The Cretaceous source rocks from East Venezuela – Trinidad-Guyana/Suriname basins, NE South America

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Actus Veritas Geoscience, LLC

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Abstract

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The major contribution to the oil fields in East Venezuela and Trinidad are Cretaceous source rocks, Late Albian – Santonian in age. The Querecual Formation, from the Guayuta Group, is the source rock of the oil and gas from the giant and super giant oil fields like Carito, Furrial_Musipan, Quiriquire, Great Oficina, Anaco Trend, and Santa Barbara oil fields, among others. The Orinoco Belt huge deposits of oil are aromatic-asphaltic oils biodegraded interpreted as originated in organic rich carbonate sediments, with some components of siliciclastic, deposited in an anoxic environment as the one described for the Querecual Formation at the type section and outcrops around the Pozuelos Bay, northern Anzoátegui state, southwest of the Cariaco Basin.

Studies at the type section of the Querecual Formation described black shales, limestones and marls, rich in foraminifers and other macrofossils, which were used to identify biostratigraphic zones from late Albian to Santonian, and a hiatus at the early Cenomanian. Paleowater depths were interpreted as middle to upper bathyal (based on microfossils content). Mainly microlaminated foraminiferal microfacies were linked to anoxic-dysoxic levels. Total carbon (TC), Total organic Carbon (TOC), inorganic carbon (Cinorg), and total Sulfur (tS), and the calcium carbonate concentration ($CaCO_3$) were measured and interpreted: high values of $CaCO_3$, of the TOC and planktonic foraminifers decreases from base to top, and were identified in strata from late Cenomanian, late Turonian, Coniacian and Santonian.. >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

Abstract

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High sulfur concentrations are associated to laminated microfacies of foraminifers and linked to high values of TOC, which average is 2.41 %, and range from 0.1 to 7.2 %. Siliciclastic material was observed for first time at beds of Coniacian age, from where the ratio of benthic/planktic foraminifers is increasing, probably an indication of more oxygenated levels. The kerogen is type II.

The main source rock identified in Trinidad is the Naparima Hill Formation or the combination of Naparima Hill-Gauthier Formations. These rocks are of the same age of the Querecual Formation and its geochemical characteristics are similar. Naparima Hill outcrops in a few areas but has been reached by several offshore wells (South, West and East). It consists of well bedded, occasionally bituminous mudstones and shales, with some marls and bituminous limestones, deposited under low oxygen conditions. The upper part is made of silicified siltstones / claystones with abundant cherts. Studies of the siliceous facies exhibit evidence of formation of biogenic chert, within environments with limited terrigenous input, deposition above the carbonate compensation depth, and with very abundant siliceous organisms (Opal-A). The TOC values are ranging from 3.8 to 5.0 %, and amorphous type II kerogen has been identified.

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Abstract

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The Guyana – Suriname basin discoveries indicate that the main source rock is the Canje Formation, Late Albian/Cenomanian – Santonian in age. Several offshore wells have penetrated this Cretaceous formation, equivalent of the Querecual and Naparima Hill formations from Venezuela and Trinidad, respectively. The marine shales have TOC ranging from 4-7 % and kerogen type II. Since this area is still a high target for exploration, more studies will improve the characteristics of this source rock.

A better known Late Cretaceous source rock in Texas is the Eagle Ford Formation, composed of organic matter-rich fossiliferous marine dark shales with some interbedded limestones. After many years of conventional production from the overlying Austin Chalk or the Albian Edwards Limestone formation, this is now a non-conventional reservoir, which has been characterized with detailed seismic, petrophysics, and geochemistry to better understand the reservoir quality and the production optimization.

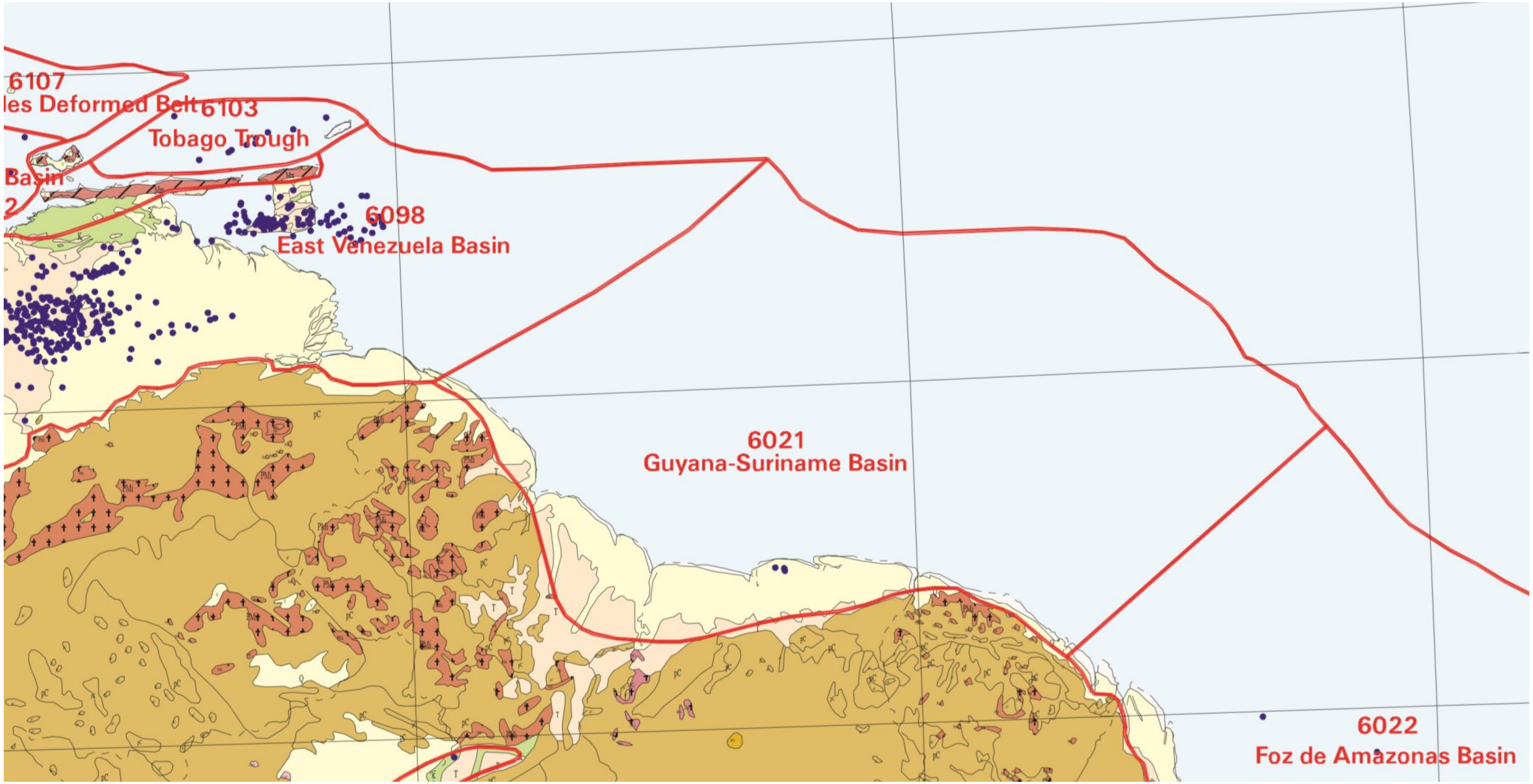
Considering tectono-stratigraphic uncertainties in the region, detailed sedimentology, high resolution biostratigraphy, and all the comprehensive seismic, petrophysics and chemostratigraphic studies that have been done for the Eagle Ford Formation can be successfully applied to the Late Cretaceous source rocks from offshore new exploration areas, North East South America.

Presentation Outline

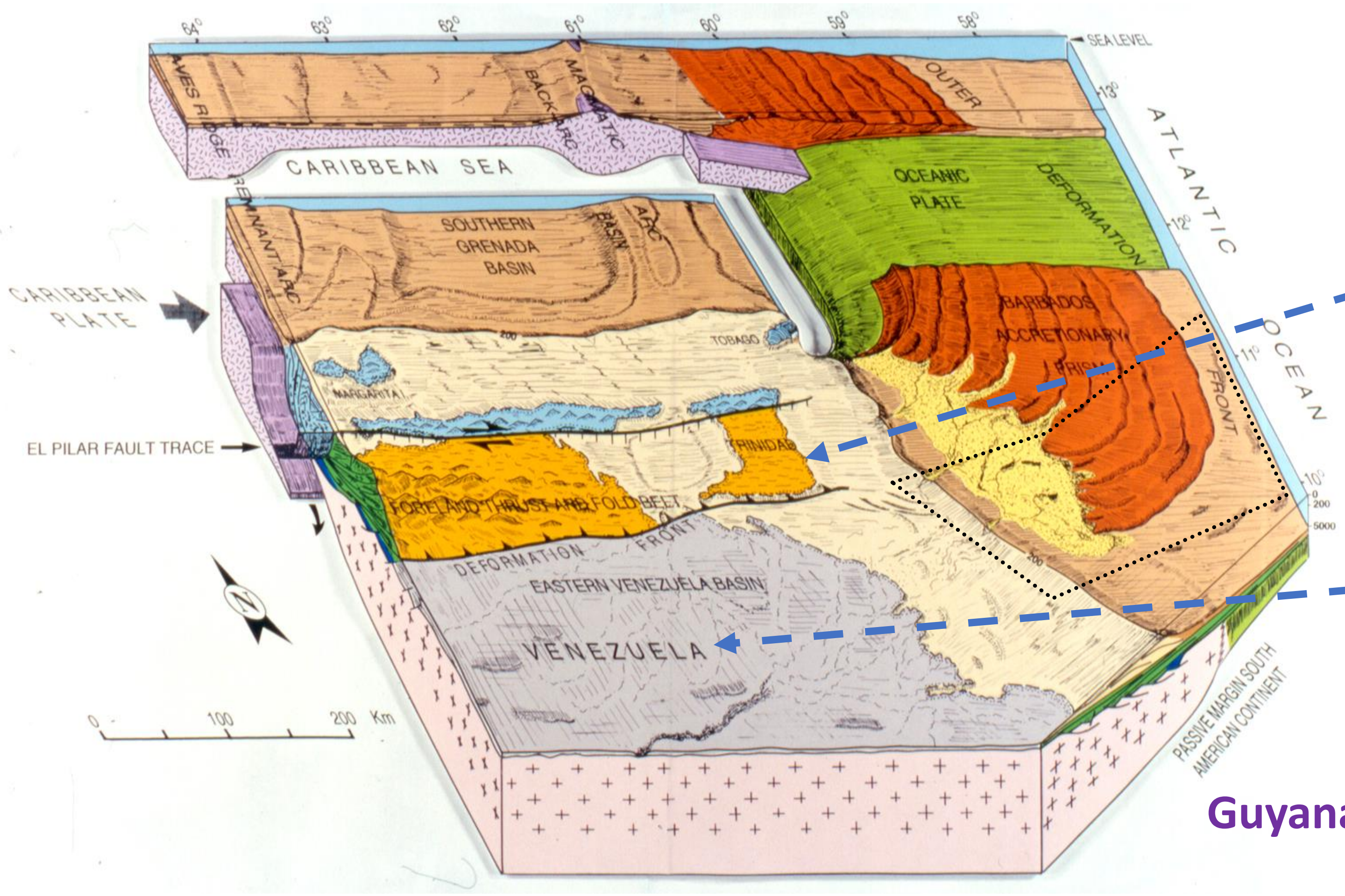
- General Introduction
- East Venezuela Basin
    - General Stratigraphy
    - Cretaceous Stratigraphy
    - THE QUERECUAL FORMATION
- Trinidad and Tobago, South Basins
    - General Stratigraphy
    - Cretaceous stratigraphy
    - THE NAPARIMA HILL AND GAUTIER FORMATIONS
- Guyana y Suriname
    - Cretaceous Stratigraphy
    - THE CANJE FORMATION
- Remarks
- Acknowledgements
- References and Bibliography

The Basins

USGS location of the basins. Assessment 2000



North - East Venezuela Tectonic Setting



Trinidad

East Venezuela Basin

Guyana

Copy with permission. Modified after: Di Croce, J. 1995. Eastern Venezuela Basin: Sequence stratigraphy and structural evolution. PhD Dissertation. Rice University. Houston, TX. 225 p.

East Venezuela - Regional Stratigraphy and Petroleum system elements

Updated from Parnaud et al. 1995

Age / Area	Guarico / Anzoategui	Central Anzoategui	Anzoategui / Monagas	North Monagas	Monagas	NE Anzoategui /N Monagas / S Sucre (To El Pilar Fault)
	SW Faja Oil Fields (Zuata)	Greater Oficina Oil Fields	Onado Casma Oil Fields	El Furrial Oil Fields	Outcrops South Limit	Outcrops North Limit
Pleistocene	Mesa	Mesa	Mesa	Mesa	Mesa	Alluvium
Pliocene	Las Piedras	Las Piedras	Las Piedras	Las Piedras	Las Piedras	
Late Miocene			La Pica	La Pica	Morichito	
Middle Miocene	Freites	Freites	La Pica	Carapita B/C		
Early Miocene	Oficina	Oficina	Carapita E/F	Carapita E/F		Naricual
Oligocene	Merecure	Merecure	Merecure	"Naricual"		Areo Los Jabillos
Eocene					Caratas	Caratas
Paleocene					Vidoño	Vidoño
Late Cretaceous	Tigre	Tigre		"Late Cretaceous Sands"	San Juan San Antonio Querecual	San Juan San Antonio Querecual
Early Cretaceous	Canoa				Chimana El Cantil Barranquin	Chimana El Cantil Barranquin
Carboniferous	Carrizal					
Devonian	Hato Viejo					
Basement	Basement					

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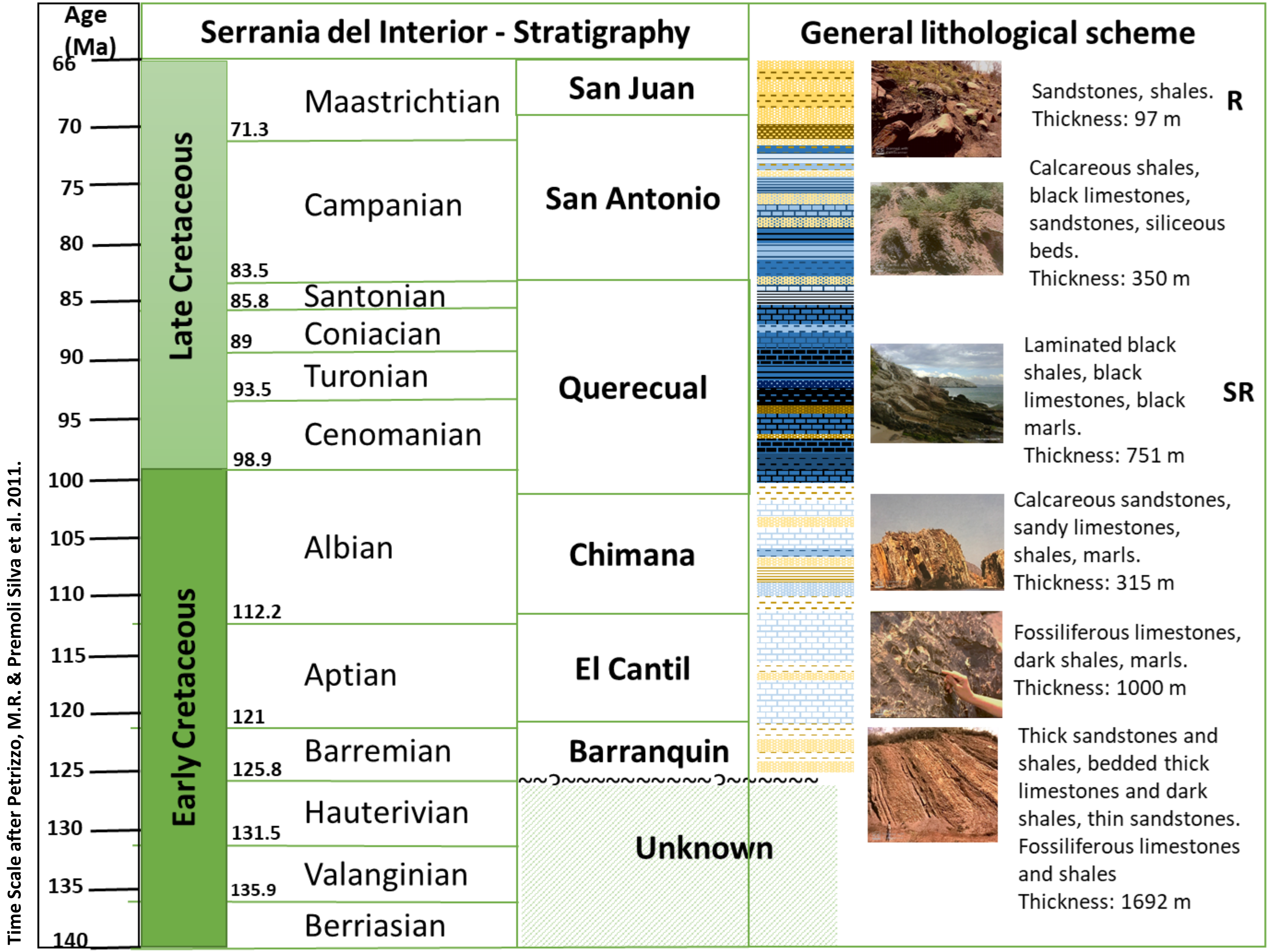
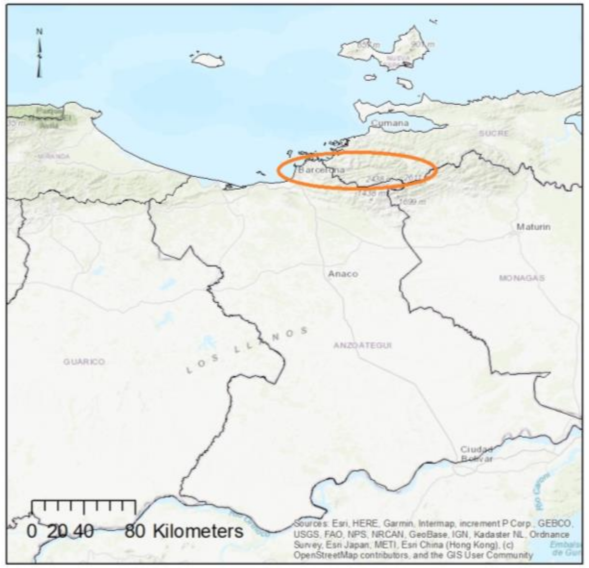
Venezuela. Cretaceous Stratigraphy. Serrania del Interior





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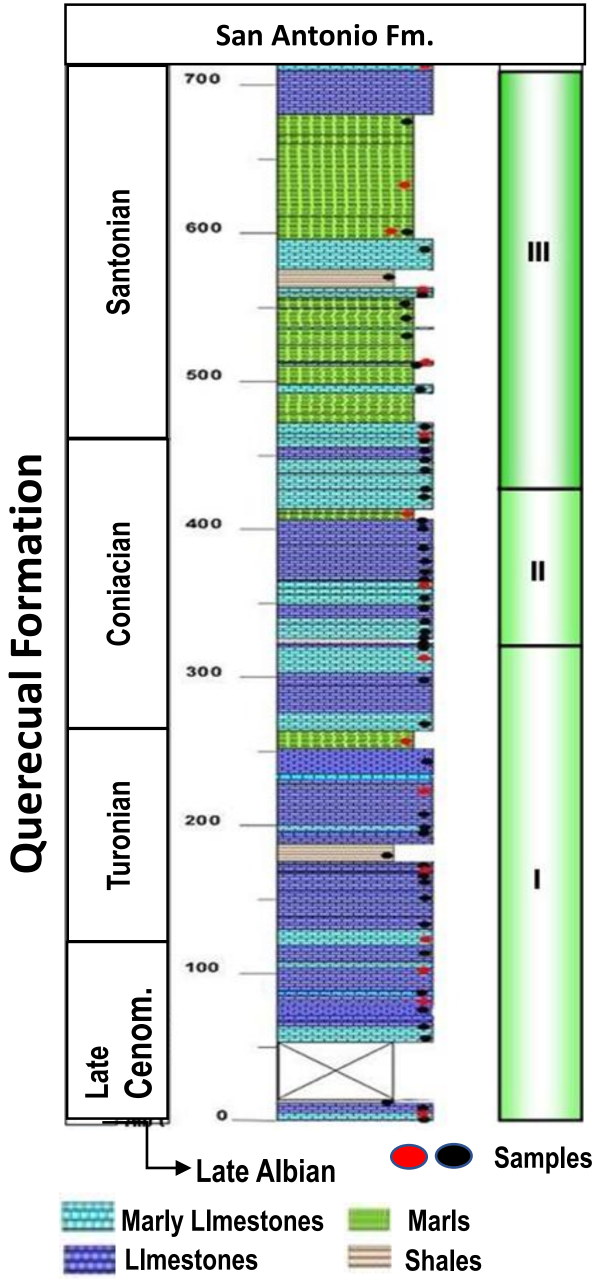
Photographs by *FGaleaAlvarez*

Querecual Formation at the type section

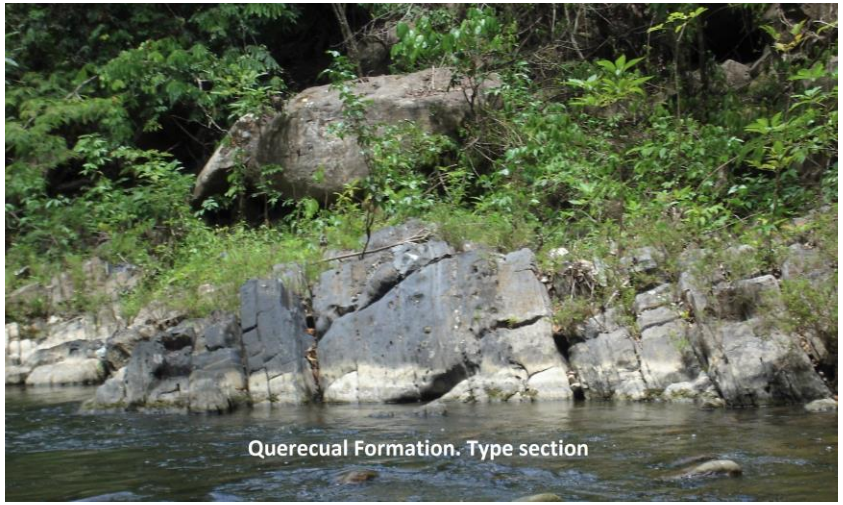


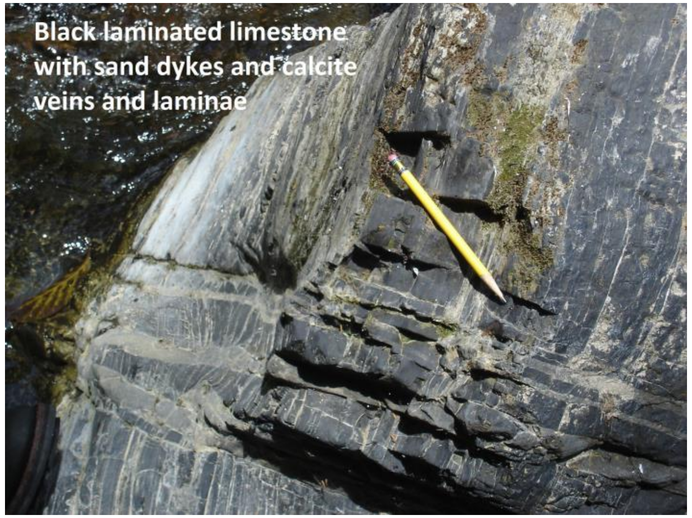
Informal Units

Dark gray-black marls with some marly limestones. Benthic foraminifers abundant and diverse (85%). Common nodules with pyrite. Clastic (Qrtz) and small sand dykes (2-3 mm), more frequent.

Dark gray-black marly limestones with interbeded limestones. 60% planktonic foraminifers; Frequent small sand dykes.

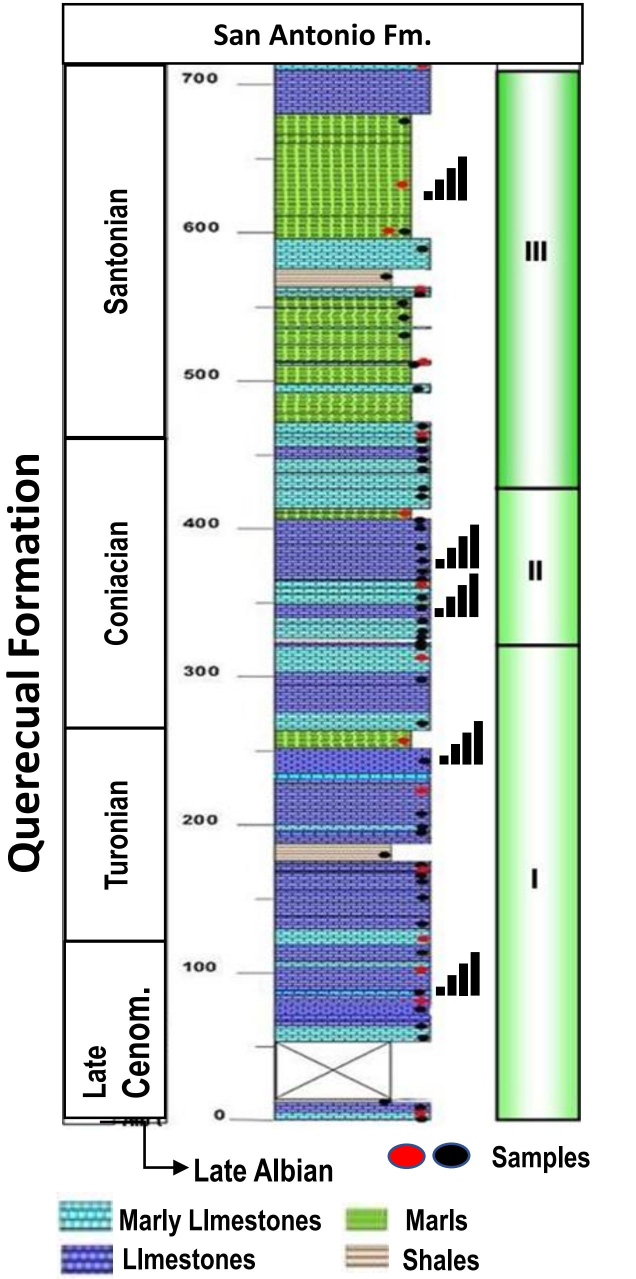
Dark gray-black massive to laminated limestones. 80 - 100 % planktonic foraminifers. Scarce fragments of *Inoceramus* and few molds and casts of Ammonites. To the top small (cm) qtz. sand dykes





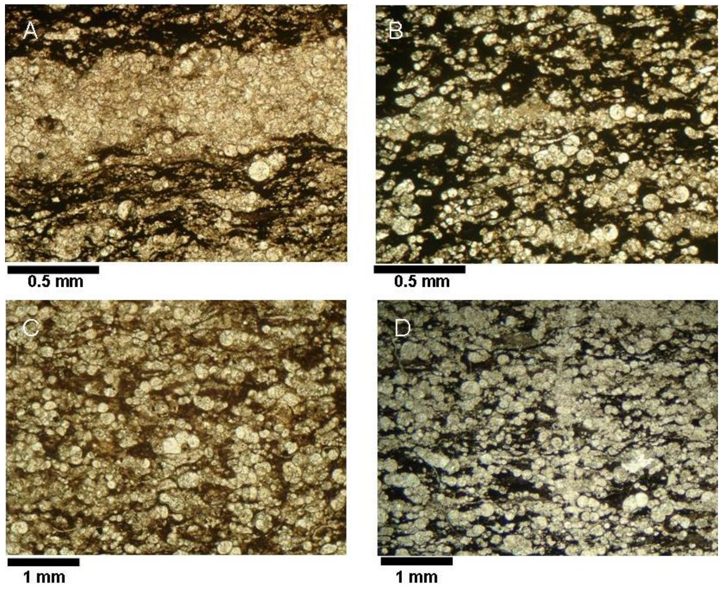
Photos and lithology from Truskowski, 2006

Querecual Formation. Microfacies

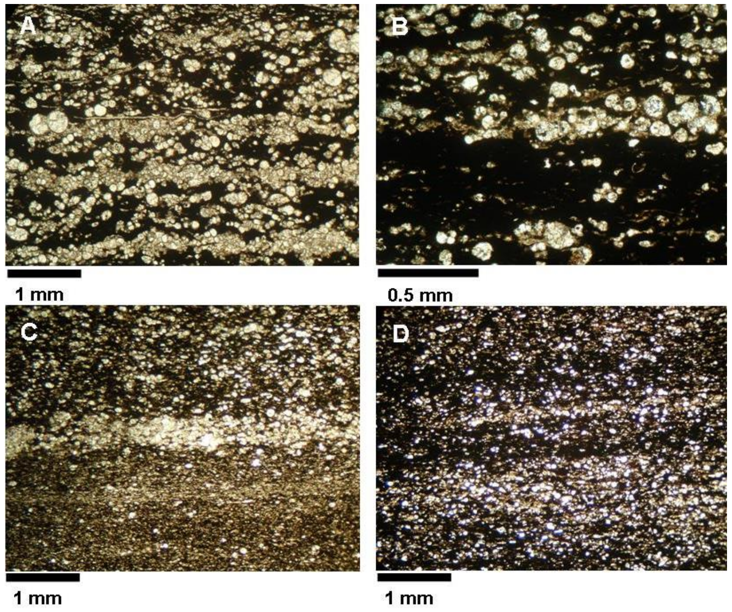


Photos and lithology and microfacies from Truskowski, 2006

Microfacies L2: Coarsely Laminated. Mainly planktonic foraminifera (Unit I), organic matter & planktic/benthic forams (Units II & III). Dysoxic when benthic occurs

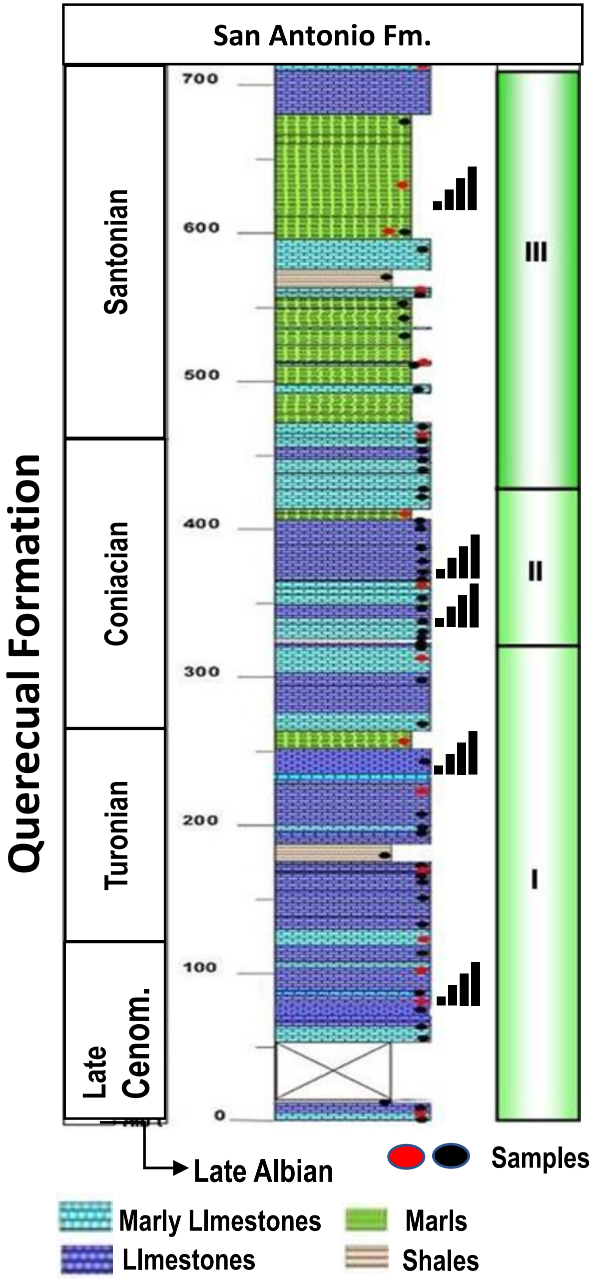


Microfacies L1: Finely Laminated. Mainly planktonic foraminifera and organic matter and dark clay. Typical at the bottom. Anoxic facies



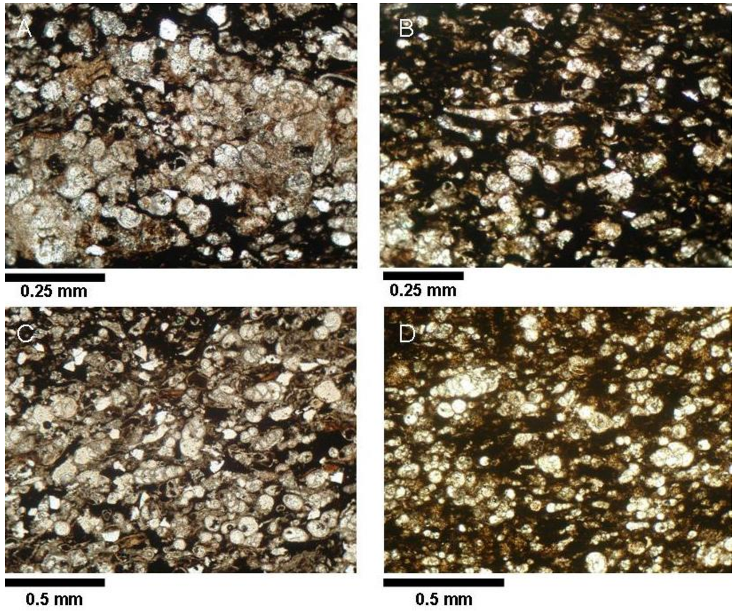
Highest TOC values 4-7%

Querecual Formation. Microfacies

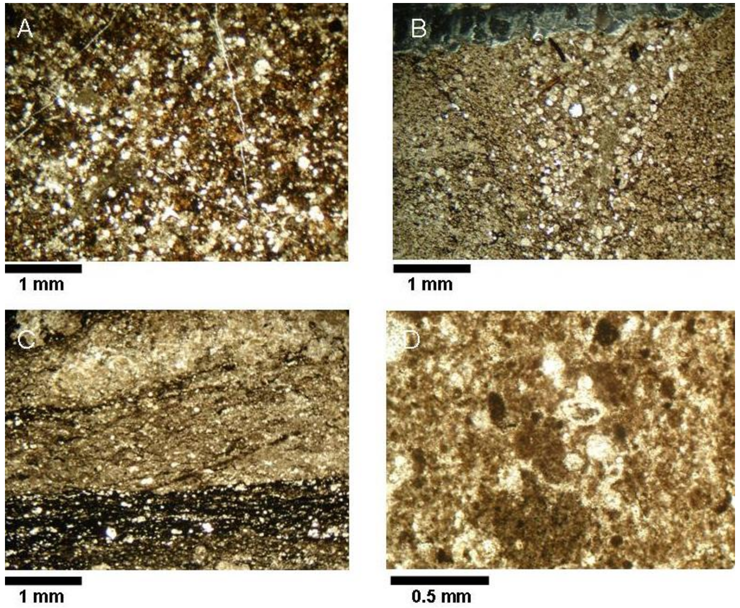


Photos and lithology and microfacies from Truskowski, 2006

Microfacies L3: Lamination with some breaks. Organic matter, planktonic Foraminifers and common benthic interpreted as displaced by local currents. Still dysoxic, more oxygenated. Mostly in Units II and III



Microfacies L4: Discontinuous Lamination. Mainly planktonic foraminifera, organic matter & benthic forams. Common bioturbation. Mainly at Units I, II. Dysoxic



Highest TOC values 4-7%

Querecual. Geochemistry

QUERECUAL INFORMAL UNITS	MICROFACIES	PALEOWATER DEPTH	OXIC CONDITIONS	CaCO3 CONTENT	TOTAL ORGANIC CARBON	Age of Samples with Highest TOC	MINERALS	ORGANIC ANOXIC EVENTS -OAE
III	L3 BENTHICS, L2 BENTHICS, L1 PLANKTICS + BENTHICS, L2 PLANKTICS, L4	UPPER BATHYAL	Dysoxic, with better bottom oxygenated conditions	40 - 60 %	0.2 - 4.2 %. Avg. 1.4 ± 1.2 Standard Deviation (SD)	Santonian age	Calcite, dolomite, quartz, pyrite, siderite and rare glauconite to the top. Clay minerals	OAE 3: Coniacian - Santonian. Foraminifera Biozone *Dicarinella asymetrica*
II	L3 PLANKTICS, L2 BENTHICS, L1 PLANKTICS + BENTHICS, L4	MIDDLE BATHYAL	Dysoxic	50 - 80 %	1 - 5 %	Coniacian age		Non
I	L1 PLANKTICS, L2 PLANKTICS, L3 PLANKTICS	MIDDLE BATHYAL	Mainly anoxic	40 - 90 %	0.4 - 7 %. And to the base 0.2 - 5.6 %. Avg. 2.5 ± 1.7 SD	Late Turonian and Late Cenomanian		OAE 2: Cenomanian - Turonian boundary. Foraminifera Biozone *Whiteinella archaeocretacea*
Highest values of CaCO3 associated to limestones and microfacies with planktonic forams								

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Data from Truskowski 2006, Lugo P., et al. 2009

Querecual. Geochemistry

QUERECUAL	CaCO3	TOTAL ORGANIC CARBON	**V (ppm)	**Ni (ppm)	**S (wt %)	**V/Ni (Ratio)	MINERALS	Type Kerogen	Tmax °C
Samples from top (Limestones)	40 - 60 %	0.2 - **4.2 %**. Avg. 1.4 ± 1.2 Standard Deviation (SD)	**27 - 127** Avg. 71 ± 29 SD	**35 - 127** Avg. 55 ± 14 SD	**0.3 -1.5** AVG. 0.7 ± 0.4 SD	**0.6 - 1.7** AVG. 1.3 ± 0.4 SD	Calcite, dolomite, quartz, pyrite, siderite and rare glauconite to the top. Clay minerals	II. Amorphous marine organic matter with vitrinite particles	525±10
Samples from bottom (Limestones)	40 - 90 %	0.4 - **7 %**. To the the base 0.2 - **5.6** %. Avg. 2.5 ± 1.7 SD	**240 - 1630** Avg. 830 ± 474 SD	**45 - 135** AVG. 95 ± 35 SD	**0.3 - 1.3** Avg. 0.7 ± 0.5 SD	**5.1 - 12.0** AVG. 8.3 ± 2.7 SD			542 ± 2

*Highest values of CaCO3 associated to limestones and microfacies with planktonic forams. ** Concentration ranges. Bitumen: Max. 297 ppm. Min. 66 (Only in Limestones). Highest values of tS associated to marls, marly limestones with Laminated microfacies with planktonic foraminifera

Oil from Zuata area - Faja del Orinoco Oil Field						
V (ppm)	Ni (ppm)	S (wt%)	V/Ni (Ratio)	SARA (wt %)	Oil Classification	° API
229 - 654 Avg. 524 ± 111	65 - 124 Avg. 108 ± 16	3.4 - 5.7 Avg.4.3 ± 0.7	3.5 - 5.8 Avg. 4.8 ± 0.6	S: 5-11 A: 14-45 R+A: 49 - 75	Aromatic asphaltic	Extra heavy

Data from Truskowski 2006, Lugo P., et al. 2009; Lopez and Lo Monaco, 2010; Lopez and Lo Monaco, 2017

Venezuela. Summary

The results presented here support the theory that the Querecual Formation is the main source rock for the East Venezuela Oil.

- **The V and Ni studied at the type section of Querecual show a clear tendency that allowed to postulate a vertical migration of the bitumen, from center to the extremes of the section. Variations in redox conditions during sedimentation, lithofacies changes of the source rock, could generate crude oils with different ratios of V/Ni.**

- **Oils from FAJA generated by a mature source rock, carbonaceous, deposited in variable anoxic conditions, with marine organic mater, and some contribution of siliciclastics, which are similar conditions for the Querecual sequence. Oils from FAJA are biodegraded.**

The other Cretaceous possible source rock is the San Antonio Formation. However, an assessment done, from samples collected at the type section, indicated that it has high generation potential but there is indication of low bitumen expulsion efficiency. (Lopez, L. 1997)

Trinidad - Regional Stratigraphy and Petroleum system elements

Schematic Stratigraphy - Trinidad Southern Basins

Age / Area	North Monagas	NE Anzoategui /N Monagas / S Sucre (To El Pilar Fault)	West Southern Basin	East Southern Basin - Columbus Basin	Legend
	El Furrial Oil Fields	Outcrops North Limit	Onshore / Offshore	Onshore / Offshore	Seal
Pleistocene	Mesa	Alluvium	Cedros Erin	Palmiste	Reservoir
Pliocene	Las Piedras		Morne L' Enfer Forest Upper Cruse	Mayaro Gross Morne	Source Rock
Late Miocene	La Pica		Lower Cruse	Lower Cruse	Lower Forest Shale
Middle Miocene	Carapita B/C		Lengua	Lengua	Upper Cruse Shaly Interv.
Early Miocene	Carapita E/F	Naricual	Cipero	Cipero	Karamat Sands Herrera Sands Retrench Sands
Oligocene	"Naricual"	Areo Los Jabillos			
Eocene		Caratas	San Fernando		
Paleocene		Vidoño	Navet / Lizard Springs		
Late Cretaceous	"Late Cretaceous Sands"	San Juan San Antonio Querecual	Guayaguayare Naparima Hill Gauthier	Guayaguayare Naparima Hill Gauthier	
Early Cretaceous			Cuche	Cuche	

Curtis, A. Carr-Brown, 2009; Geological Society of Trinidad)

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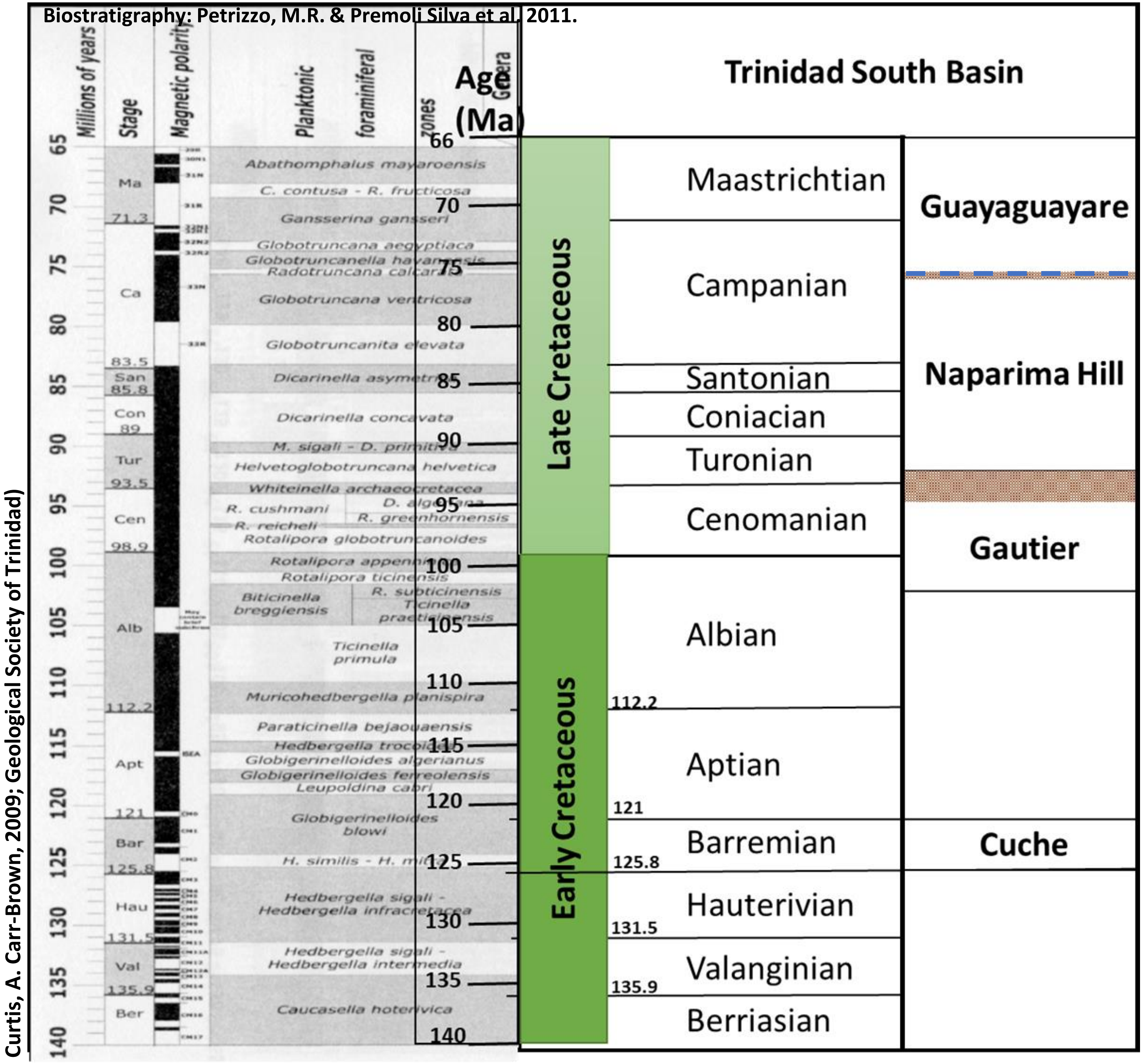
Trinidad Cretaceous Stratigraphy



Guayaguayare: Dark gray calcareous shales. Thickness estimated in 120 m.

NH: Well bedded, sometimes bituminous mudstones and shales, marls and limestones. The upper part described as “argillite”, is made of silicified siltstones / claystones. Diatoms, Quartz, bioturbation are mentioned in literature. Thickness estimated: 400 – 700 m

Gautier: Bituminous and calcareous shales, mudstones and some sandstones. Thickness is up to 610 m.

Cuche: Calcareous shales, marls, sandstones. Estimated thikness 600-1500 m

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OAE 2

Hiatus

Trinidad. Geochemistry

FORMATION	MICROFAUNA	PALEOWATER DEPTH	OXIC CONDITIONS	CaCO3 CONTENT	TOTAL ORGANIC CARBON	Age of Samples with Highest TOC	MINERALS	ORGANIC ANOXIC EVENTS -OAE
NAPARIMA HILL	Abundant Planktonic and benthonic foraminifera	MIDDLE BATHYAL	Dysoxic and anoxic	High associated to calcareous	1.9 - 5.3 %	Santonian and Campanian age	Calcite, aluminosilicate Clay, low Fe/S ratio	OAE 2: Cenomanian - Turonian boundary. Foraminifera Biozone Whiteinella
GAUTIER	Abundant Planktonic and benthonic foraminifera	UPPER - MIDDLE BATHYAL	Dysoxic and anoxic	Moderate	1.6 - 4.2 %	Cenomanian age		Non described
Highest values TOC associated to carbonate lithofacies								

Data from Talukdar et al., 1990. Persad, K.M., 2009. Requejo, et al., 1994.

Trinidad. Geochemistry

FORMATION	CaCO3	TOTAL ORGANIC CARBON	HI mg/g	Tmax °C	Ro %	Type Kerogen
Naparima Hill	High associated to calcareous oil prone rocks	1.9 - 5.3 %	117 - 596	426-434	0.54	II. Amorphous kerogen with a trace of vitrinite
Gautier	Moderate	1.6 - 4.2 %	141 - 171	426-436	0.48-0.67	
One sample from Guayaguayare TOC 2.5 2.9 % and Avg. HI 402-412 mg/g: good source potential						

OILS

- **Geochemistry of oil are indicative of a source rock like Naparima Hill – Gautier**
- **A few oils retain their original composition**
- **Oils are biodegraded by several processes like biodegradation, thermal maturity and evaporative fractionation**

Data from Talukdar et al., 1990. Persad, K.M., 2009. Requejo, et al., 1994;

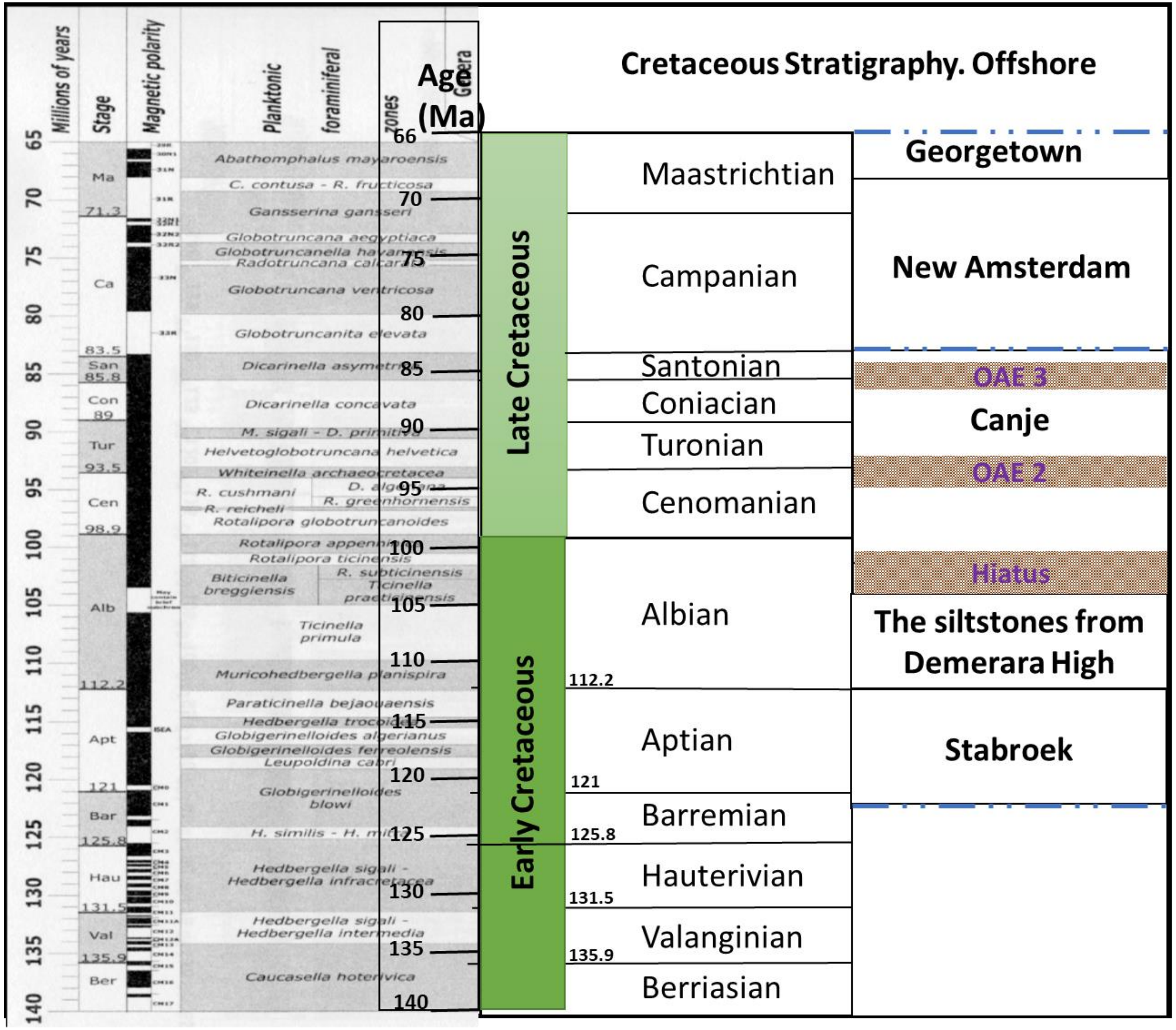
Trinidad- Summary

Oil related to the Late Cretaceous Naparima Gautier formations, but the results shown here indicate that the sediments are immature – early mature with respect to hydrocarbon generation. The source rock that generated the oil in Trinidad could be deeper than the material sampled and tested, from South Basin.

The petroleum system that produced ~ 2.5 billion barrels of oil from more than 25 oil fields, including 7 giants, is
Naparima Hill – Gautier / Cruse / Forest / Gross Morne

Biostratigraphy: Premoli Silva et al. 2011.

Guyana – Suriname Cretaceous Stratigraphy



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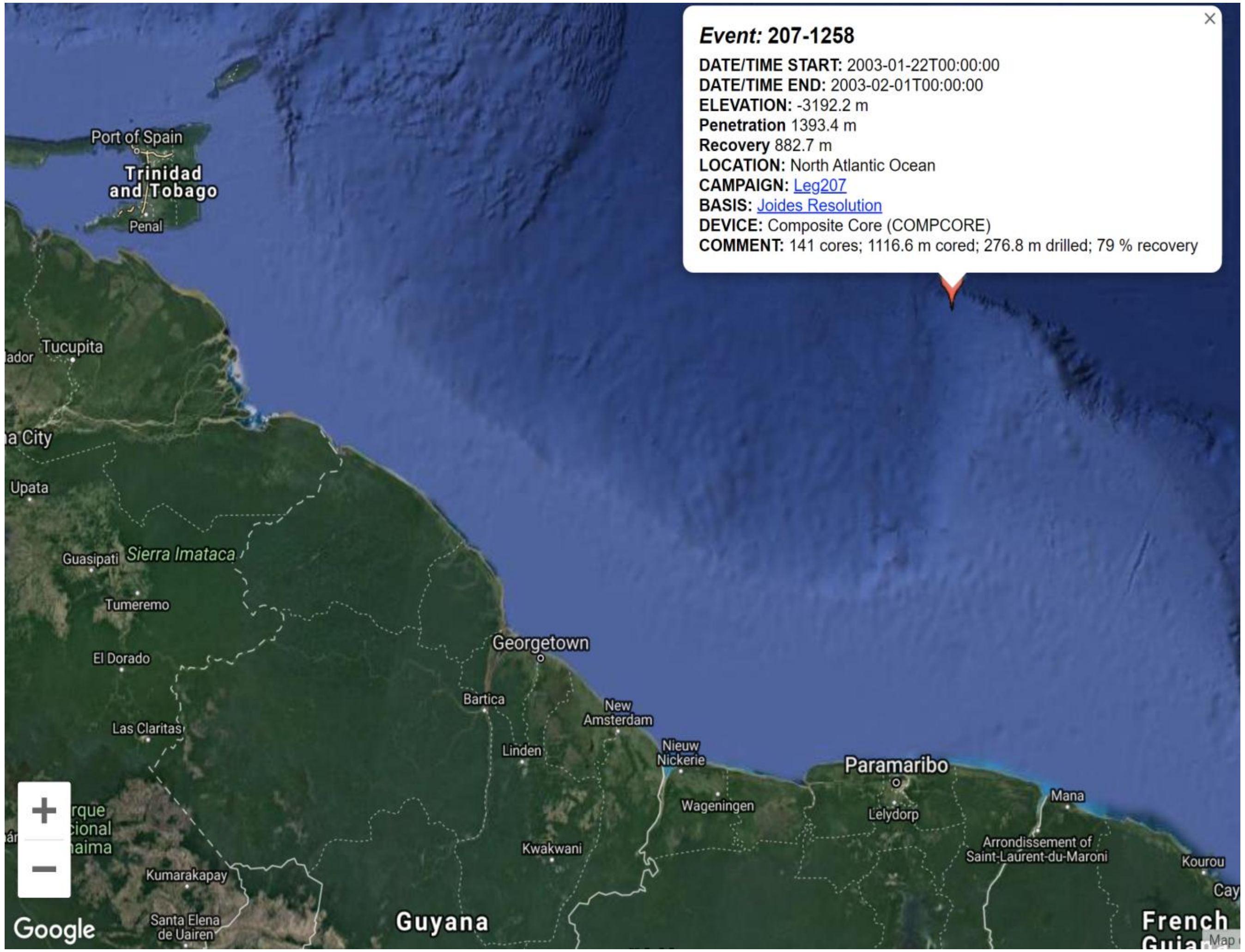
Unconformity

Guyana – Suriname. Canje Formation



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Google Map from https://doi.pangaea.de/10.1594/PANGAEA.757124

Canje Formation – ODP Leg 207
Sites 1257, 1258, 1259, 1260, 1261

Dark-colored, finely laminated, organic-carbon-rich claystones interbedded with coarser lightly, laminated foraminiferal and nannofossil – bearing packstones and wackestones. Siliceous intervals are common.
Age: Late Albian? - Cenomanian – Santonian
Estimated thickness: 300 – up to 500 m
Paleowater depth is upper- mid bathyal, dysoxic-anoxic conditions (Friedrich et al., 2006).

The upper boundary is unconformable with the clastics of the New Amsterdam Formation.
The lower boundary is sharp, unconformable with homogeneous, dark-colored, lower to middle Albian siltstones.

Guyana – Suriname. Geochemistry

Canje Formation – ODP Leg 207, Sites 1257, 1259, 1260

Note: After the first publications, the depth of samples were corrected in order to get a more realistic sequence without the "missing" horizons seen here.

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Data ODP Leg 207

GEOCHEMISTRY	SANTONIAN	CONIACIAN	TURONIAN	CENOMANIAN	CALC. ALBIAN	NON-CALC. ALBIAN	ODP Site 207
CaCO3	42.54	52.61	49.17	56.62	32.59		
TOC %	7.29	8.78	8.15	4.03	0.57		
Tmax oC	404.6	397.63	400.85	398.66	418.75		1257
HI, HC/TOC mg/g	572.33	583.09	622.25	685	109.5		
Thick. m	0.68	11.1	16.77	4.19	53.75		
CaCO3	37.57	55.52	47.56	27.25		1.8	
TOC %	1.82	9.3	8.93	13.34		2.37	
Tmax oC	418.5	398.75	399	397		432	1259
HI, HC/TOC mg/g	359	595.5	628.41	595		472	
Thick. m	0.7	16.51	28.32	1.94		5.22	
CaCO3		41.16	36.87	59.38	45.38	7.84	
TOC %		4.68	10.13	9.12	3.41	0.59	
Tmax oC		400	394	398.5		405	1260
HI, HC/TOC mg/g		640	579.9	561.61		73	
Thick. m				52.68	0.89	22.41	

Guyana – Suriname. Summary

Samples with low CaCO3 values have higher TOC values. Probably these are samples described on the ODP Initial Reports as foraminifer nannofossil chalks with common radiolarians.

Regarding the CaCO3 values, the Albian samples were separated in Calcareous Albian sediments and Non-calcareous Albian sediments.

The petroleum system is Canje/Stabroek/New Amsterdam/Tertiary Sands. Effective seals are Tertiary shales.

Main risks: Migration pathways, seals and timing.

Remarks

- The formations were described with the idea to show common denominator parameters: rock descriptions, sedimentology, biostratigraphy, geochemistry.

- The Querecual Formation is the best studied because most of the formation is exposed in the Serrania del Interior. The analysis and results of biostratigraphy, microfacies and geochemistry were done as part of the same investigation, on the same set of samples.

- Data from the Naparima Hill and the Gauthier formations are the results of studies done at different times but with the same set of samples. Recent studies correspond to different sections, including some outcrops. In general, these formations have been partially studied, since they are better distributed on offshore and onshore subsurface.

- The Canje Formation is the relatively new “player” but is only found on subsurface offshore. It means, all the new studies will depend on core samples. However, the analysis and results published from the ODP Leg 207, sites 1257 – 1261 have shown the main characteristic features of this formation.

Remarks

- All of the mentioned formations are lacking diagenetic studies, like the studies of Elmore et al., 2016, on the Marcellus Shales (Devonian), Barnett Shale (Mississippian), Wolfcamp Shale (Permian) and Haynesville Shale (Jurassic).

- In general, the Querecual microfacies are quite similar to the microfacies described by Ramiro-Ramirez (2016), Gulf Coast region, for the Eagle Ford Shale, late Cenomanian – early-late Turonian. They differ in the presence of volcanic ashes described by Ramiro-Ramirez as "Claystone facies".

- The presence of siliceous microfossils is less notorious in the Querecual Formation, abundant in the Naparima Hill, especially to the top, and very abundant in the Canje Formation (ODP Site 207).

Quality of a source rock must means Corg. concentration and its maturity, quantity and distribution of the organic matter (bitumen, kerogen), oil expulsion efficiency, mineralogy and poro/permeability of the rock, migration and ………. Timing!

Acknowledgements

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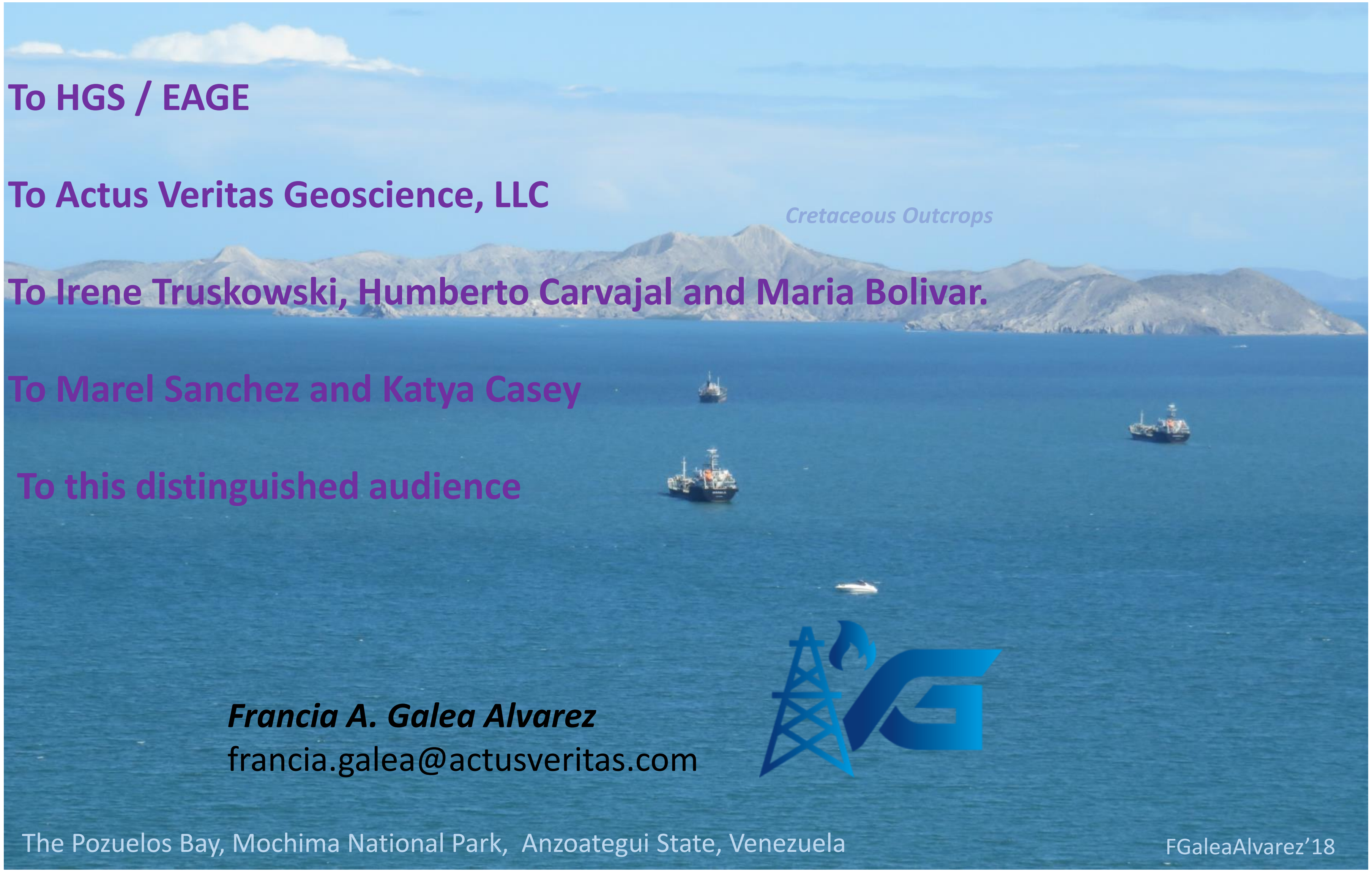
- To Actus Veritas Geoscience, LLC
- To Irene Truskowski, Humberto Carvajal and Maria Bolivar.
- To Marel Sanchez and Katya Casey
- To this distinguished audience



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The Pozuelos Bay, Mochima National Park, Anzoategui State, Venezuela

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Francia A. Galea Alvarez, Nov. 2019

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