown by the numbered and colored lines in A: 1) Casson et al., 2021; 2) Cedeño et al., 2021; 3) Di Croce et al.,1999; 4) Yang and Escalona, 2021a; and 5) Yang and Escalona, 2021b. The individual wells used for UEP modeling comparison are shown in B, including the four wells from the Southern Basin of Trinidad: (1) Marac-1, (2) Morne-Diablo-34, (3) Moruga East-15, and (4) Moruga West-45.

5) **Turonian section (93.5-89.3 Ma)** shows hydrocarbon potential across the study area although in Guyana, it is consistently less than the Coniacian section.
6) **Cenomanian section (99.6-93.5 Ma)** is commonly cited as the most significant interval for source rock potential in northern South America, yet shows inconsistent hydrocarbon potential Trinidad. In Guyana, only a single well on the Demerara Rise displays a Cenomanian section with high UEP values (IODP 1261).
7) **Late Albian (~103.0-99.6 Ma)** does not show measurable hydrocarbon potential in most wells from the Trinidad region. Only two wells in Guyana (Well 1 and IODP 1258) show any UEP, likely due to cycles of non-deposition during this time interval.
8) **Early Albian (112.0-103.0 Ma) and Aptian (125.0-112.0 Ma) sections** were not a significant time intervals for this study. However, it should be noted that in any wells where these intervals were penetrated, gas-dominant hydrocarbon potential was recorded – due to insufficiently sequestered hydrogen.

Discussion

The pattern of Cretaceous organic deposition in Trinidad and Guyana also indicates similar transitions between organofacies. In Trinidad, all samples were evaluated based on the Al_2O_3/TOC, Fe/S, and Th/U ratios compiled from Requejo et al. (1994). These data show a transition from Organofacies B in the lower Cenomanian (Gautier Fm.) to Organofacies A in the Santonian Section (beginning lower Naparima Hill Fm.). An evaluation of the Canje Formation in the Guyana-Suriname Basin shows the same transition from Organofacies B to A near the Turonian-Coniacian boundary. Based on the similar distribution of total potential and the transition in organofacies occurring at roughly the same time, we infer similar paleogeographic conditions along the Guyana and Trinidad passive margins are responsible for deposition and preservation of organic matter in both areas. The exception to this shared pattern of deposition and preservation is the interval that includes the Cenomanian-Turonian boundary. The commonly cited mechanism for the regional deposition and preservation of these source rocks is widespread magmatic activity related to the Caribbean Large Igneous Province (LIP) and subsequent onset of the Oceanic Anoxic Event at 93.6 Ma (OAE2) (Bergman et al., 2021).

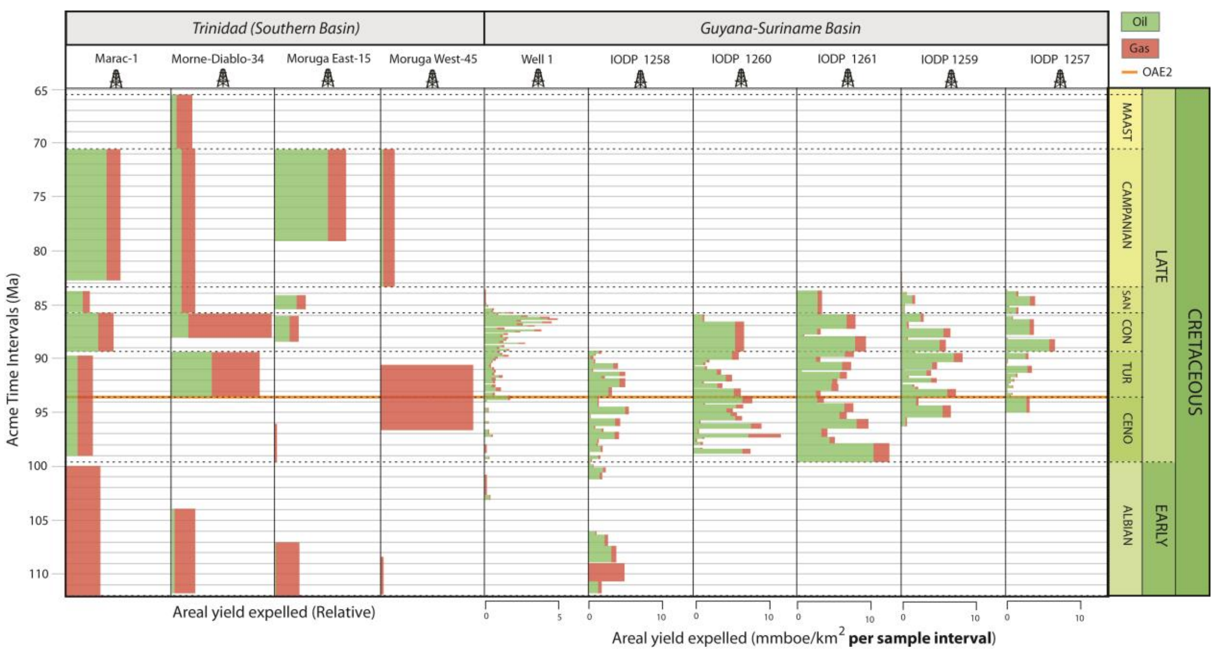

Figure 3: Ultimate Expellable Potential (UEP) modeling for four wells in the Trinidad region and six wells in the Guyana-Suriname basin. The wells in the Guyana region are currently modeled with a sufficient number of samples per geologic age. Because of this, their areal yield expelled can be described quantitatively. The available dataset in Trinidad is not as large. Therefore, fewer samples were used to model the areal yield expelled and assumptions were made about this consistent nature of organic parameters throughout each geologic age. This preliminary assumption has been made so that a relative comparison to Guyana may be completed. Therefore, the areal yield expelled in Trinidad is considered in a qualitative, or relative, sense. (Guyana UEP adapted from data provided by This !s Petroleum Systems, LLC.)

We propose more localized and non-OAE mechanisms at the Cenomanian-Turonian boundary based on these observations: 1) the variable organic and lean character of the source rocks in Trinidad (Fig. 3); 2) the inconsistent organic richness in Guyana (Fig. 3); and 3) recent studies which model the geographic upwelling effects related to OAE2 (Bergman et al., 2021); and 4) qualitative environmental paleogeography mapping of Trinidad and Guyana near the Cenomanian-Turonian boundary which indicates a deeper-marine environment during the deposition of the Cenomanian Canje Formation and a nearshore to shelf slope environment during the deposition of the Cenomanian Gautier Formation in Trinidad (Erlich and Keens-Dumas, 2007). This age geometry of the passive margin may suggest that more anoxic conditions (and subsequent preservation of organic matter) existed in Guyana and that more oxic to suboxic conditions existed in Trinidad, and were less favorable for preservation of organic material.

Conclusions

UEP modeling is used to estimate the hydrocarbon potential for discrete time intervals - or acmes - of Cretaceous source rock deposition in the deformed Trinidad Southern Basin and the Cretaceous-Cenozoic passive margin of the Guyana-Suriname Basin. While the two regions show similar patterns of source rock potential and a transition in organofacies at similar points in time, the Cenomanian-Turonian section shows minimal hydrocarbon potential in the Trinidad region and variable potential throughout the Guyana-Suriname Basin. We propose that source rock potential in both areas is unrelated to OAE2, and more likely related to localized, paleogeographic variations along the single rifted-passive margin between Trinidad and Guyana.

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Sub Category:

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References:

Bergman, S.C., Eldrett, J.S., and Minisini, D., 2021, Phanerozoic Large Igneous Province, petroleum system, and source rock links, in Ernst, R.E., Dickson, A.J., and Bekker, A., *eds.*, Large Igneous Provinces: A Driver of Global Environmental and Biotic Changes: Geophysical Monograph 255, p. 191-228.

Casson, M., Jeremiah, J., Calves, G., de Ville da Goyet, F., Reuber, K., Bidgood, M., Rehakova, D., Bulot, L., and Redfern, J., 2021, Evaluating the segmented post-rift stratigraphic architecture of the Guyanas continental margin: Petroleum Geoscience, v. 27-3, p. 1-27.

Cedeño, A., M. Ahmed, A. Escalona, and P. Abrahamson, 2021, Tectono-stratigraphic evolution of the western Barbados Accretionary Prism and the Tobago Basin: Implications for petroleum systems, in C. Bartolini, *ed.*, South America– Caribbean–Central Atlantic plate boundary: Tectonic evolution, basin architecture, and petroleum systems: AAPG Memoir 123, p. 649–676.

Cooles, G.P., Mackenzie, A.S., and Quigley, T.M., 1985, Calculation of petroleum masses generated and expelled from source rocks: Organic Geochemistry, v. 10, p. 235-245.

Di Croce, J., Bally, A., and Vail, P., 1999, Sequence stratigraphy of the Eastern Venezuelan Basin, in Mann, P. and Hsu, K.J., *eds.*, Sedimentary Basins of the World, Elsevier Science B.V., Amsterdam, v. 4C, p. 419-476.

Erikson, J.P., 1994, A lower Cretaceous shelf and delta in the Eastern Venezuela Basin: Conference Proceedings, 5th Simposio Bolivariano - Exploracion Petrolera en las Cuencas Subandinas. Puerto la Cruz, Venezuela.

Erlich, R.N., and Keens-Dumas, J., 2007, Late Cretaceous palaeogeography of the northeastern South America: Implications for source and reservoir development: Conference Proceedings for 4th Geological Society of Trinidad and Tobago, Caribbean Exploration – Planning for the Next Century. Port of Spain, Trinidad.

Escalona, A., and Mann, P., 2011, Tectonics, basin subsidence mechanisms, and paleogeography of the Caribbean-South American plate boundary zone: Marine and Petroleum Geology, v. 28, p. 8-39.

Pepper, A.S. and Corvi, P.J., 1995, Simple kinetic models of petroleum formation, Part I: Oil and gas generation from kerogen: Marine and Petroleum Geology, v. 12, p. 291-319.

Pepper, A. and Roller, E., 2021, Ultimate expellable potentials of source rocks from selected super basins: What does “world class” look like?: AAPG Bulletin, v. 105, n. 6, p. 1069-1097.

Requejo, A.G., Wielchowsky, C.C., Klosterman, M.J., and Sassen, R., 1994, Geochemical characterization of lithofacies and organic facies in Cretaceous organic-rich rocks from Trinidad, East Venezuela Basin: Organic Geochemistry, v. 22, p. 441-459.

Yang, W. and Escalona, A., 2011a, Basin modelling and source rock evaluation in the Guyana Basin: EAGE First Break, v. 29, p. 17-27.

Yang, W. and Escalona, A., 2011b, Tectonostratigraphic evolution of the Guyana basin: American Association of Petroleum Geologists Bulletin, v. 95, p. 1339-1368.