The Hypothetical Cretaceous Petroleum System of Trinidad and Tobago*

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Abstract

With the successes of the Early-Late Cretaceous deep-water fan play offshore Western Africa and Eastern South America, growing attention has been paid to the possible extension of this play across the entire conjugate Atlantic margins. Due to the potential of this play type onshore Trinidad and Tobago, four deep wells were critically assessed to construct four petroleum system models which were used to assess the thermal evolution of the sedimentary section onshore Trinidad and Tobago with a focus on understanding the underdeveloped Cretaceous play. This study delineates the components of the currently sub-commercial Gautier/Naparima Hill-Gautier (onshore Southern Basin) and the Gautier/Naparima Hill-Naparima Hill (offshore eastern Trinidad) petroleum systems. Sub-commercial amounts of light oil were produced in various wells in the Guayaguayare area, along the crest of the Southern Range anticline in wells drilled in the 1950s. There were also shows of relatively light oils in wells that were drilled in the western part of the Southern Basin onshore in the 1950s. Within recent years, gas and condensates were tested from wells in the offshore extension of the Central Range Transpressive belt within Cretaceous reservoirs. These reservoirs consisted of the Gautier turbidites and fractured Naparima Hill argillite. The major components and processes of the system have also been assessed, in particular the timing of source rock maturation and the generation of possible fluid migration pathways. The accuracy of the four models was then tested by comparing them with published vitrinite reflectance plots and present day geothermal gradients. The ultimate goal of this study is to focus on the geodynamic evolution of the greater Trinidad region and to use these results to calculate maturity levels and petroleum generation stages within the Cretaceous Petroleum System. This work could serve to highlight the underexplored potentially prolific Cretaceous Petroleum System of Trinidad and Tobago.

References Cited

Allen P.A., and J.R. Allen, 2005, Basin Analysis, 2nd Edition: Blackwell Publishing, Malden, MA, p. 349-401.

Dow, W.G., 1977, Kerogen studies and geological interpretations: Journal of Geochemical Exploration, v. 7, p. 79-99.

Erlich, R.N., T. Villamil, and J. Keens-Dumas, 2003, Controls on the deposition of Upper Cretaceous organic carbon– rich rocks from Costa Rica to Suriname: in C. Bartolini, R.T. Buffler, and J. Blickwede, eds., The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics: AAPG Memoir 79, p. 1–45.

Garciacaro. E., P. Mann, and A. Escolana, 2011, Regional structure and tectonic history of the obliquely colliding Columbus foreland basin, offshore Trinidad and Venezuela: Marine and Petroleum Geology, v. 28, p. 126–148.

Jarvie, D.M., B.L. Claxton, F. Henk, and J.T. Breyer, 2001, Oil and Shale Gas from the Barnett Shale, Ft. Worth Basin, Texas: AAPG National Convention, June 3-6, 2001, Denver, CO, AAPG Bulletin, V. 85/13 (Supplement), p. A100.

Lo, H.B., 1993, Correction criteria for the suppression of vitrinite reflectance in hydrogen-rich kerogens: preliminary guidelines: Organic Geochemistry, v.20/6, p. 653-657.

Magoon, L.B., and W.G. Dow, 1994, The petroleum system: in L.B. Magoon, and W.G. Dow, eds., The petroleum system — from source to trap, AAPG Memoir 60, p. 3-24.

Moonan, X.R., 2011, 4D Understanding of the Evolution of the Penal/Barrackpore Anticline, Southern-Sub-Basin, Trinidad, W.I.: Search and Discovery article 20122, Web Accessed October 16, 2014. http://www.searchanddiscovery.com/pdfz/documents/2011/20122moonan/ndx_moonan.pdf.html.

Palumbo, F., I.G. Main, and G. Zito, 1999, The thermal evolution of sedimentary basins and its effect on the maturation of hydrocarbons: Geophys. J. Int., v. 139, p. 248–260.

Pearson, D.L., 1990, Pollen/Spore Color "Standard" (Ver. 2): Bartlesville, OK (Phillips Petroleum Co., Geology Branch).

Peters, K.E., and M.R. Cassa, 1994, Applied source-rock geochemistry: in L.B. Magoon and W.G. Dow, eds., The Petroleum System - From Source to Trap: AAPG Memoir 60, p. 93-120.

Pindell, J.L., and L. Kennan, 2001, Kinematic evolution of the Gulf of Mexico and the Caribbean: in D. Fillon, ed., Transactions, 21st Bob Perkins Gulf Coast Section Society of Economic Paleontologists and Mineralogists Research Conference, Houston, Gulf Coast Section SEPM Foundation, p. 32.

Pindell, J.L., and L. Kennan, 2007, Cenozoic Kinematics and Dynamics of Oblique Collision Between Two Convergent Plate Margins: The Caribbean South American Collision in Eastern Venezuela, Trinidad and Barbados: Transactions of GCSSCEPM 27TH Annual Bob F. Perkins Research Conference, p. 458-553.

Rider, M.H., 1999, The Geologic interpretation of well logs: Whittles Publishing Services, 280 p.

Rodrigues, K., 1988, Oil source bed recognition and crude oil correlation, Trinidad, West Indies: Organic Geochemistry, v. 13/1-3, p. 365-371.

Rodrigues, K., 1990, Significance of geothermal gradients in Petroleum Exploration in Trinidad: Transactions of the 12th Caribbean Geological Conference, St Croix, U.S. Virgin Islands, August 7-11, 1989, p. 444.

Wood, L.J., 2000, Chronostratigraphy and tectonostratigraphy of the Columbus Basin, eastern offshore Trinidad. Am. Assoc. Petrol. Geol. Bull., v. 84, p. 1905-1928.

Wygrala B., 1989, Integrated study of an oil field in the southern Po Basin, Northern Italy: Berichte kernforschungsamlage, Julich, 2313, p. 217.

Petroleum Company of Trinidad and Tobago Limited

The Hypothetical Cretaceous Petroleum System of Trinidad and Tobago

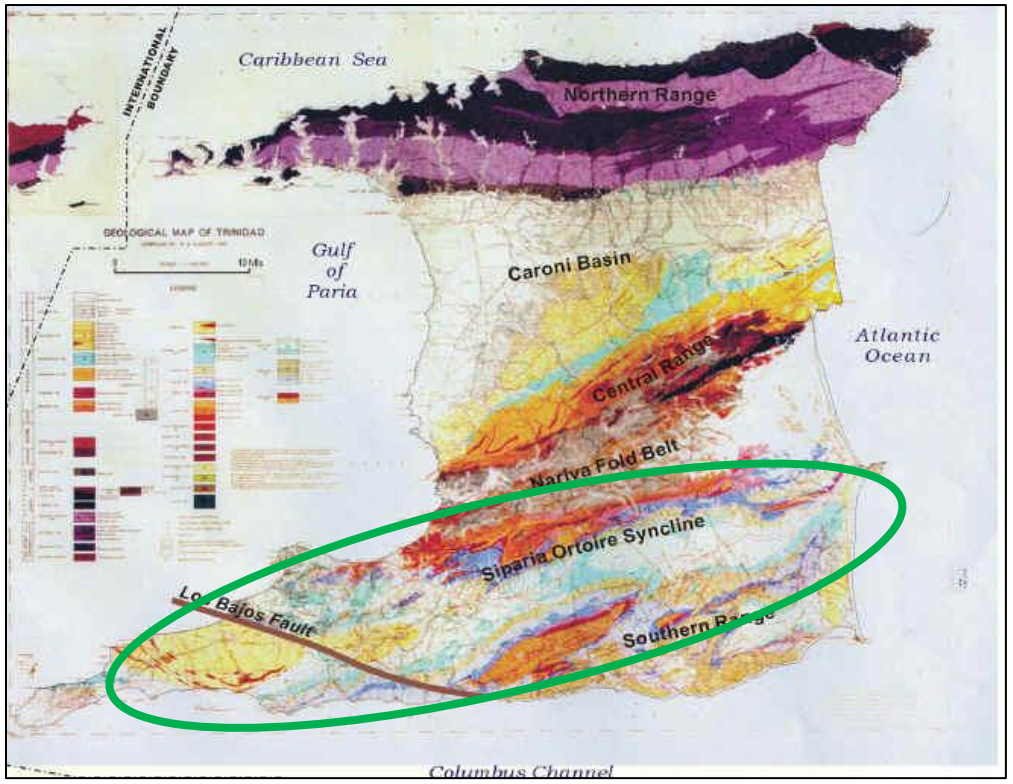
Presentation to

The AAPG GTW

by Adrian Thomas

MISSION STATEMENT

" Onshore Trinidad has an underexplored **Cretaceous** Petroleum System? "



The green circle highlights the study area.

Kugler , 1959. (gstt.org)

Presentation Outline

- What is a petroleum system?
- What are the Cretaceous Formations?
- Data Set
- Components of the Petroleum System
- Previously drilled areas
- Summary

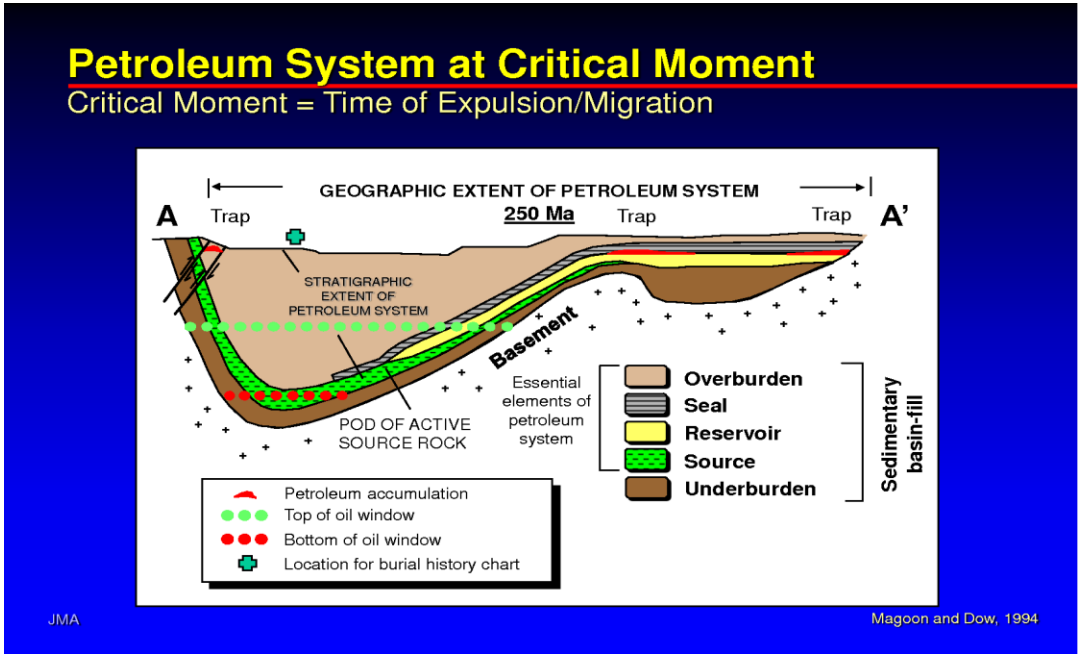
What is a Petroleum System?

It has *four* elements

- Source rock
- Reservoir rock
- Seal rock
- Overburden rock

Two main processes

- Trap Formation
- Generation-Migration-Accumulation



http://ugmsc.files.wordpress.com/2011/03/picture4.jpg

Petroleum Systems Have Different Levels of Certainty

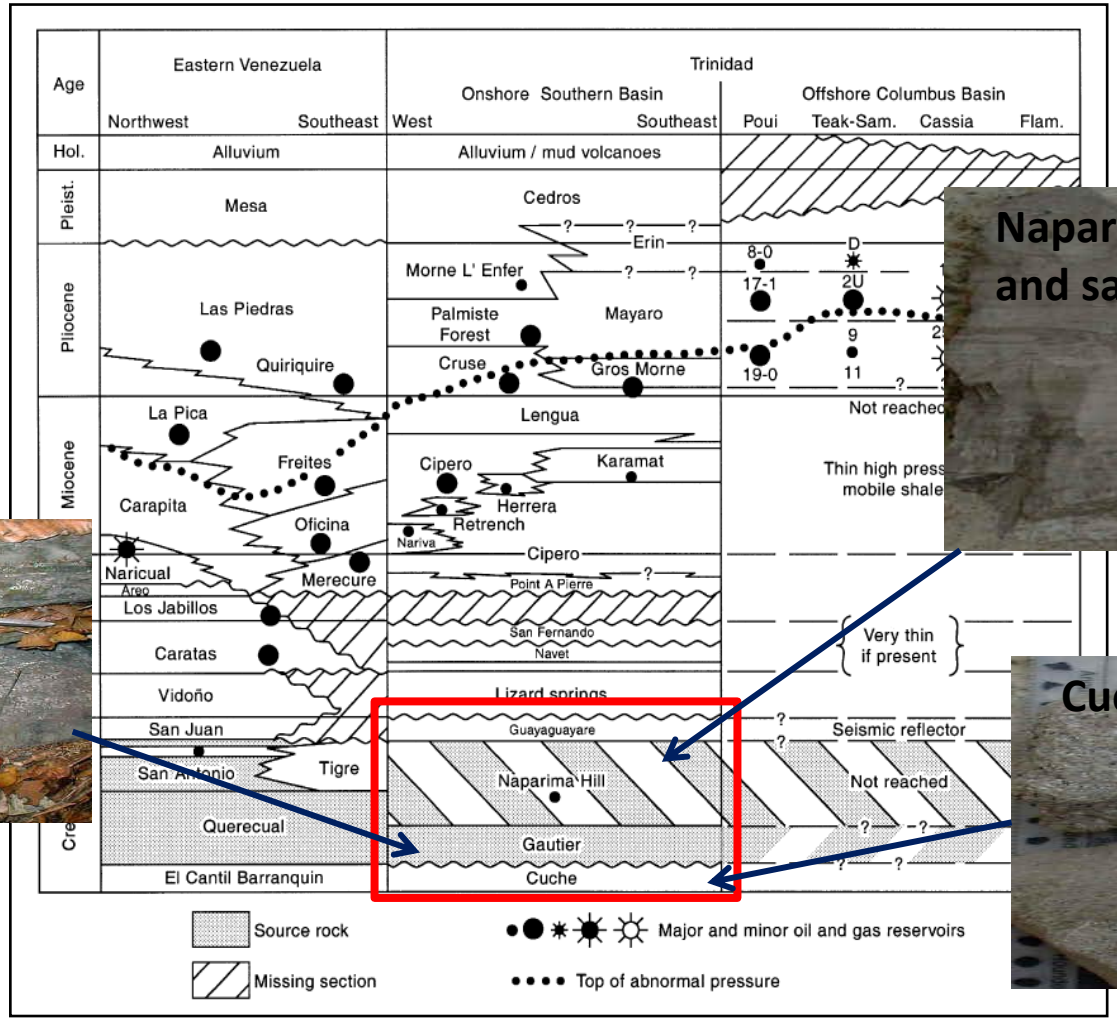
Known - Oil-to-source rock or gas-to-source correlation (!)

Hypothetical - Geochemical evidence suggests petroleum origin (.)

Speculative -Geological or geophysical evidence only(?)

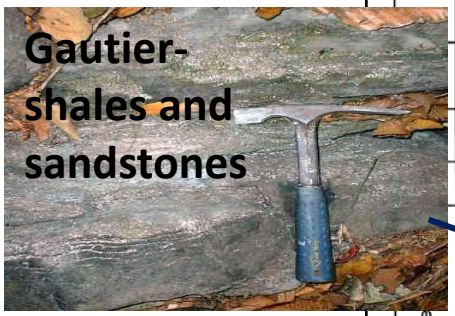
Magoon and Dow (1994)

Stratigraphic Column with a focus on the Cretaceous Formations of interest

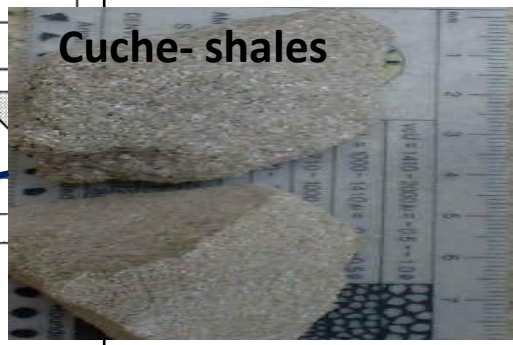


Naparima Hill- argillite and sandstones

Gautier- shales and sandstones



Cuche- shales



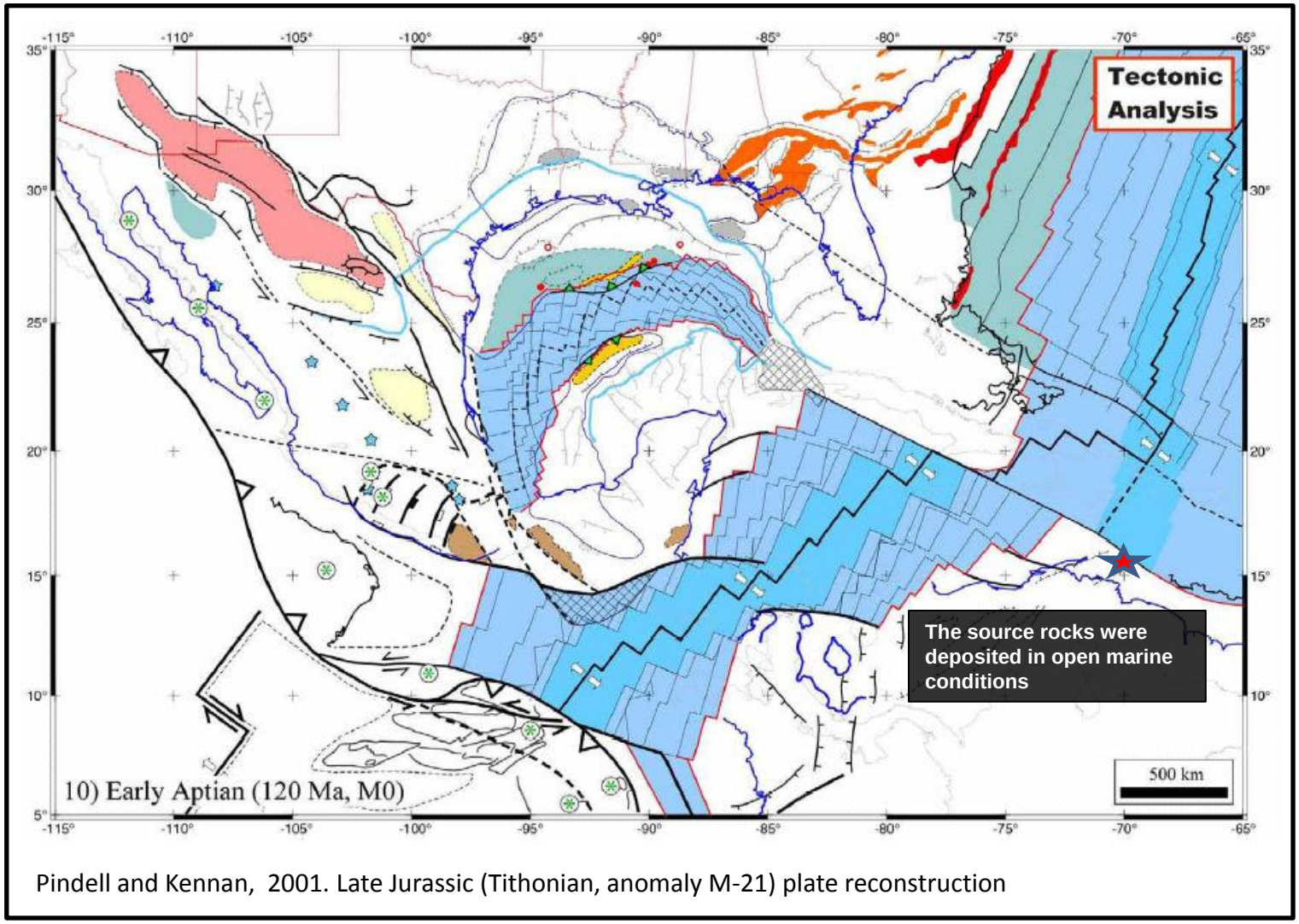
After Wood, 2000

http://www.gstt.org

The proposed system

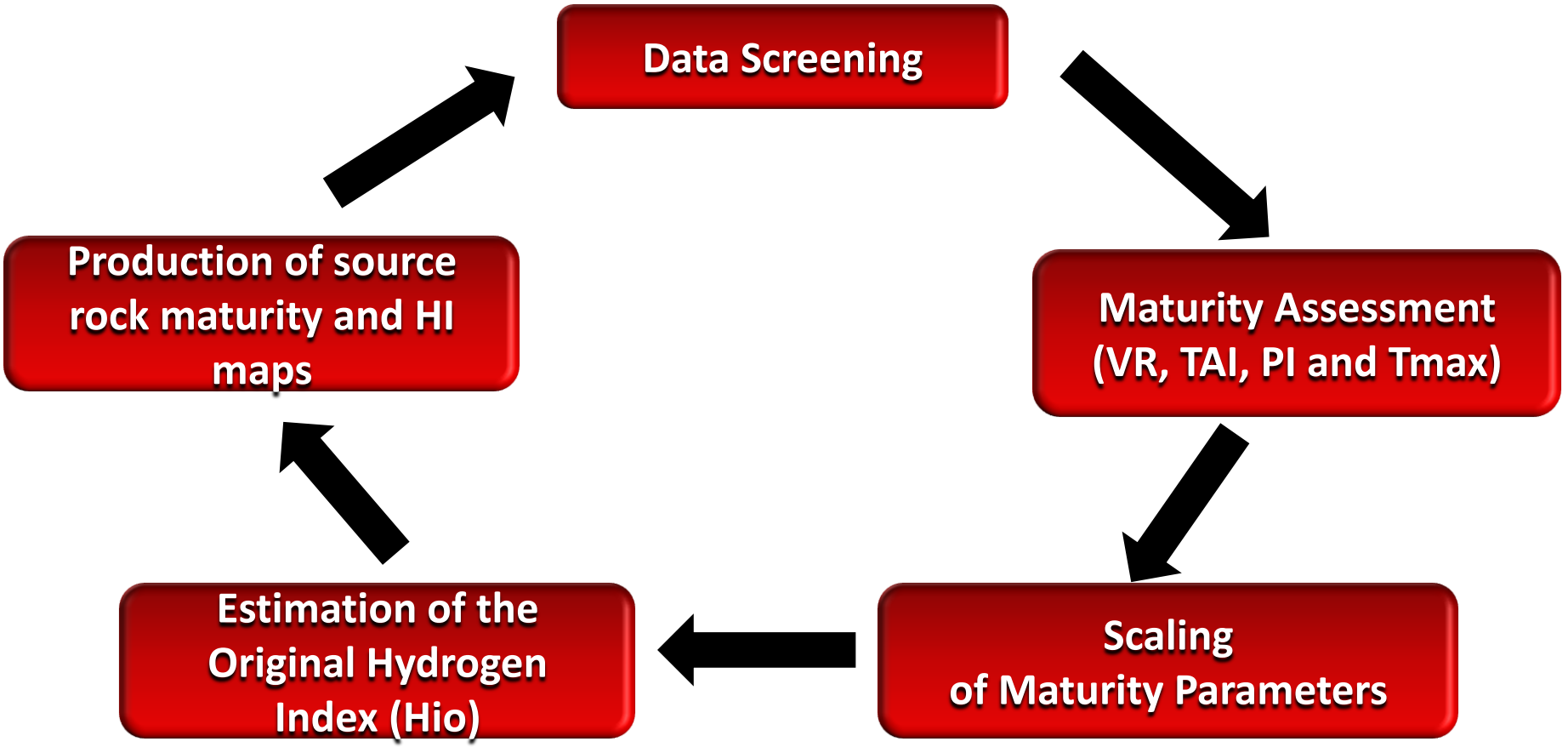
Source rocks environment of deposition

Aptian (125-112Ma)



Pindell and Kennan, 2001. Late Jurassic (Tithonian, anomaly M-21) plate reconstruction

Source Rock Assessment Work-Flow



Database and Software

- Twenty-three (23) wells.
- Geochemical and biostratigraphic reports.
- 1D Basin Models done using BasinMod software (2012).

Problem: Maturity Assessment

- The dataset included Vitrinite Reflectance readings (Ro%), TAI (Thermal Alteration Indices), PI (Production Indices) and Tmax (/C) values. An attempt was made to bring all of these to Ro% equivalents

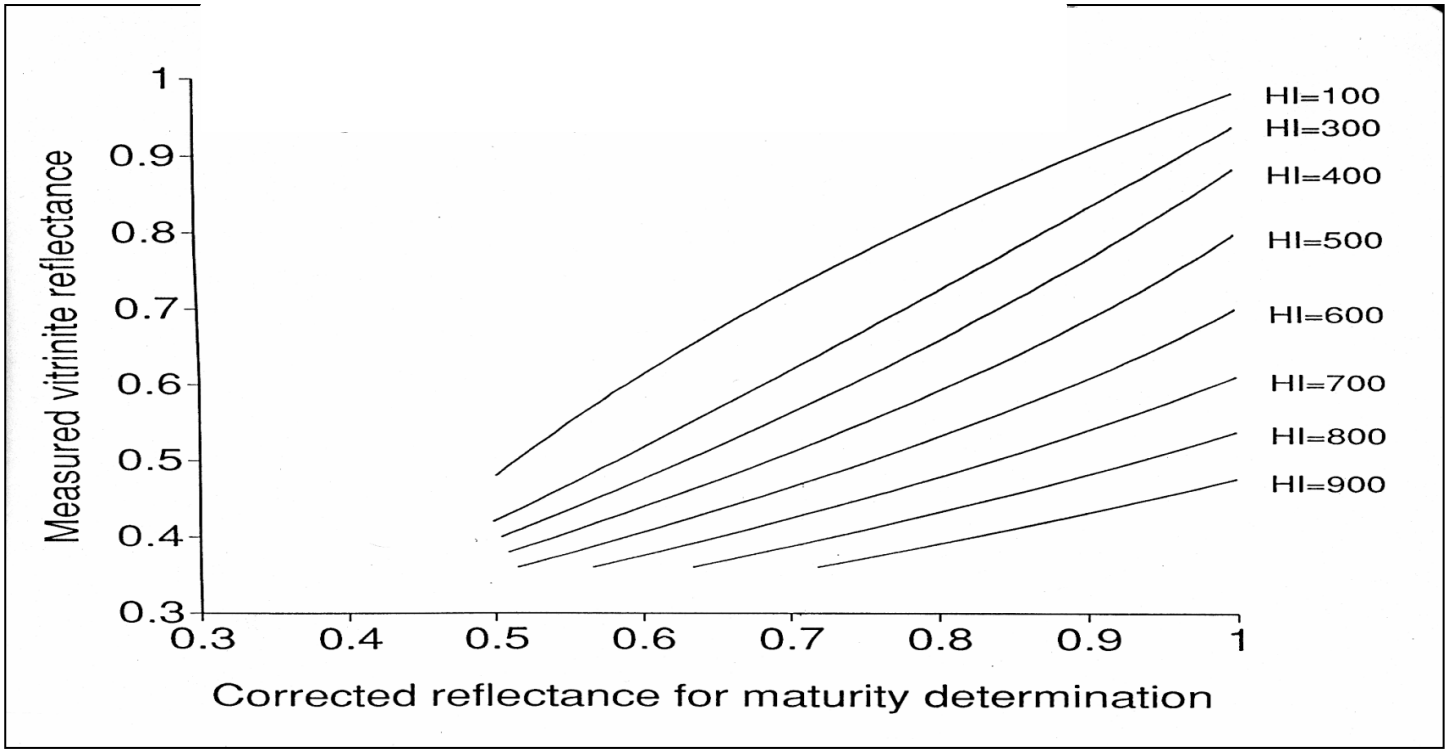
Data Screening

It is always important to screen geochemical data hence the following steps were taken to try to reduce bad data being used in the interpretation.

1) Average vitrinite reflectance values derived from 40 or more readings with standard deviation readings of 0.05 or less
2) Only values of S_2 above 3 mg HC/g rock were used.
3) TAI values were converted as a range and not as an absolute value
4) Only HI(hydrogen Indexes) calculations with 3 or more samples were considered for the evaluations.

Handling suppressed Vitrinite?

- It is well known that vitrinite readings from a source rock which has expelled large volumes of hydrocarbons are generally suppressed. To correct for this Lo (1993) was used to propose a method to get a fairly accurate maturity reading. See below.



Method- Converting Tmax to VR(%)

- All of the studied maturity data for the Cretaceous Fms were brought to Ro equivalents for modelling purposes.
- The maturity of the studied source rocks were assessed using VR values, Tmax and TAI (1 to 5 scale).
- The Tmax was converted to Ro equivalents using two equations. The first averaged due to work based on the Barnett shale (Jarvie et al. 2001)

  $R_o = 0.0180 (T_{max}) - 7.16$ (1)
- The second was converted using relationships observed in this study

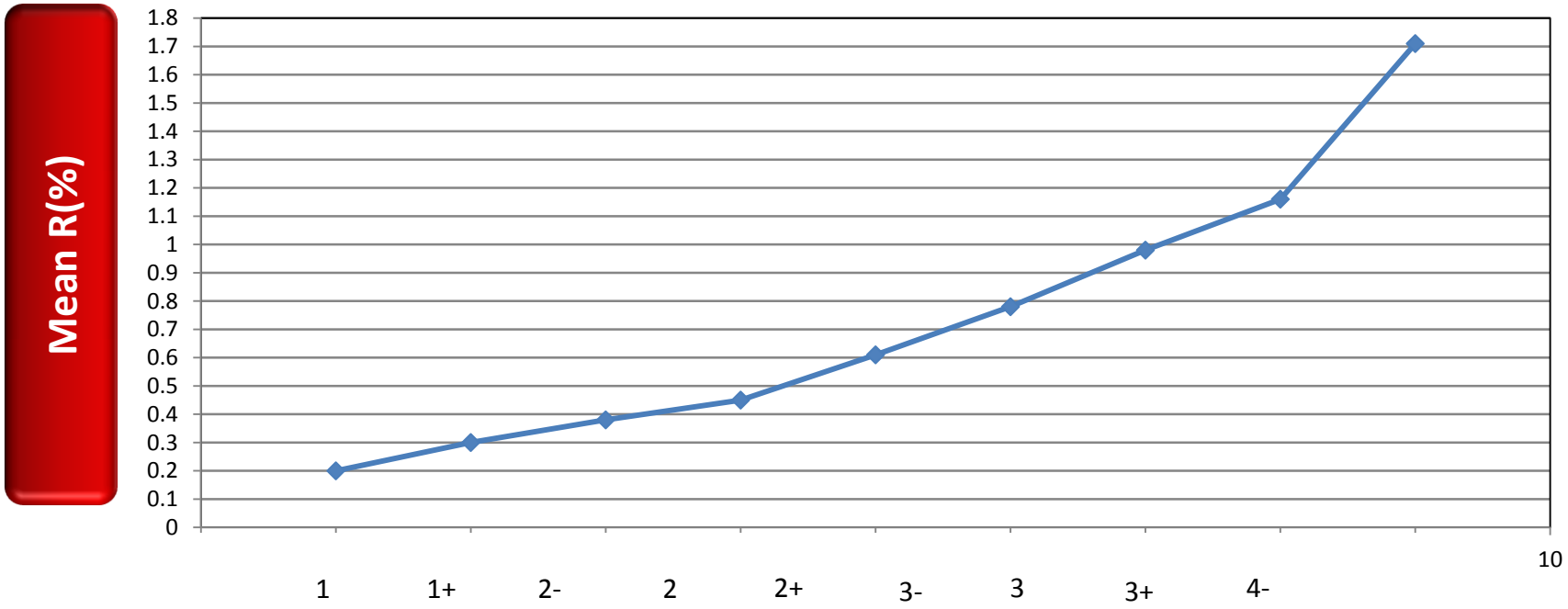
  $R_o = 0.023 (T_{max}) - 9.28$(2)

  The results were then cross referenced using relationships outlined by Peters and Cassa (1994) for validity.

A numerical average of the two values was then calculated based on the two readings from (1) and (2) above

The TAI was converted to VR(%) using a relationship derived by Pearson (1990)

Conversion of TAI to mean VR equivalents



(Thermal Alteration Index)

Pearson, 1990

Method- Reservoirs

- The potential reservoirs are the source rocks themselves , mainly the sand prone facies of the Cuche ,Naparima Hill and Gautier Formations.
- The reservoirs were analysed by incorporating work from Erlich et al.(2003) and by basic log motif analysis with the palaeoenvironments in mind.
- The stratigraphic thicknesses of the Cretaceous formations were estimated primarily using log data and corrected by calculated bed dip angles.

Generation- Migration Accumulation

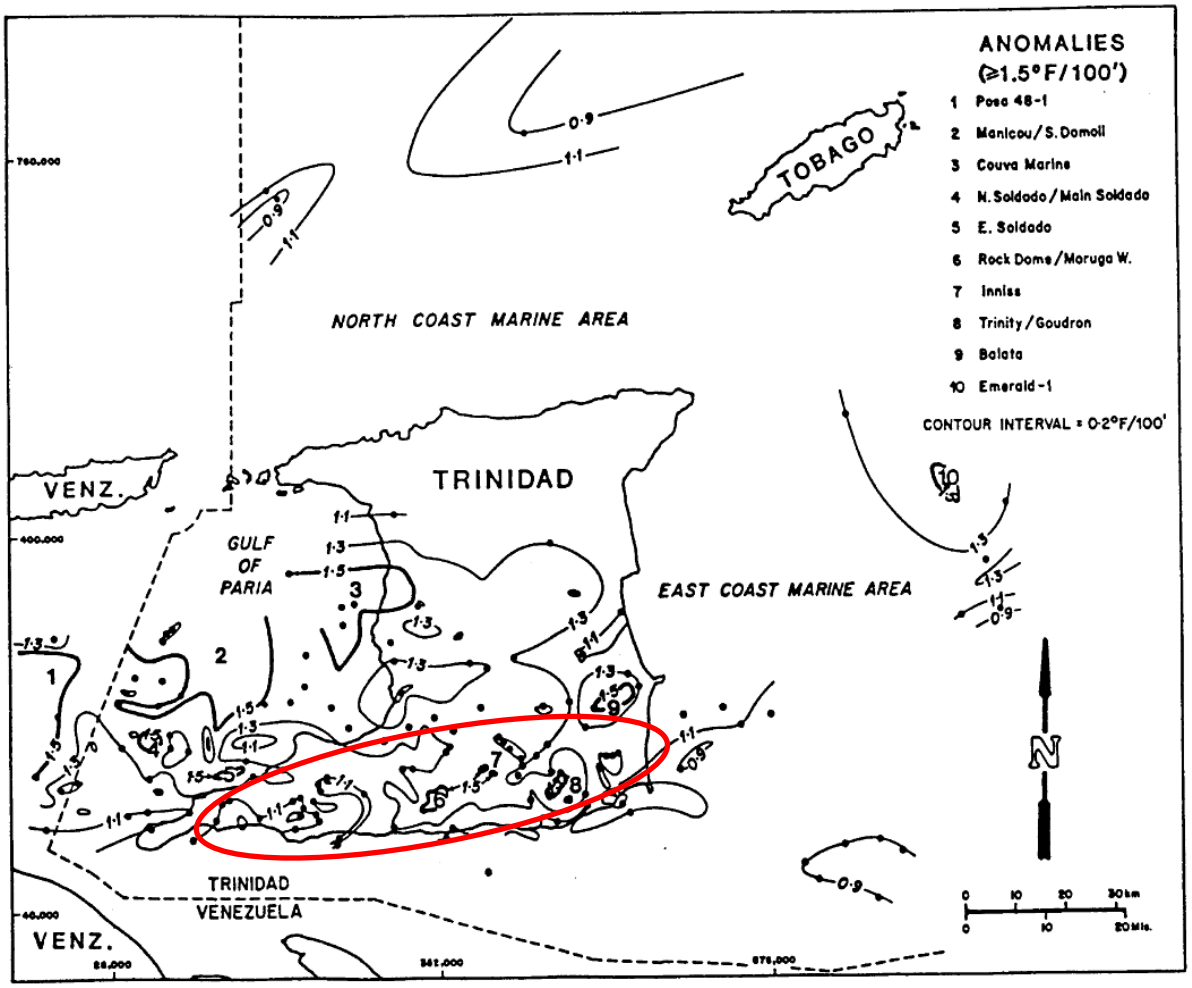
- Four (4) 1D Basin Models – two drilled wells and two extrapolated wells

Boundary Conditions

- Palaeowater depth (based on palaeontologic data) , sediment water interface temperature (based on Wygrala ,1989) and heat flow (based on Allen & Allen 2005 and present day measured data).
- Eroded sediment estimated by using Ro data extrapolated to 0.2%.
  (Dow , 1977)
- Input- Llg data and event timing mainly from Pindell and Kennan (2007).
- HIo and maturity estimated using results seen here.
- TOC original assumed to be between four and twelve percent (4- 12%) based on publications (Rodrigues , 1988)
- The calibration points used in the models were the present day geothermal gradients, (20- 23C/km) and the modelled maturity profiles (Ro).

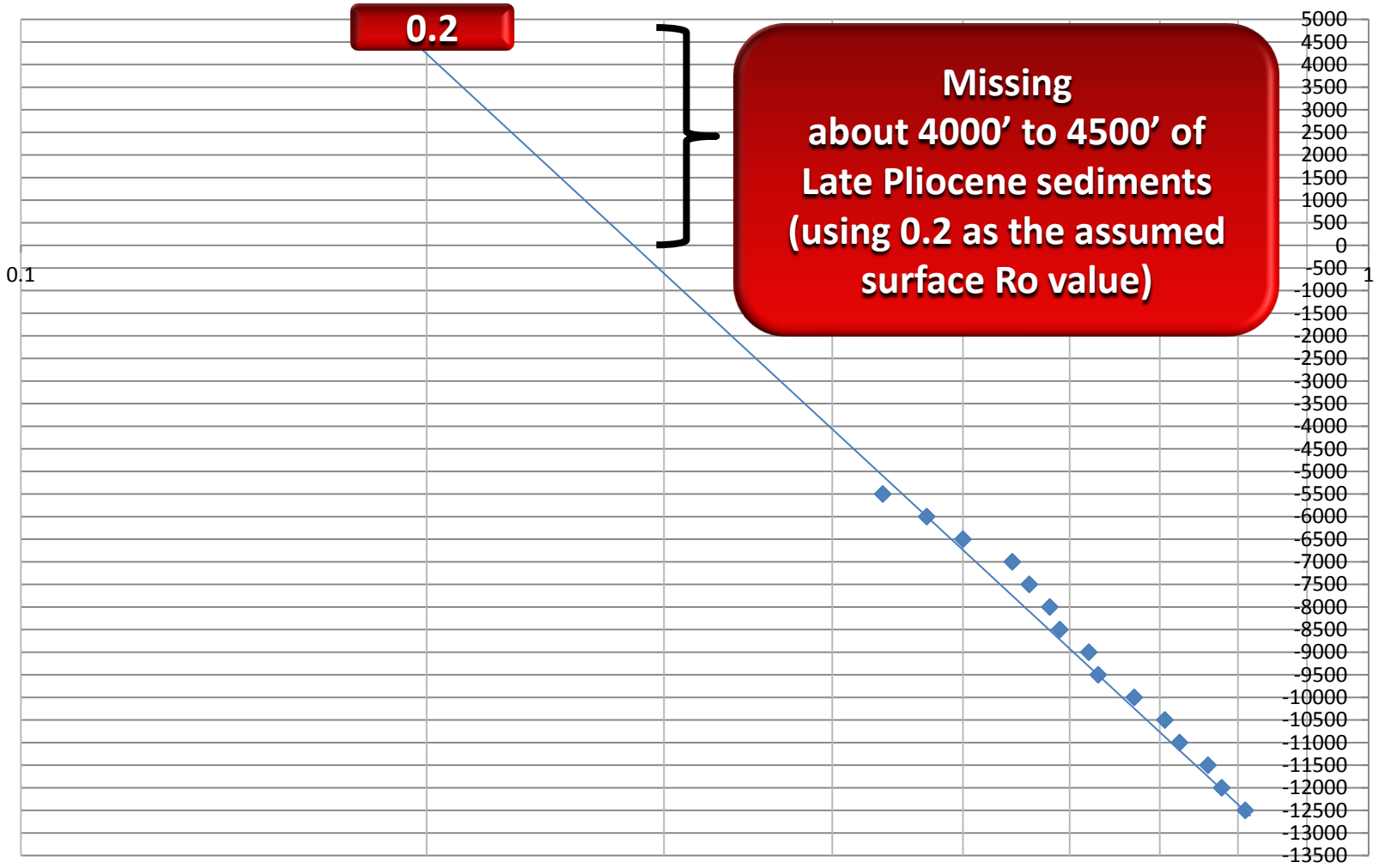
Present day geothermal gradients

- Converted average geothermal gradients range from 20 to 23 C/km (based on bottom hole temperatures).



Rodrigues, 1990

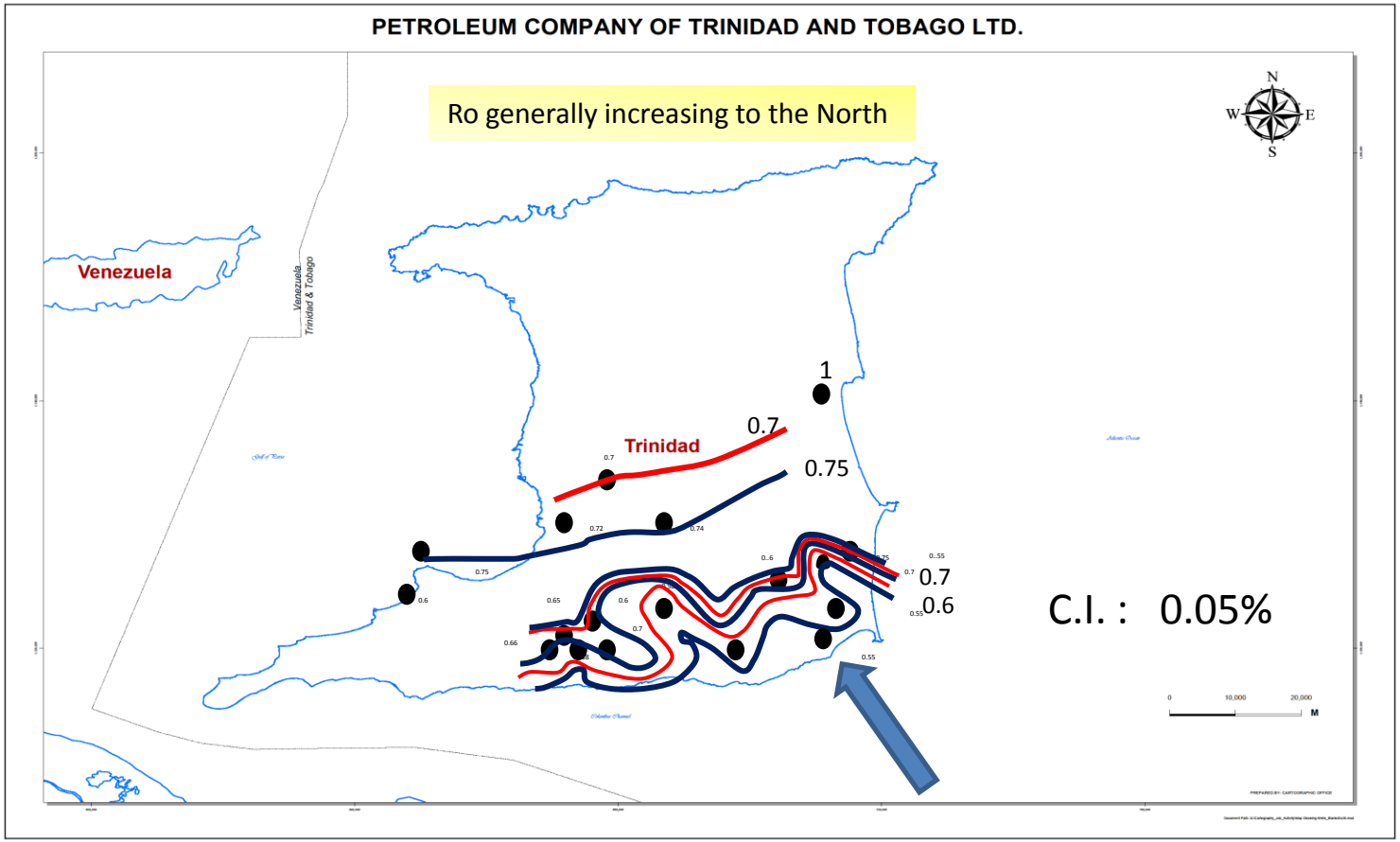
Example showing the estimation of missing sediment from mean VR data



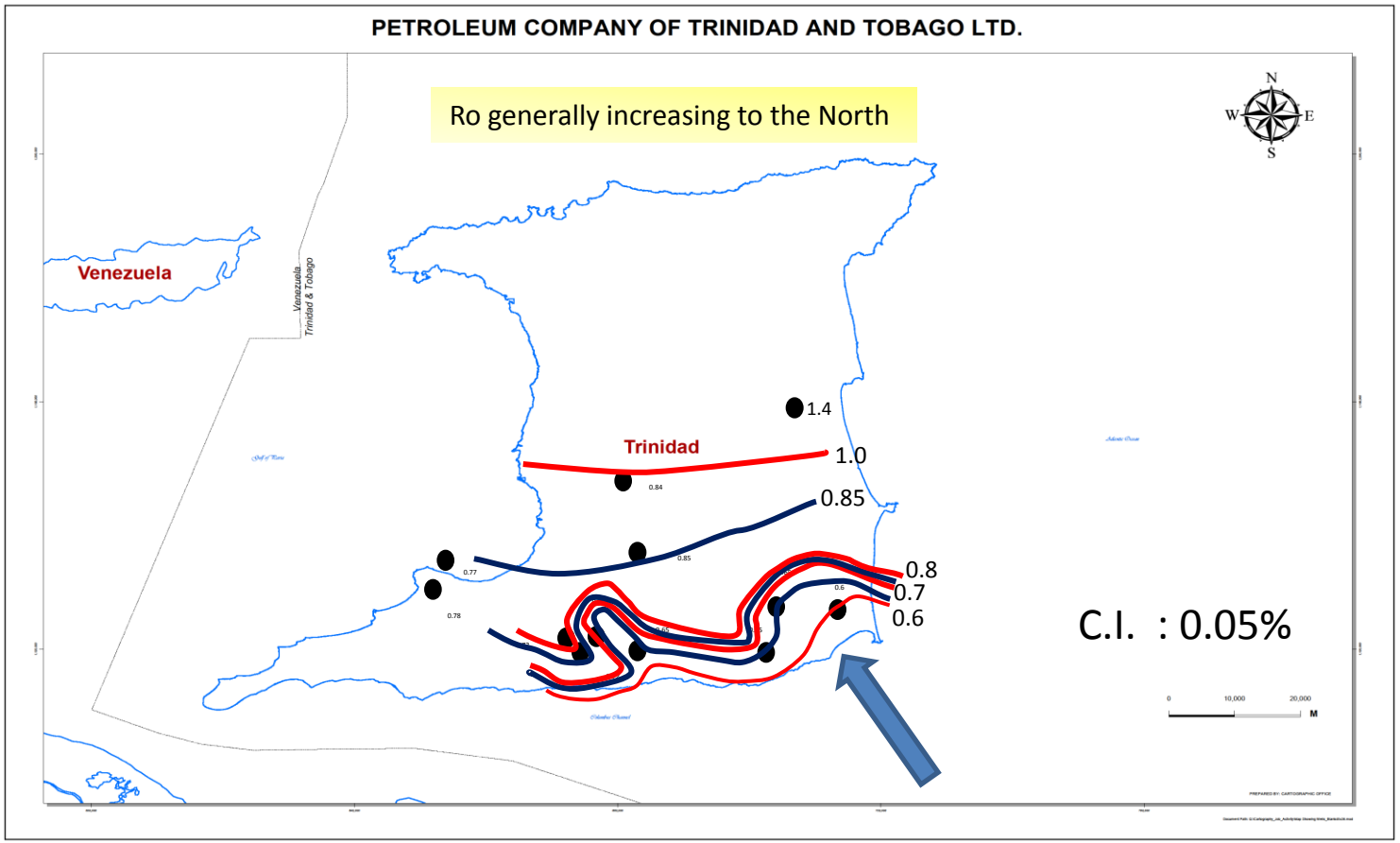
Maturity Assessment- comparisons

MATURITY	Ro	TMAX	TAI	PI
Immature	0.2-0.4	410-420	1- 2-	
Immature	0.4-0.6	420-432	2- to 2+	<0.1
Mature (Early)(Oil)	0.6-0.65	430-433	2+	0.1-0.15
Mature(Peak) (Oil)	0.65-0.75	433-438	2+ to 3-	0.25
Mature (Peak) (Oil)	0.75-0.85	438-443	3-	
Mature(Peak) (Oil)	0.85-0.9	443-446	3-	0.4
Mature(Late) (Oil)	0.9-1.35	446-468	3- to 3+	0.4
Postmature Oil	>1.35	>468		
Mature Oil (Early) (wet gas)	1.0-1.1			
Mature Oil (Peak) (wet gas)	1.2-1.8		3+ to 4-	
Mature(Late) (gas)	1.8		4-	
Postmature (wet gas floor)	2.0			

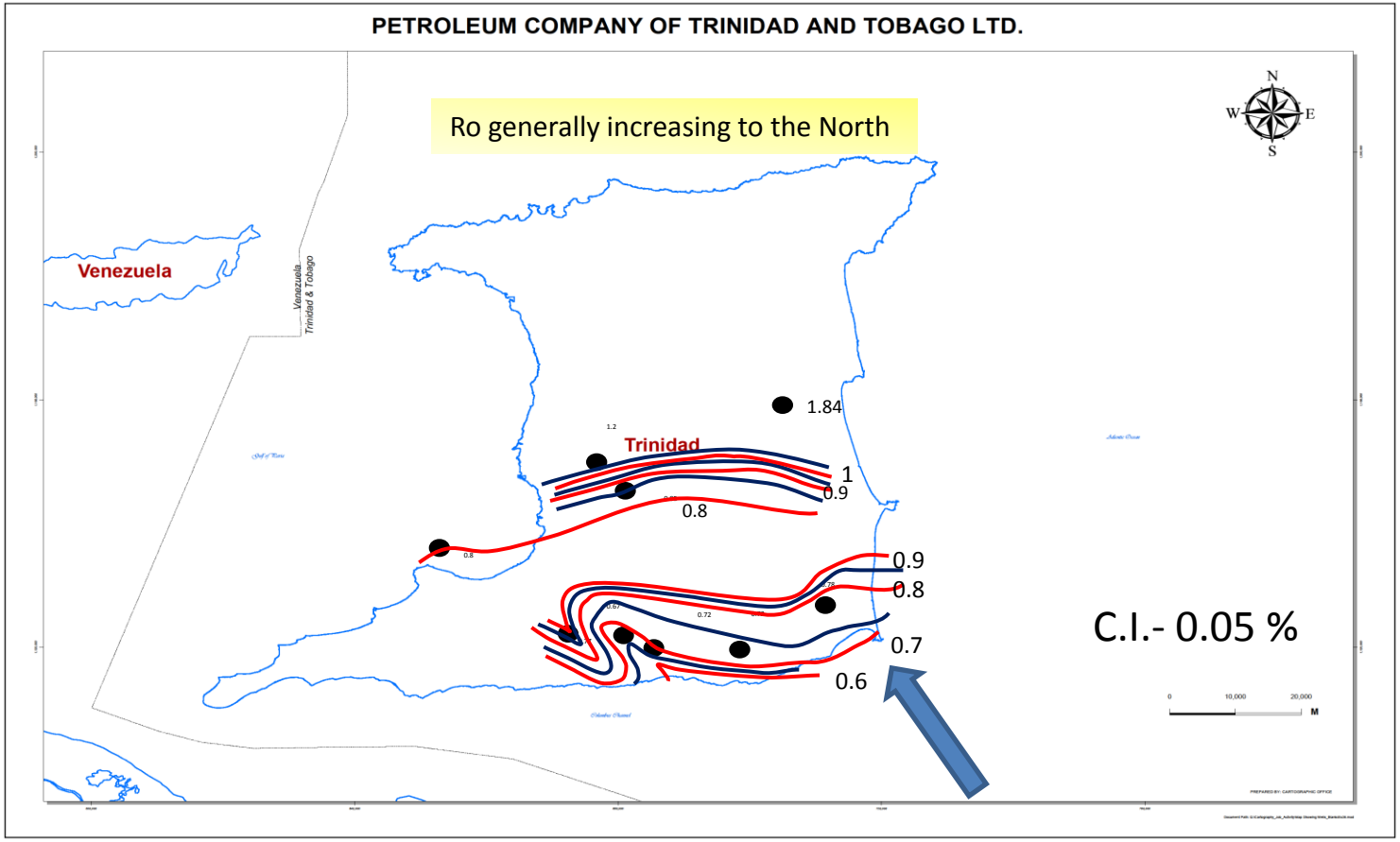
Naparima Hill Maturity (Ro%) equivalent



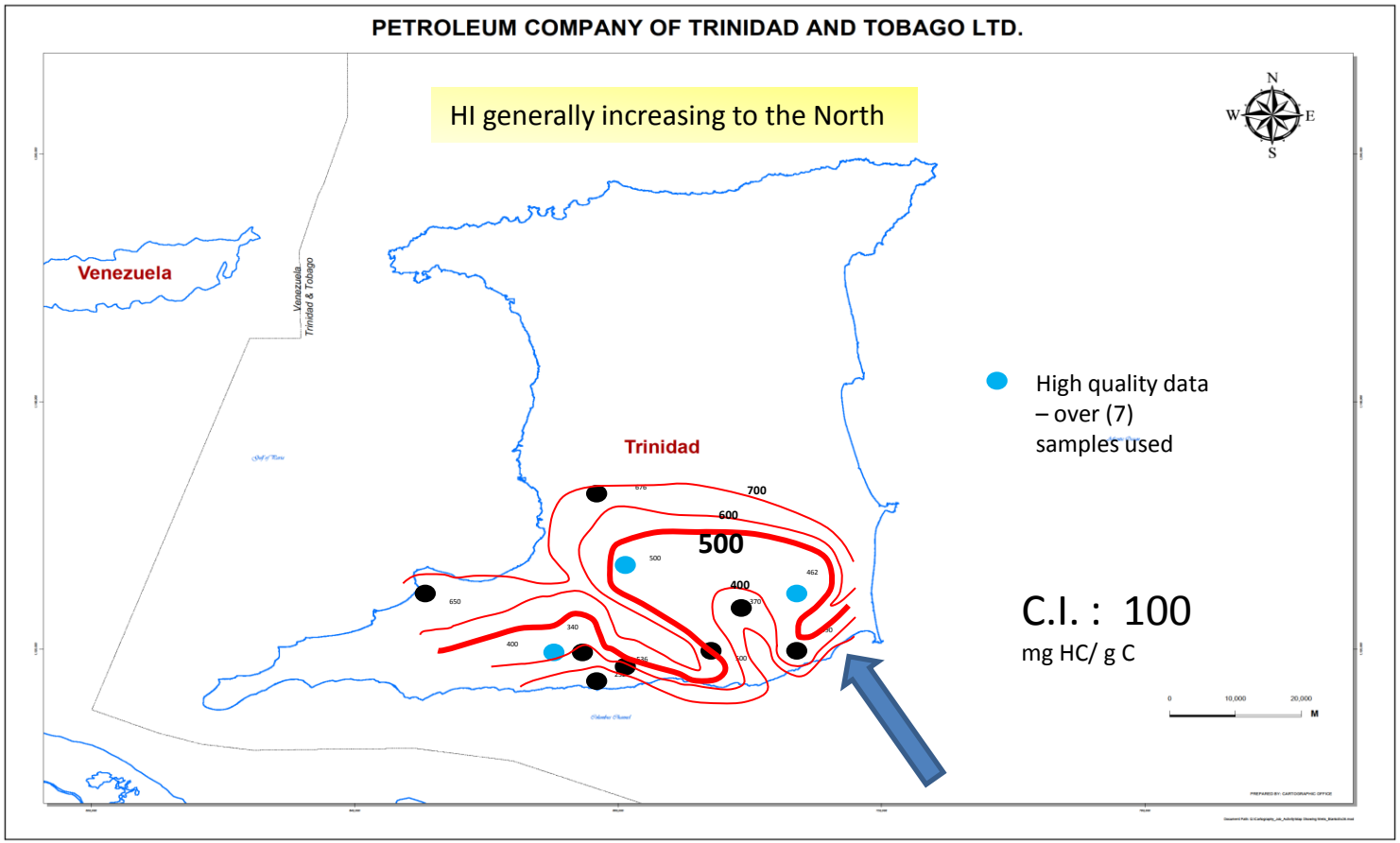
Gautier Maturity (Ro%) equivalent



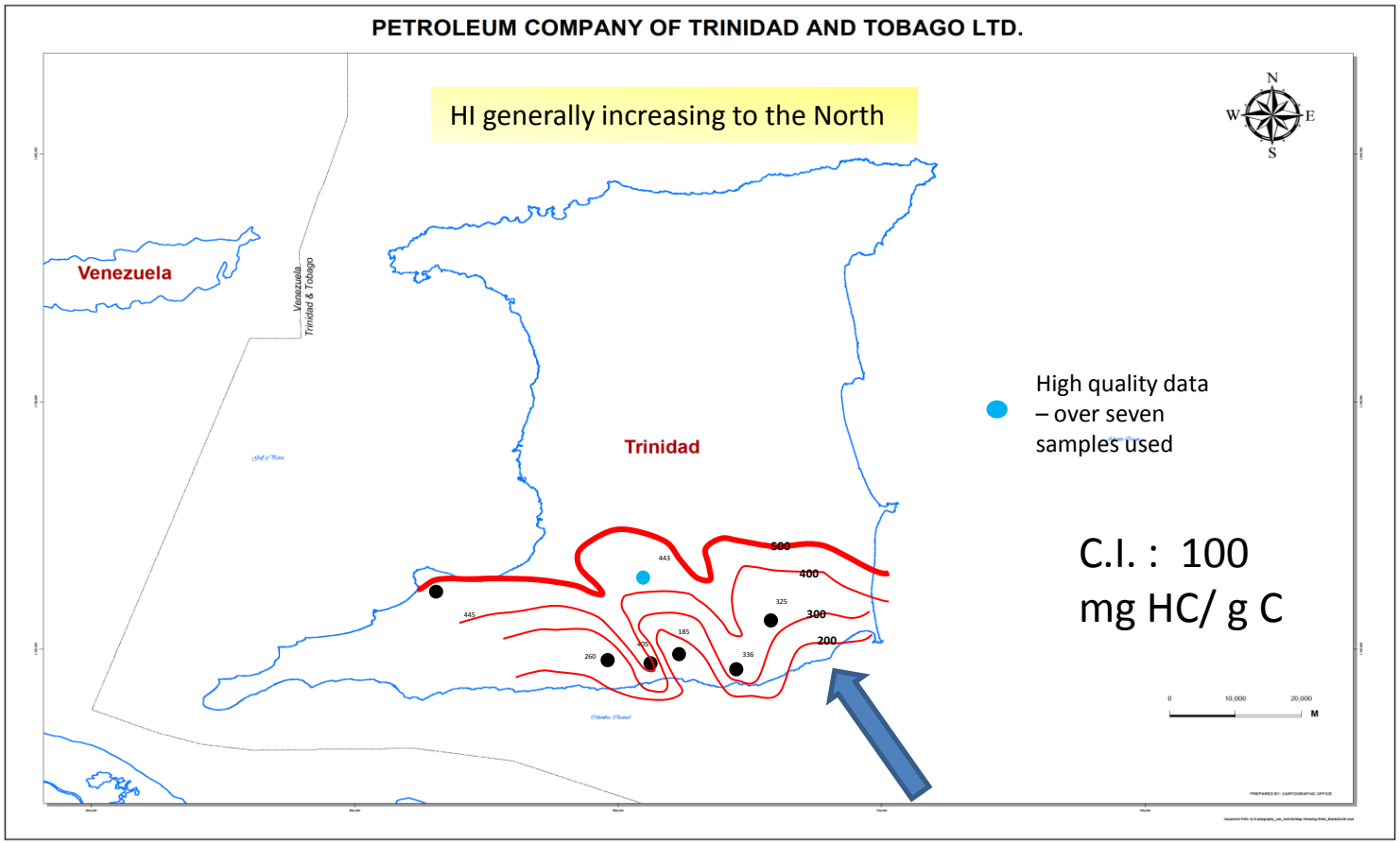
Cuche Maturity (Ro%) equivalent



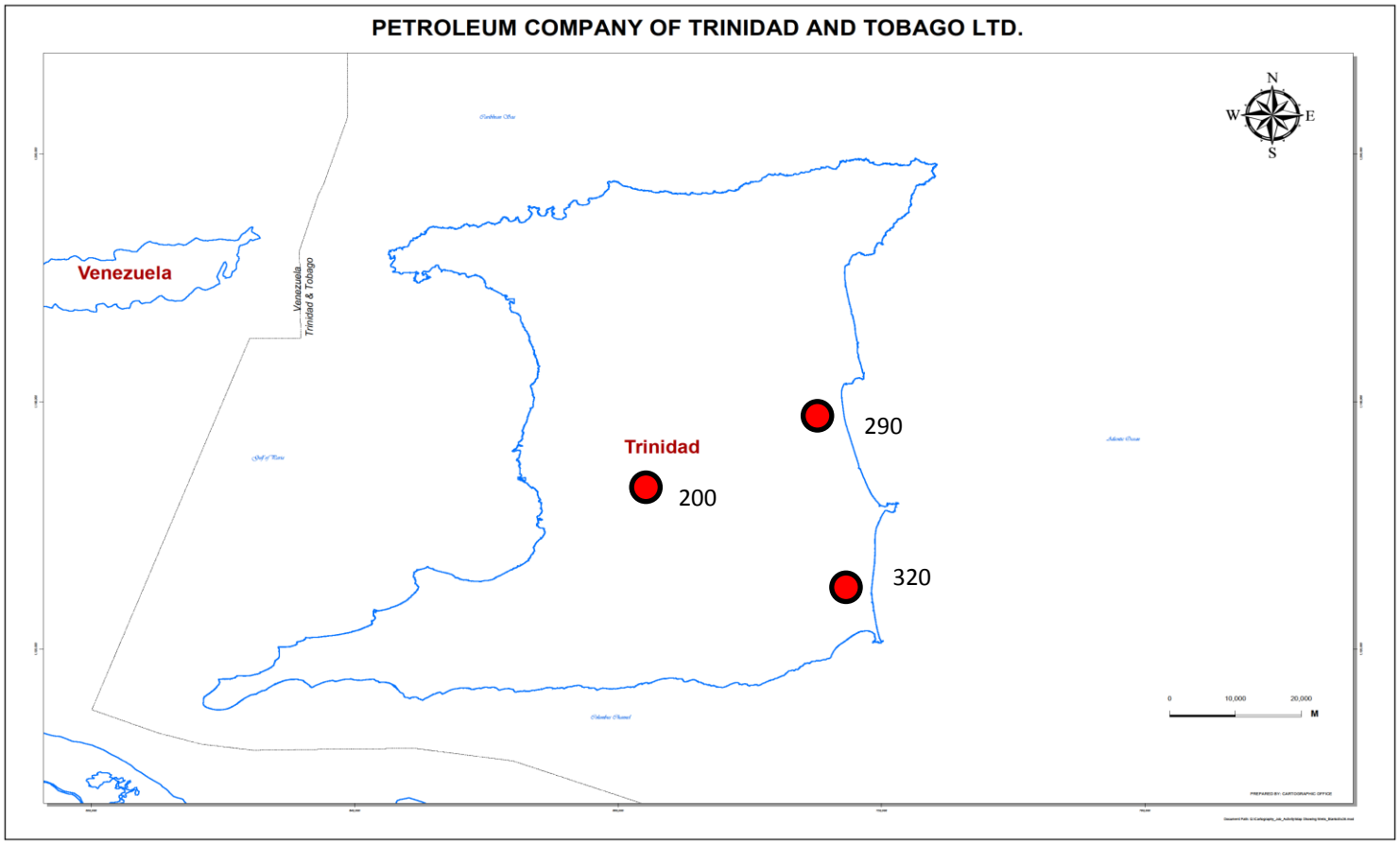
Original Hydrogen Index (HIo) (mg HC/ g C) of the NH



Original Hydrogen Index (HIo) (mg HC/ g C) for the Gautier

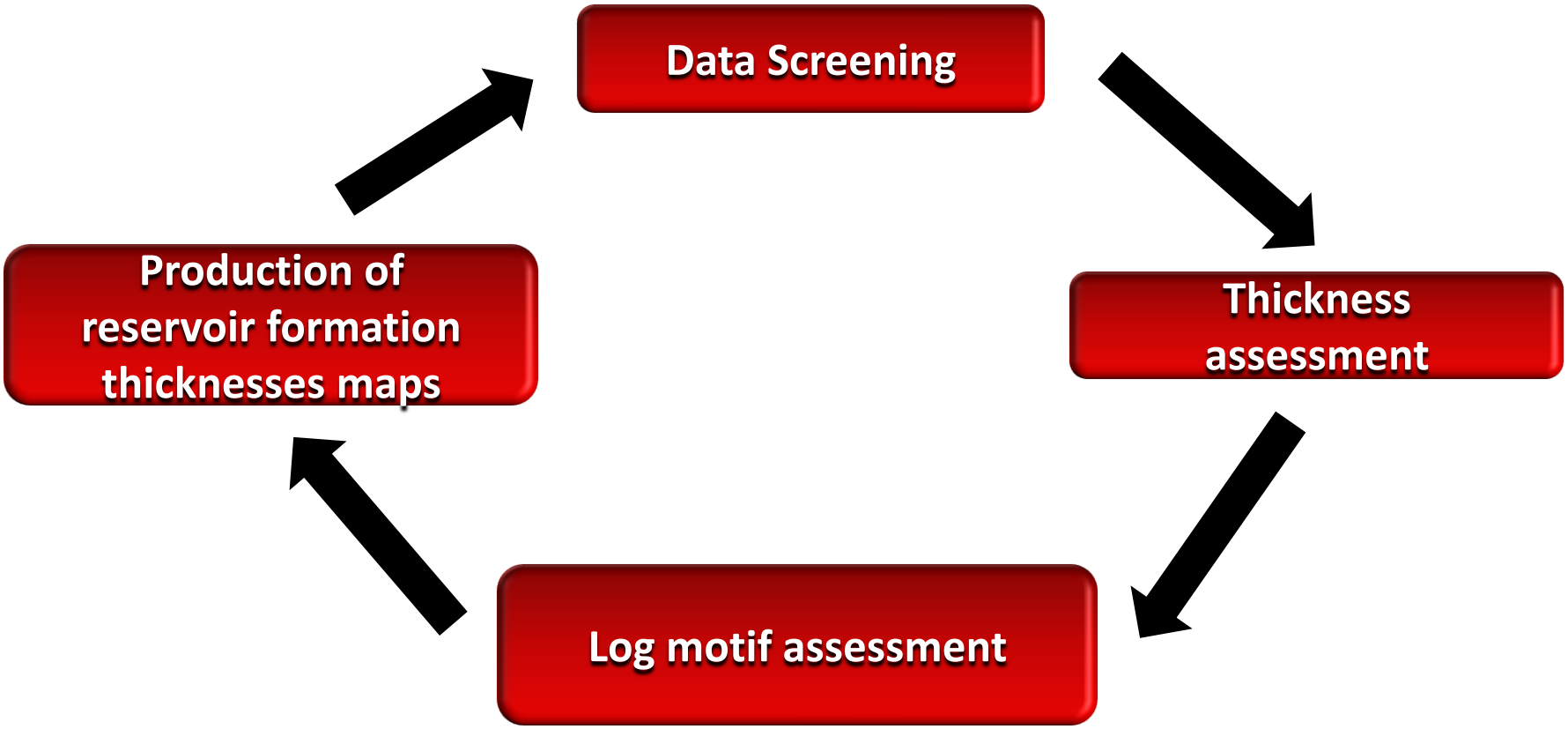


Original Hydrogen Index (HIo)/Cuche (only 3 points)

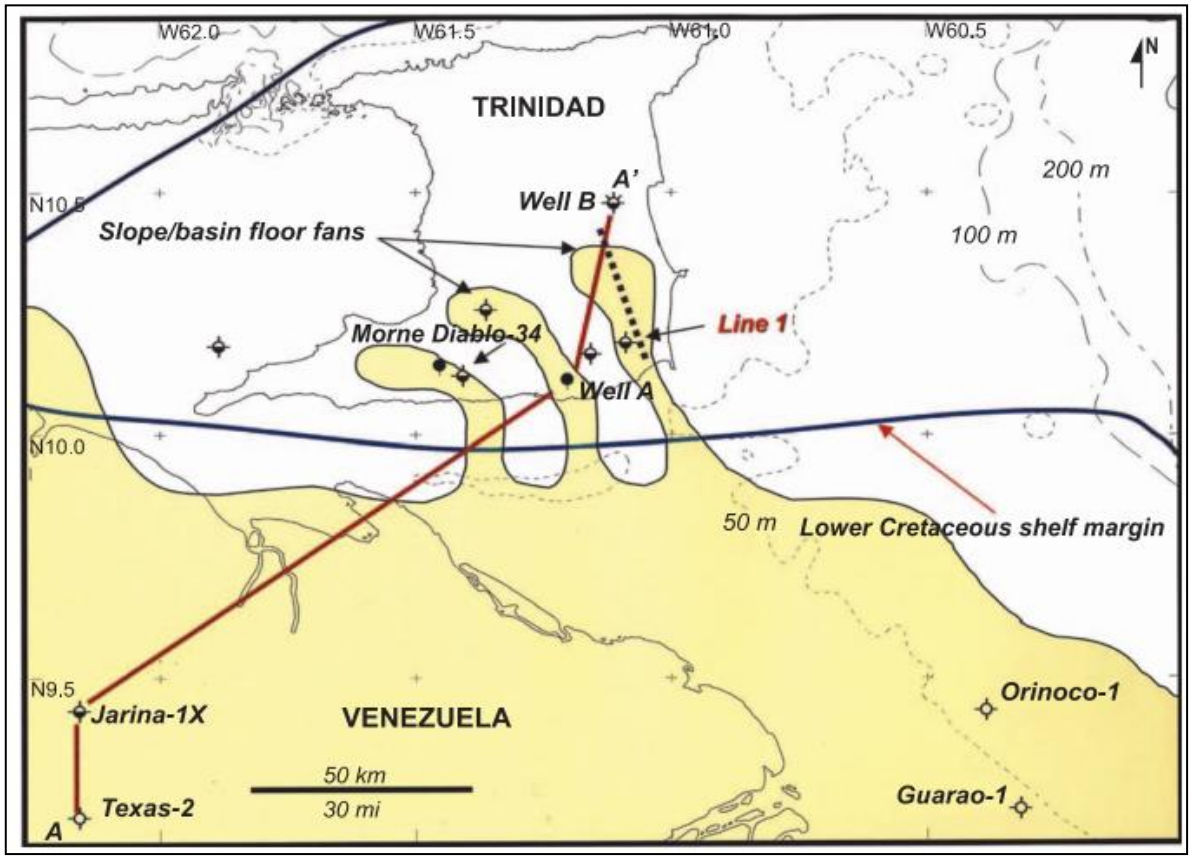


Reservoir

Reservoir Assessment Work-Flow

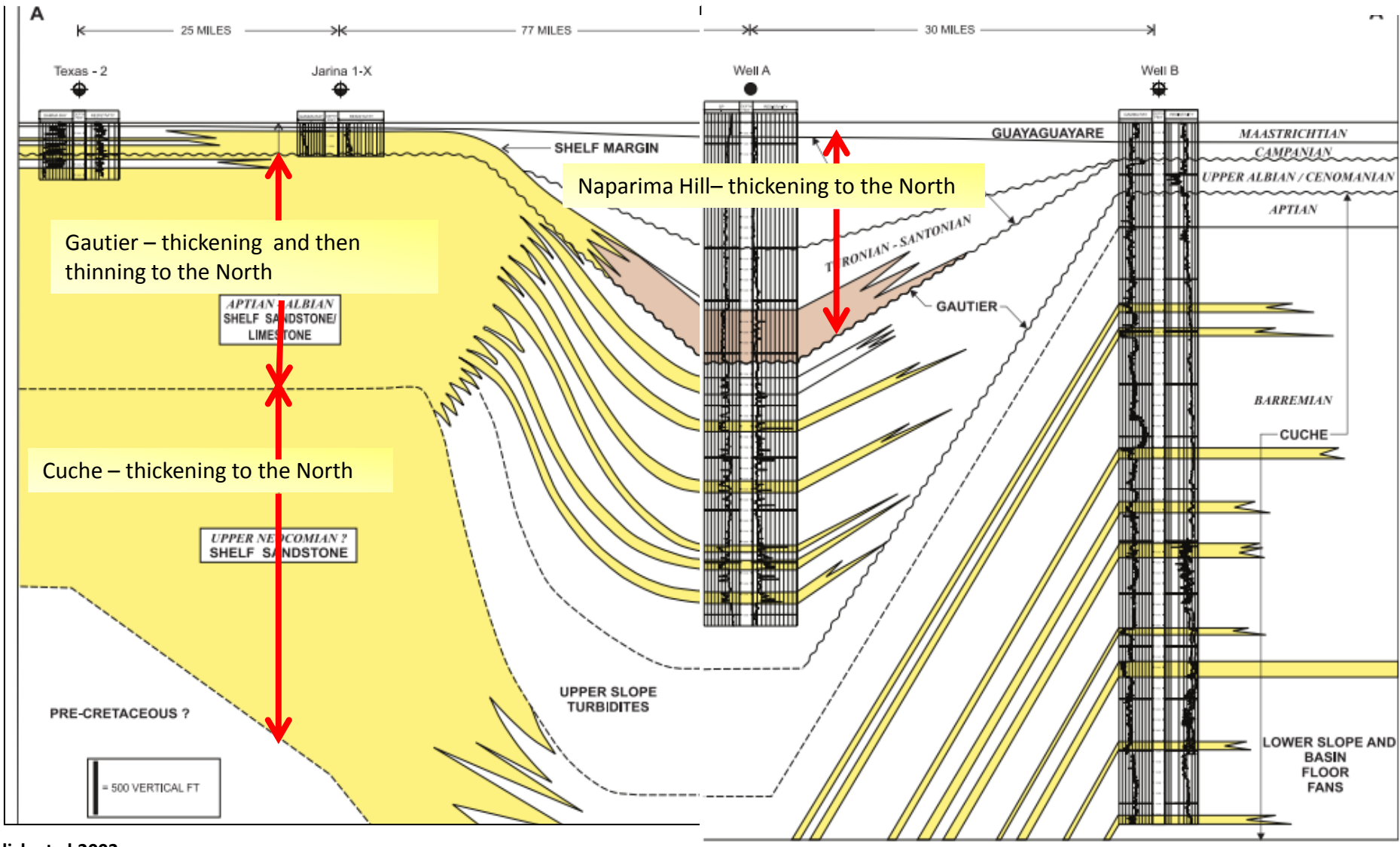


Palaeoenvironment of the Cretaceous Formations – (upper to mid slope)



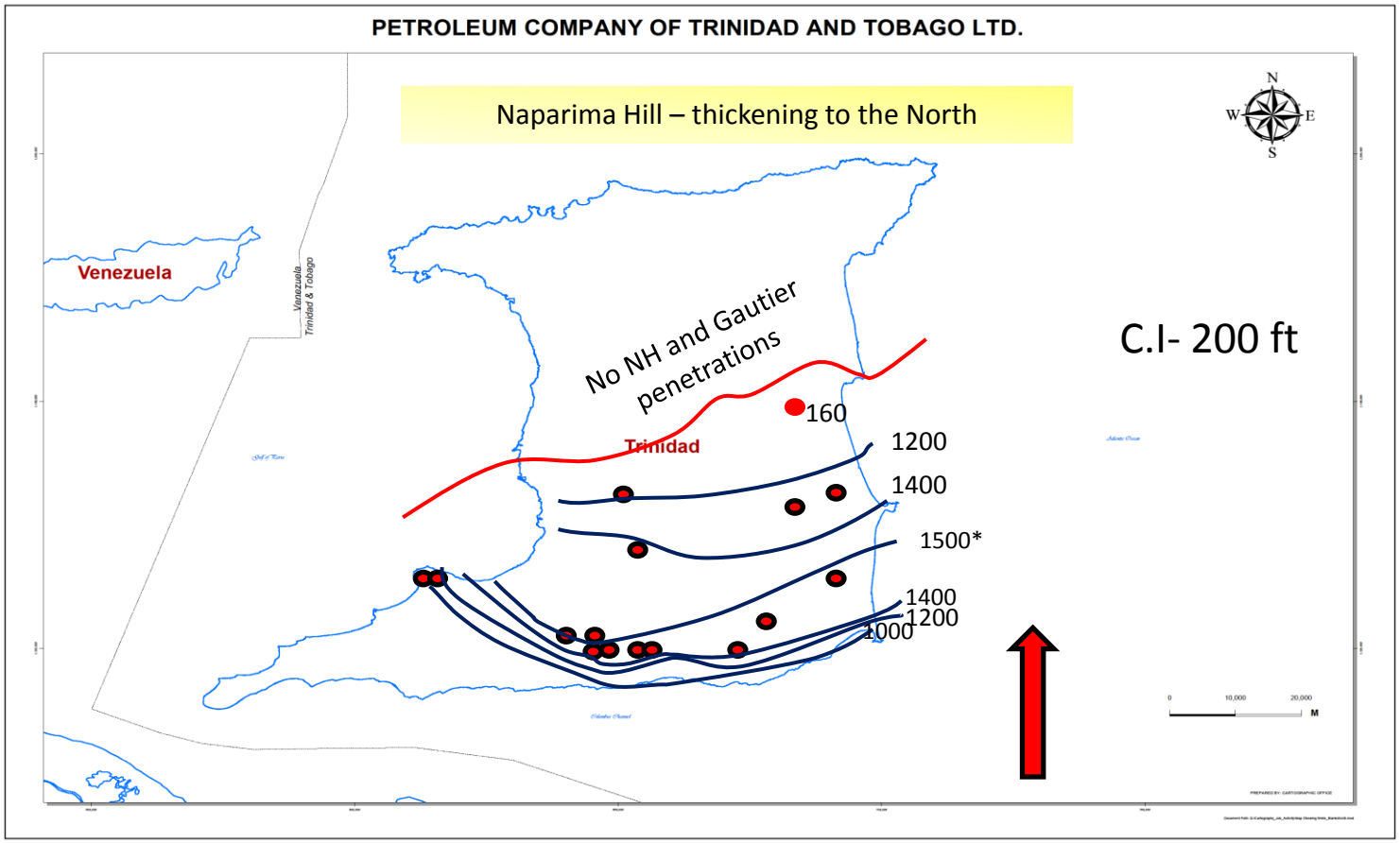
Possible reservoirs are deep water turbidites deposited in an upper slope environment

Thickness of the Cretaceous Formations (North thickening formations)

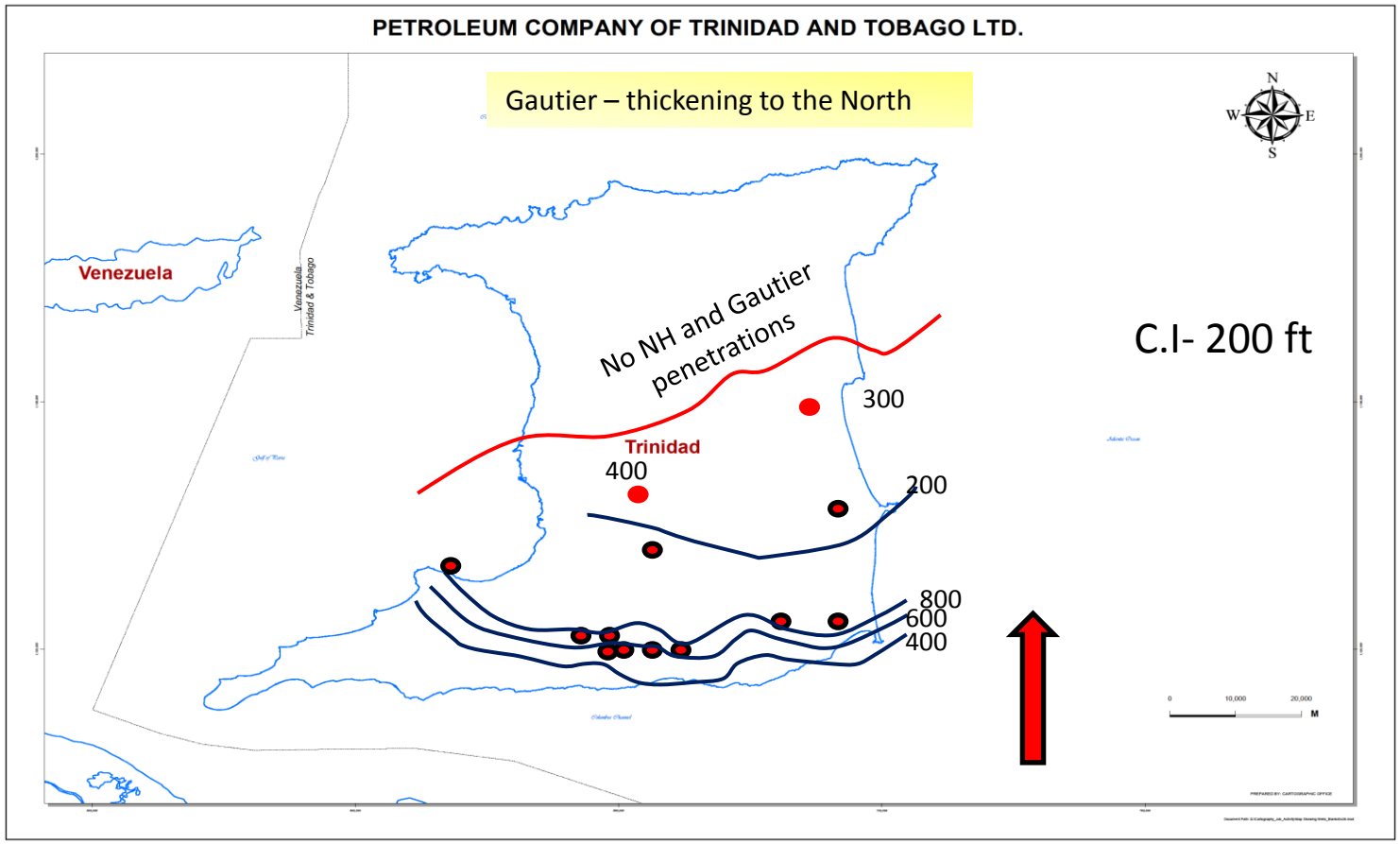


Erlich et al.2003

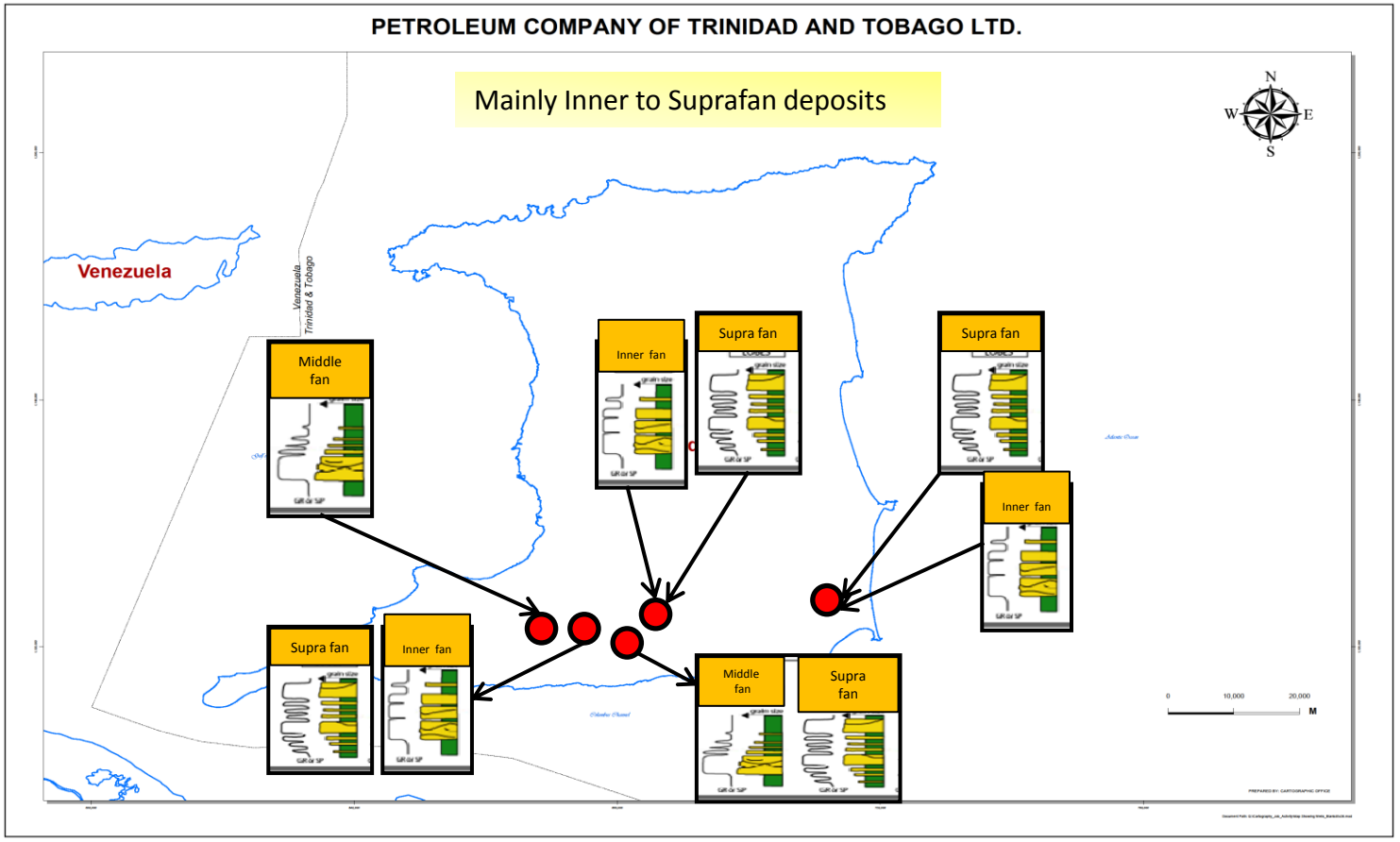
The thickness of the Naparima Hill (ft)



The thickness of the Gautier Formation (ft)

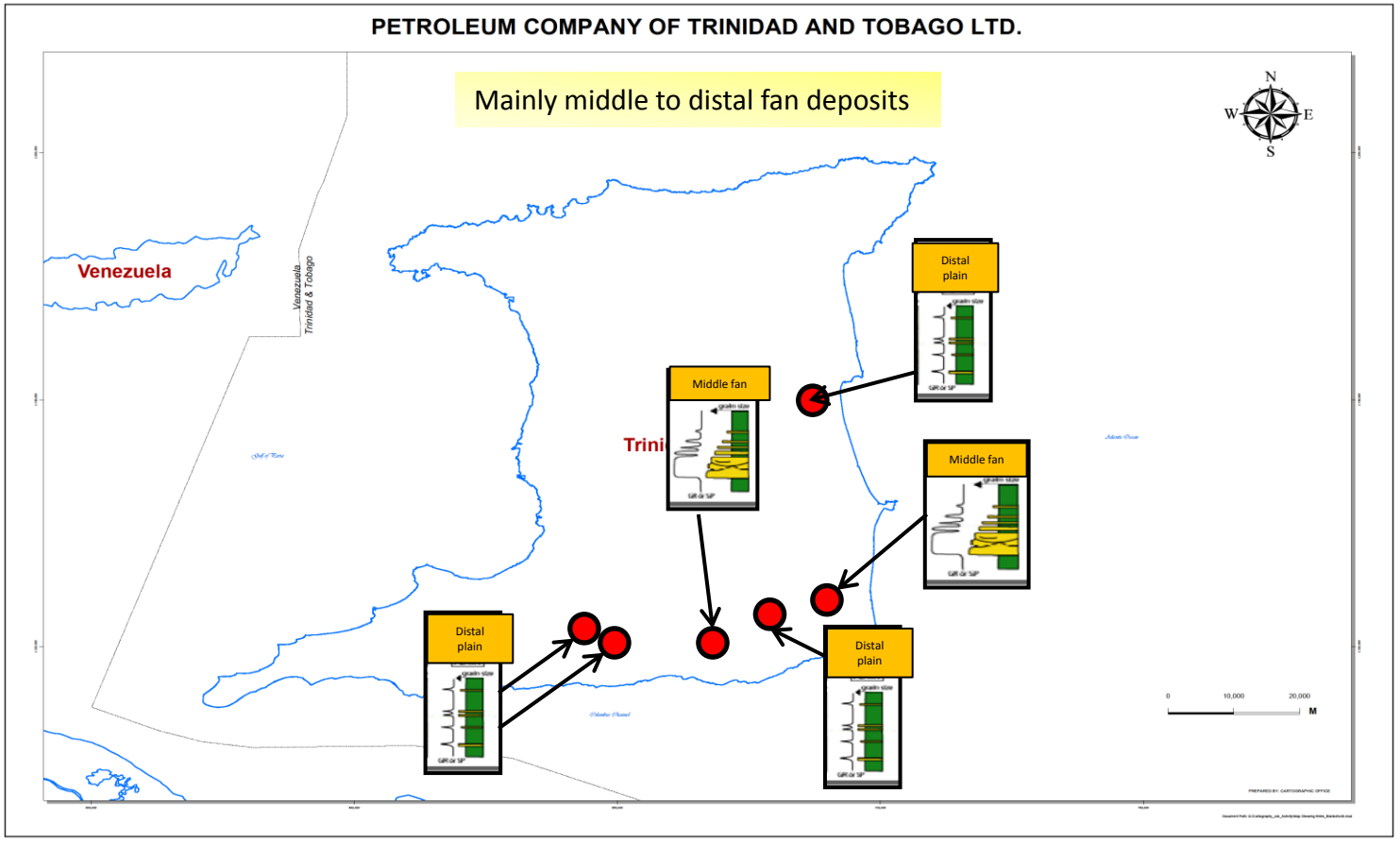


Sedimentary deposits based on log motifs (Naparima Hill)



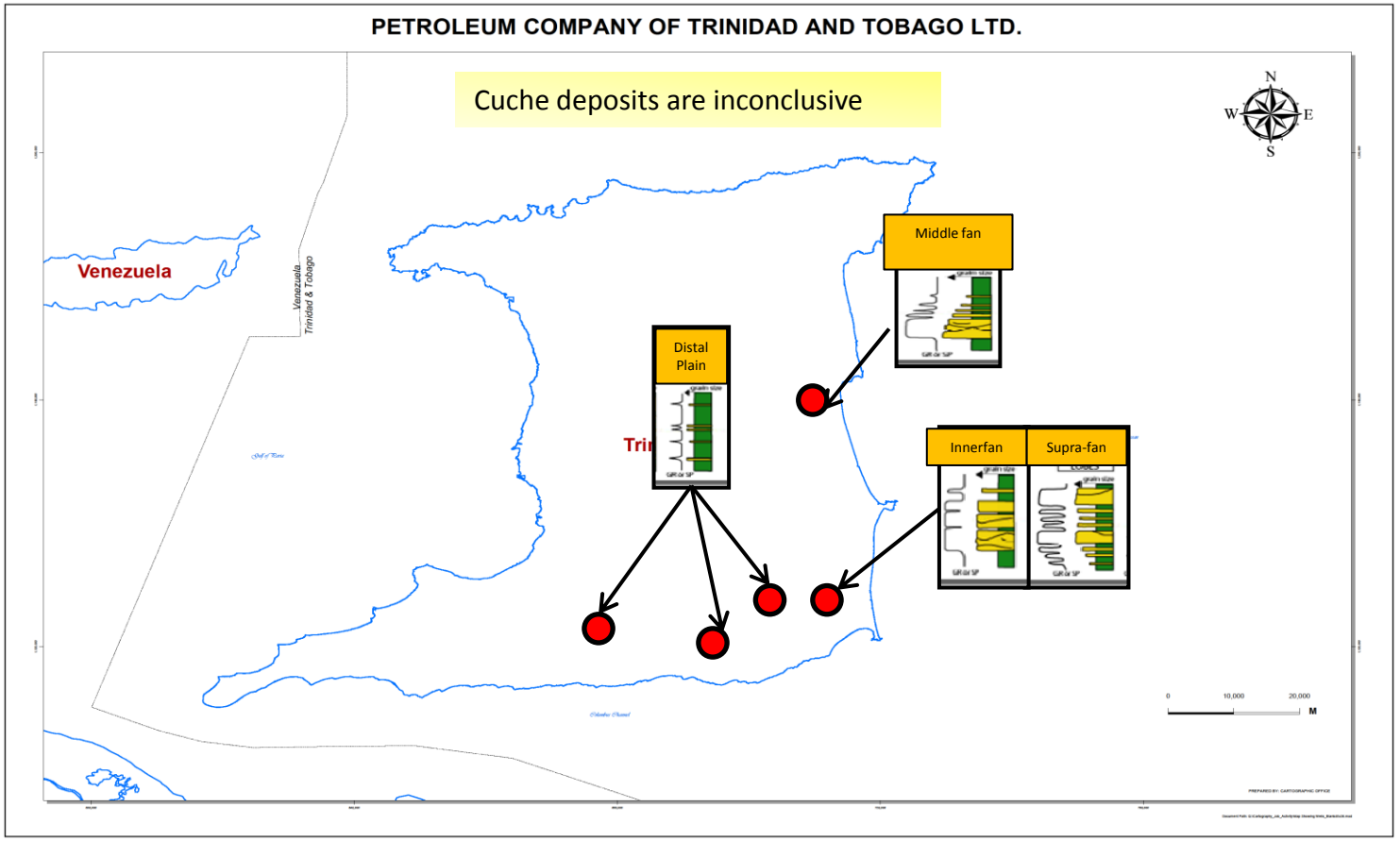
(Images adapted from Rider 1999)

Sedimentary deposits based on log motifs (Gautier Fm)



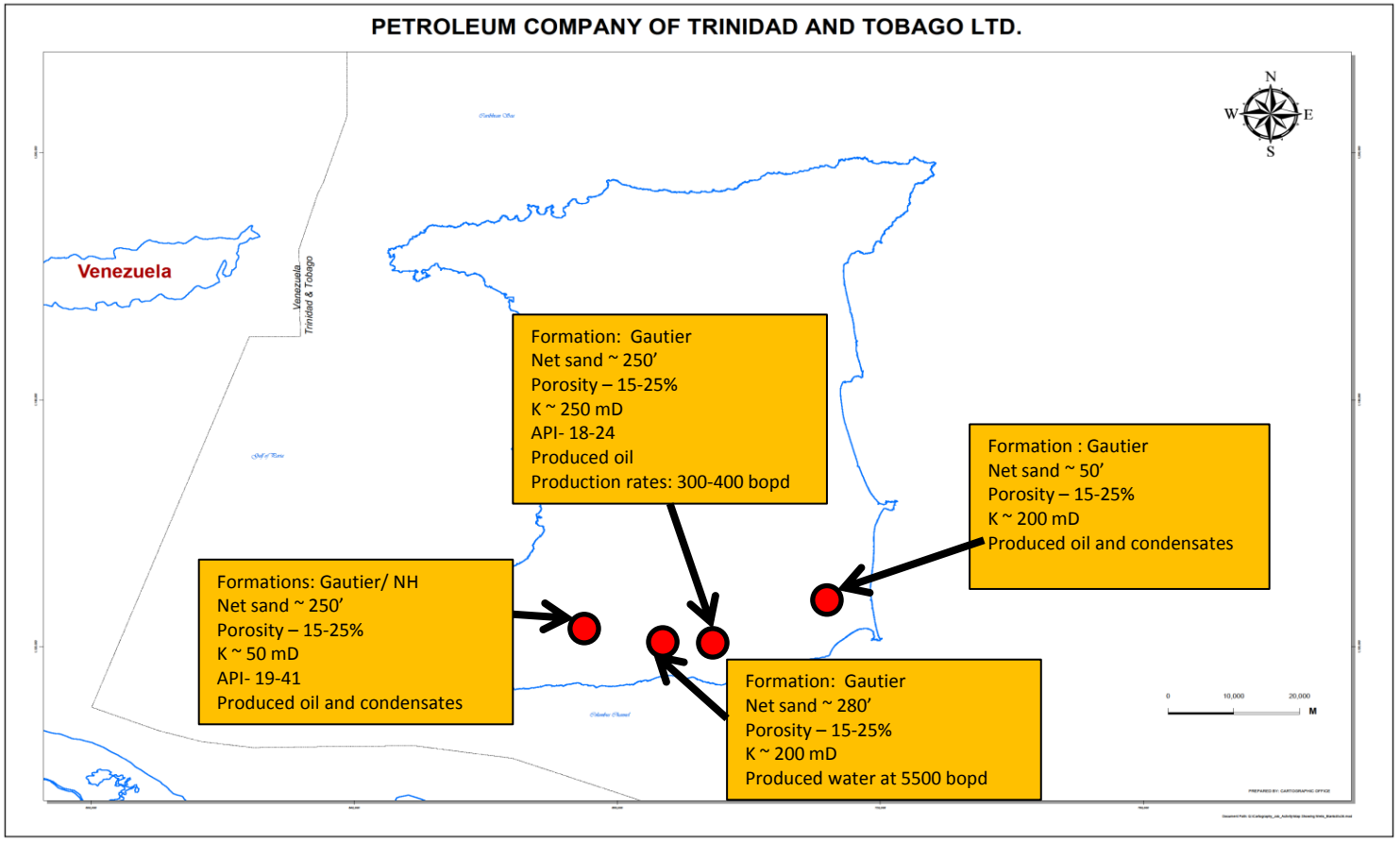
(Images adapted from Rider 1999)

Sedimentary deposits based on log motifs (Cuche Fm)



(Images adapted from Rider 1999)

Reservoir properties (Cretaceous Formations)



Seals and Overburden

- Seal- Intraformational shales of their respective formations. Assumed to be well compacted .

- Overburden- Tertiary and Quaternary sediments onshore Trinidad

Processes

Trap Formation

Cenozoic structural history: Evolution of the Caribbean Plate

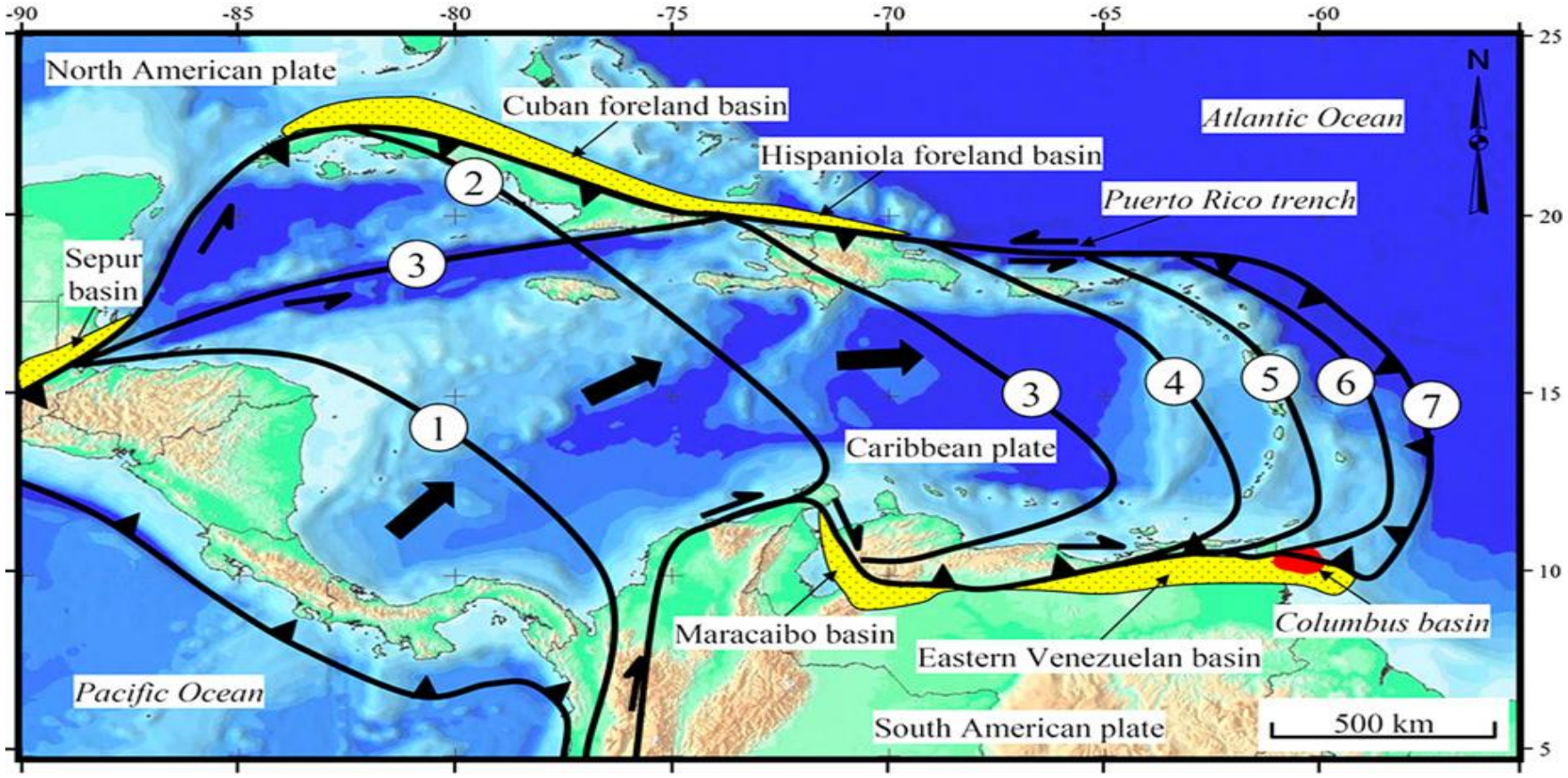
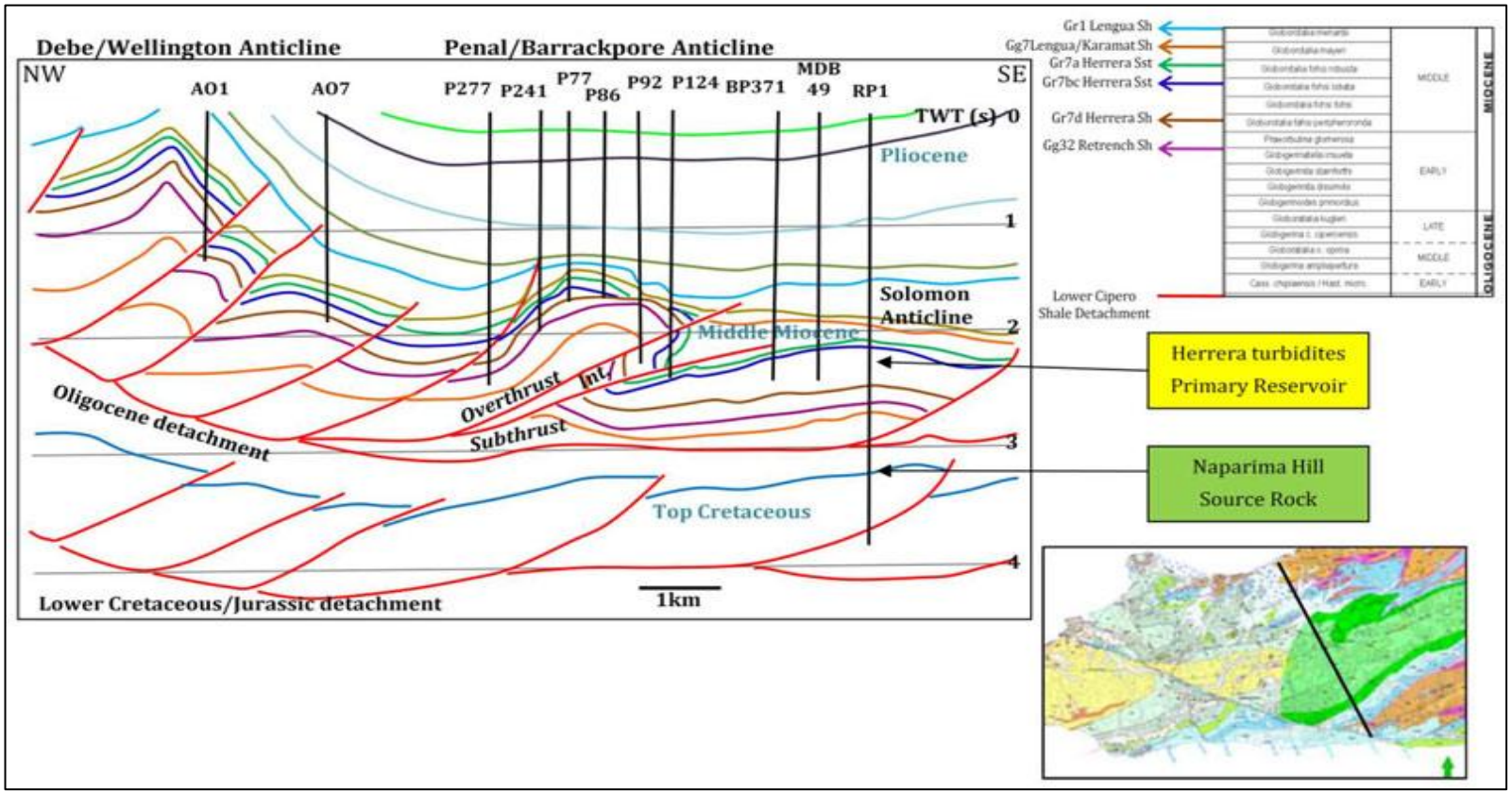


Plate reconstruction of the Caribbean plate relative to North and South America showing successive positions of the leading edge of the Caribbean plate based on ages of foreland basins (yellow) deposited on the North and South American plates: 1 = Late Cretaceous (80 Ma); 2 =Paleocene (60 Ma); 3 =middle Eocene (44 Ma); 4 = Oligocene (30 Ma); 5 = middle Miocene (14 Ma); 6 =Pliocene (5 Ma); 7 =Recent. The Columbus foreland basin in the southeastern Caribbean near Trinidad is highlighted in red.

Garciacaro, et al. 2011

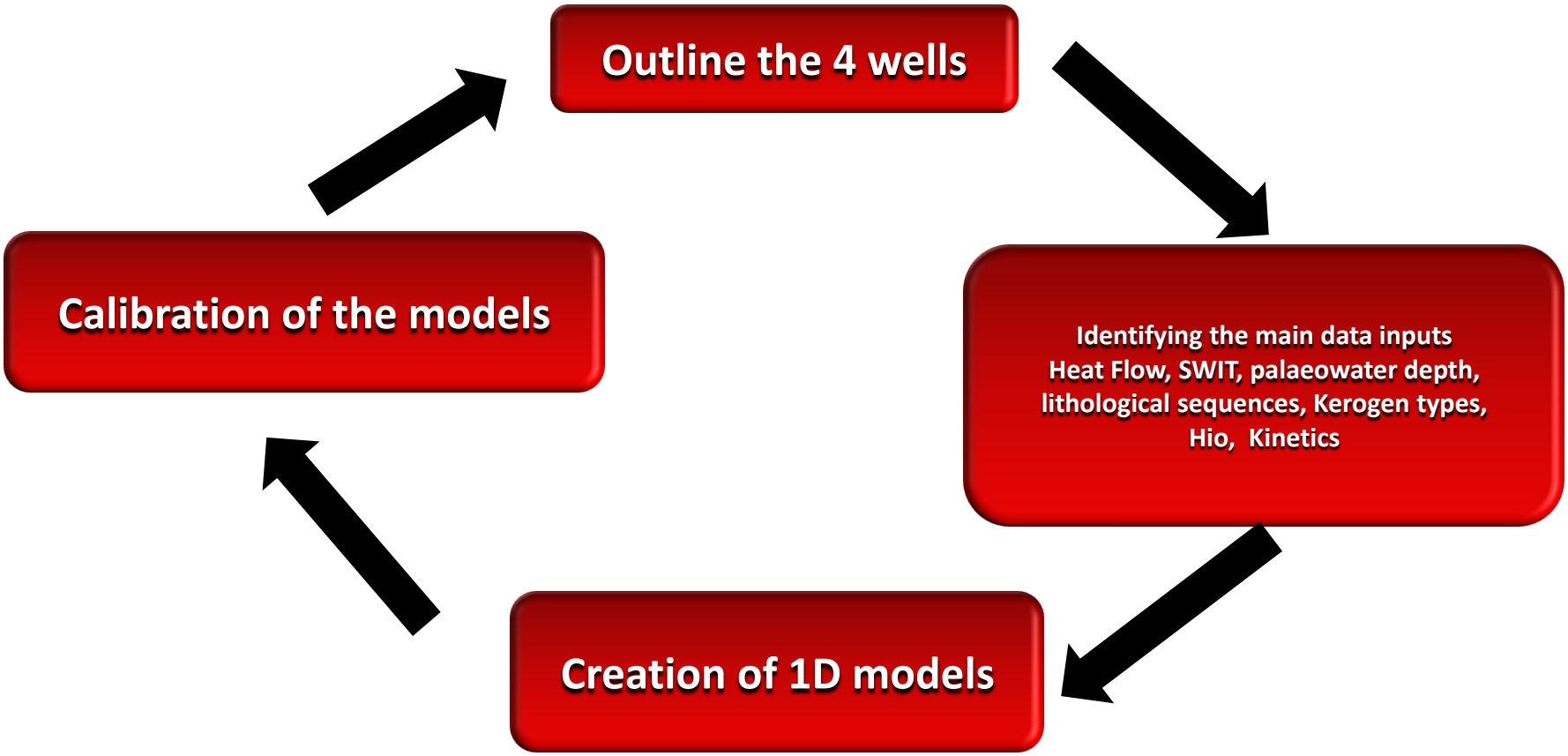
Traps- Folds created due to Miocene compression event



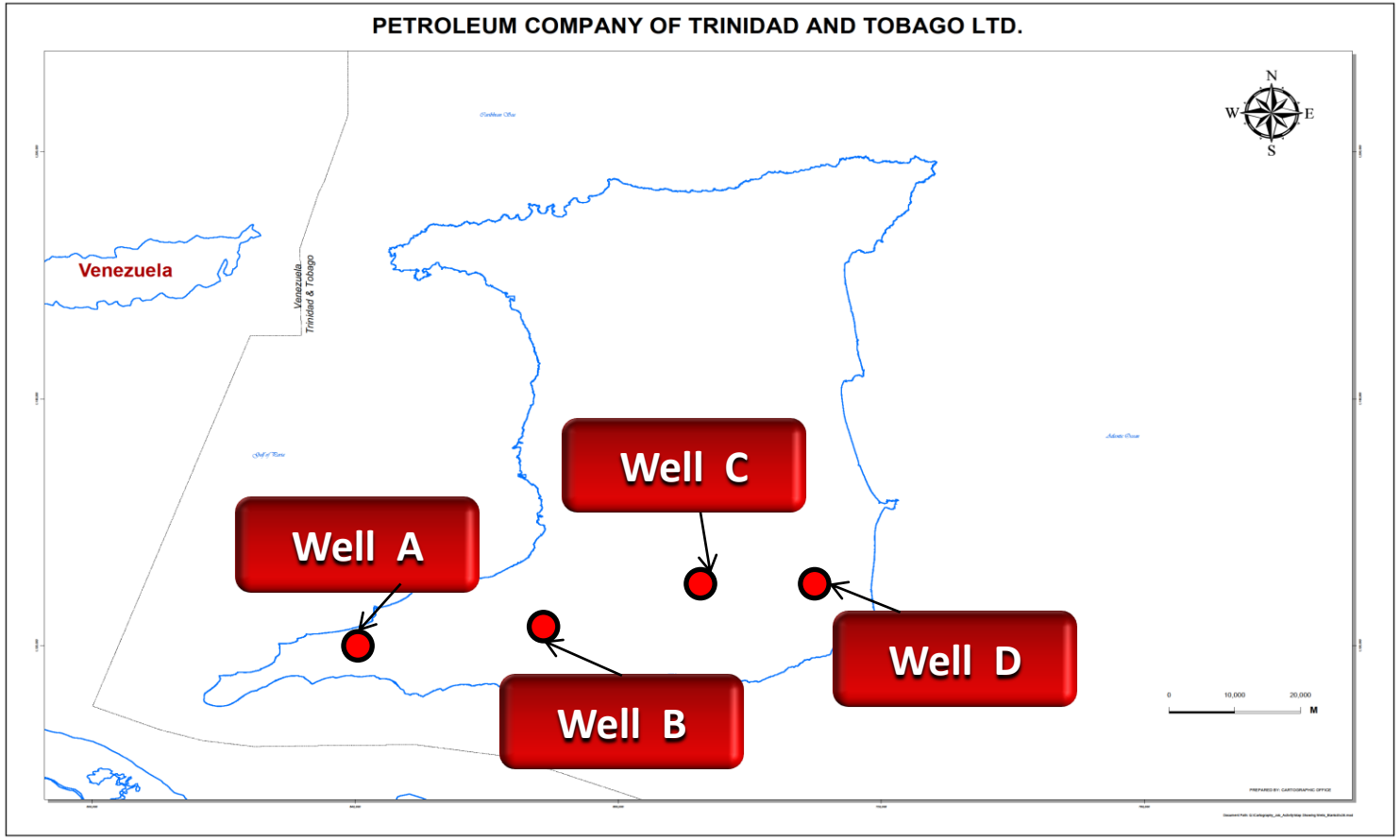
Moonan, 2011

Generation- Migration Accumulation

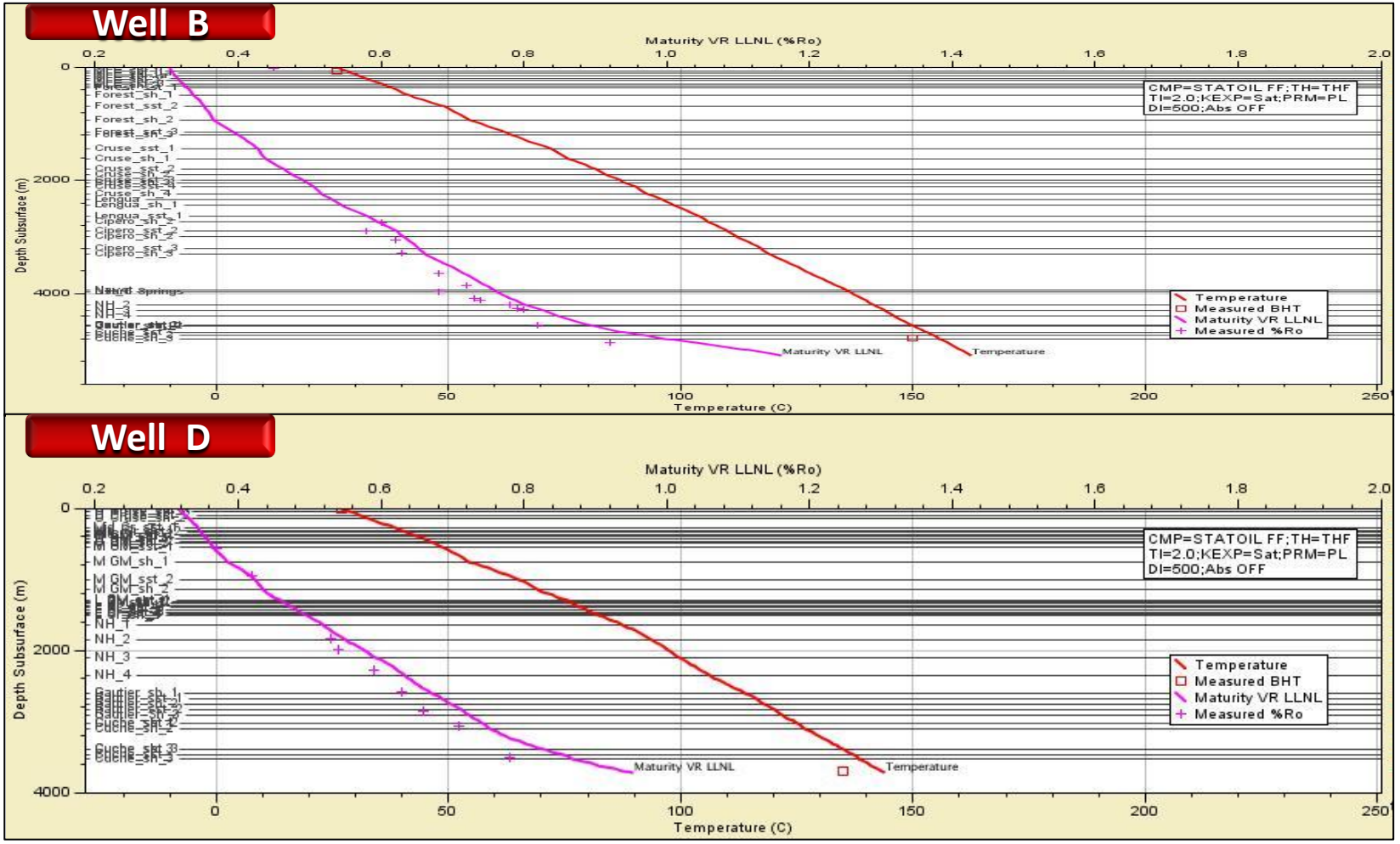
Generation- Migration and Accumulation Work-Flow



Location of the modeled wells



Model calibration: Comparison of measured to calculated Vitrinite Plots and BHTs

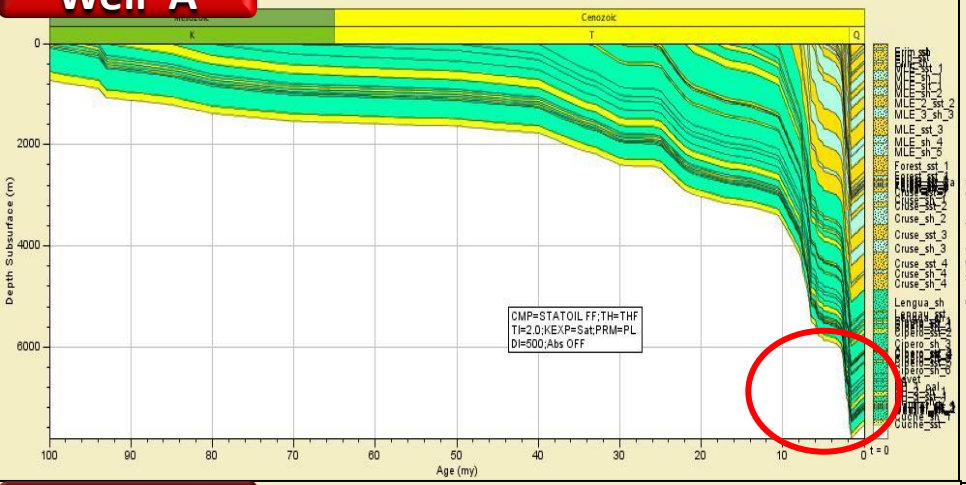


The pink crosses represent the observed Ro data

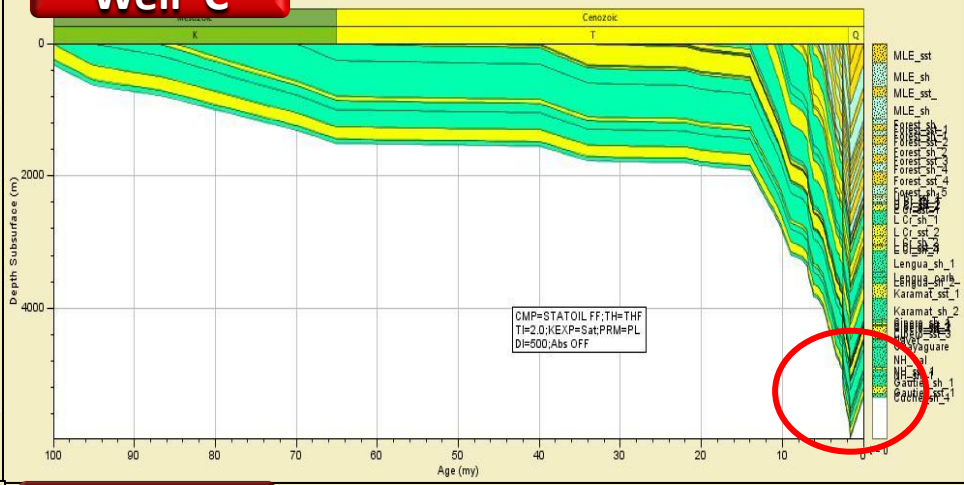
Burial profiles- Large rates of subsidence from the Late Miocene to present

Petrotrin

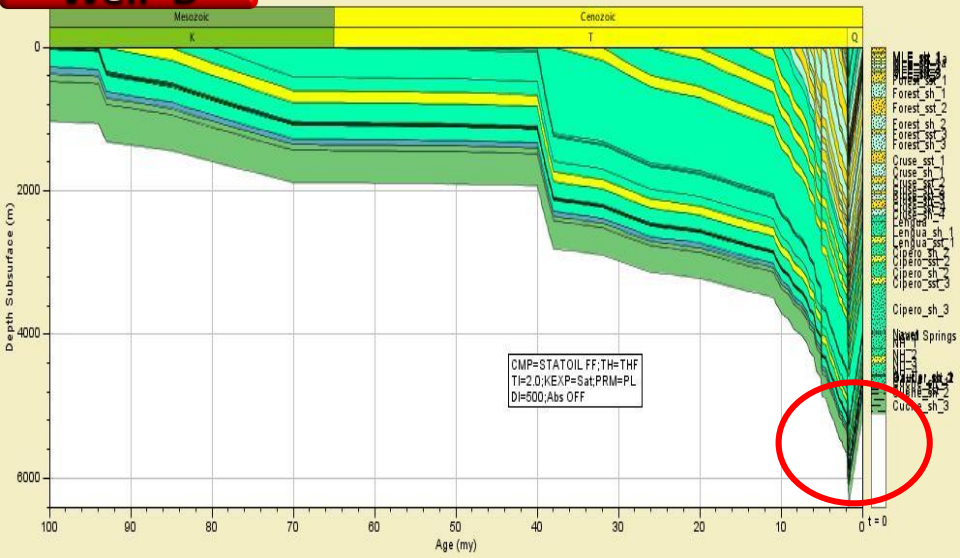
Well A



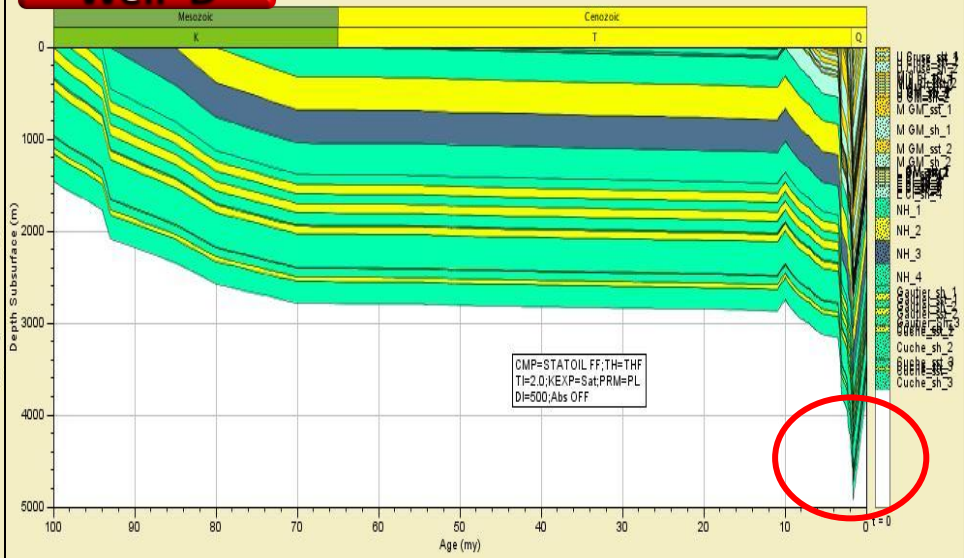
Well C



Well B



Well D



Heat Flow

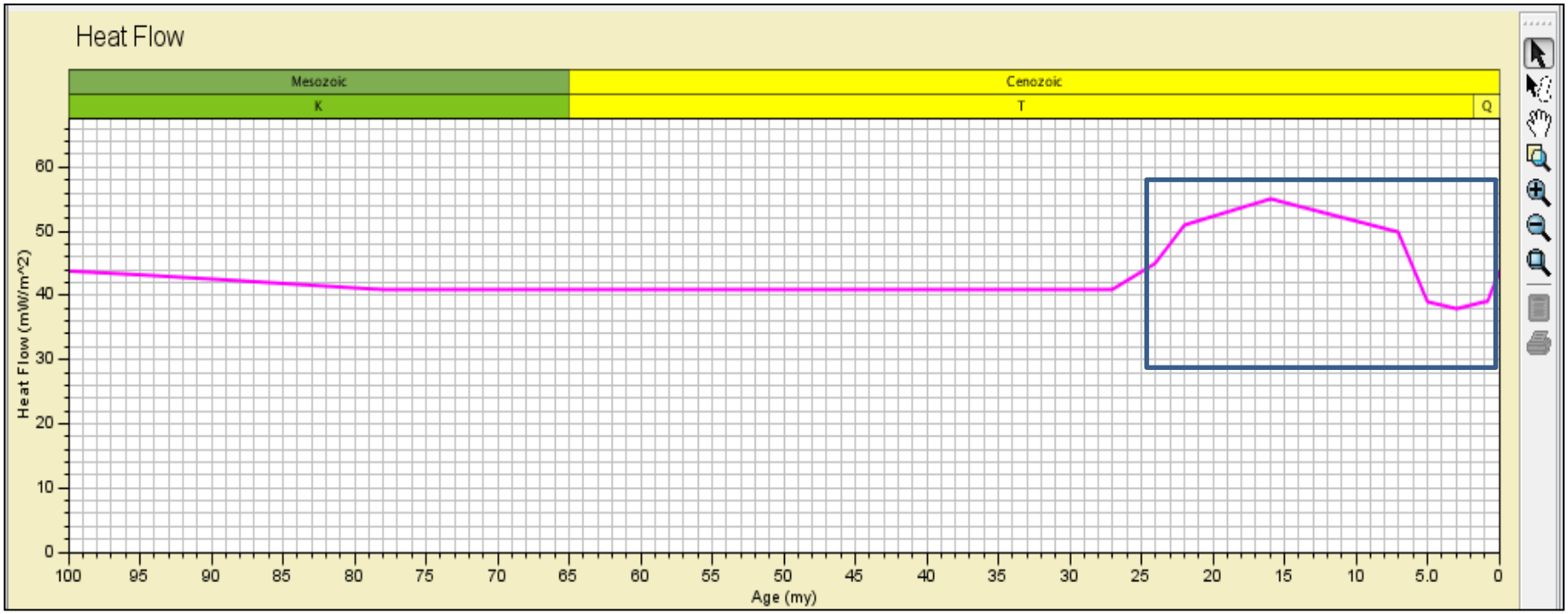
The heat flow was estimated using generic values based on Allen and Allen (2005).This was based on analysis from several basins globally.

Rifting : 80mW/m_2

Compressional basins: 65-70mW/m2

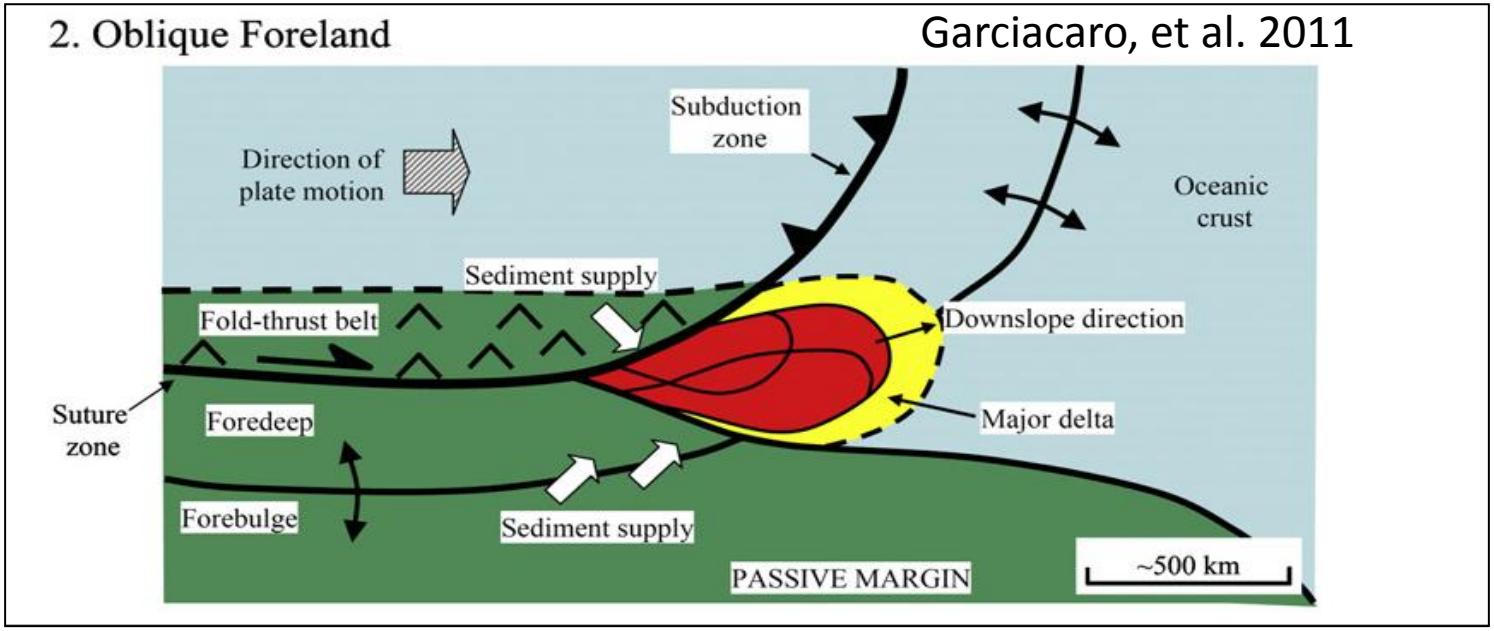
Strike Slip basins: Active crustal deformation ~ 50-60mW/m2

Heat Flow profile: The marvel that is Trinidad and Tobago- (The Trinidad wobble)



- Transient Heat Flow- fast burial and fast uplift
  (Pliocene- Pleistocene)
- Using a Heat flow model of Palumbo et al. (1999) which tries to model instantaneous sedimentation.

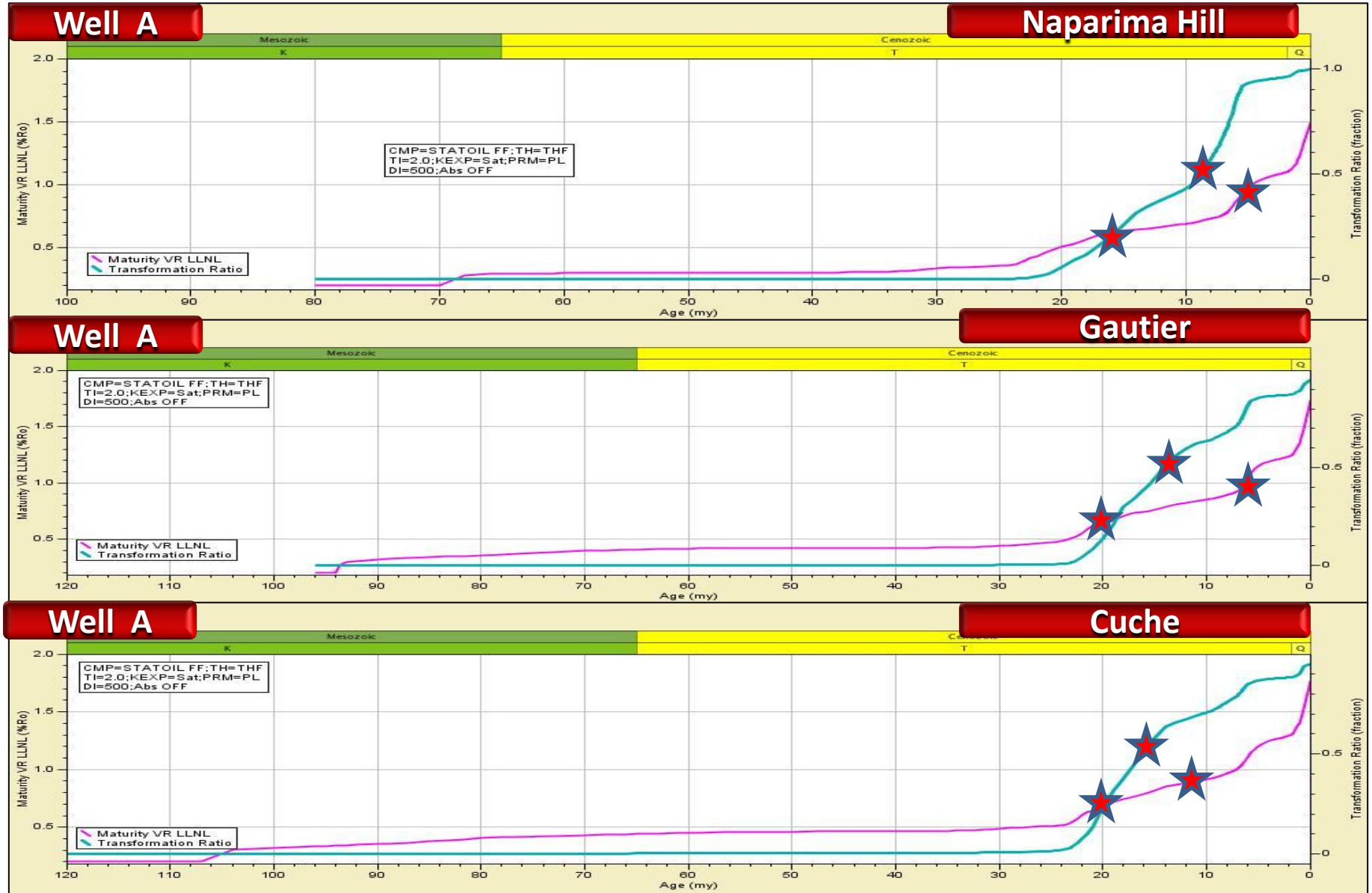
Heat Flow profile: The marvel that is Trinidad and Tobago



- During the Pliocene to the Pleistocene the greater Trinidad area was impacted on by large rates of progradation due to the migrating Proto-Orinoco river. This reduced the heat flow to below 40mW/m2

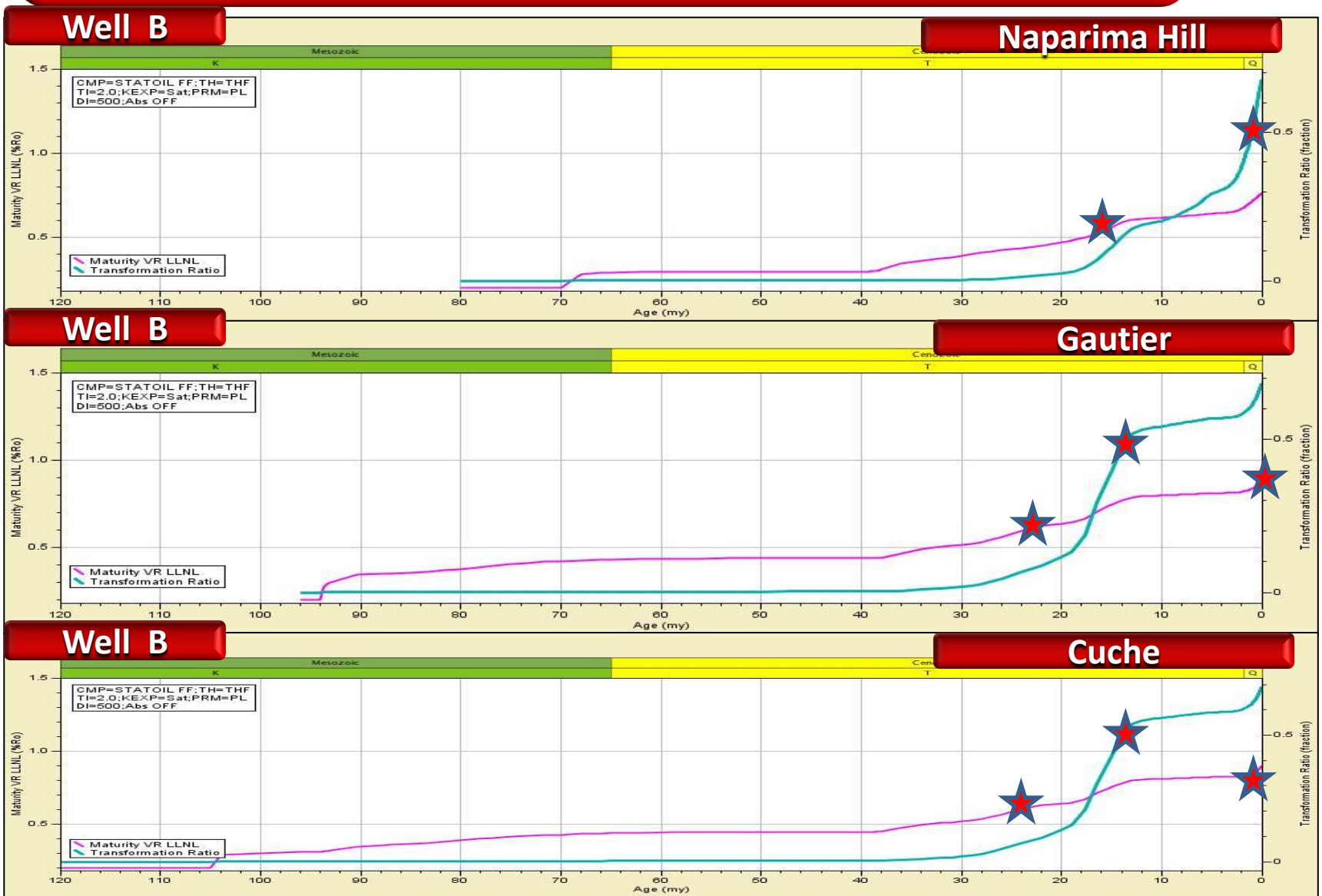
Timing of Source Rock generation
Well A

Petrotrin



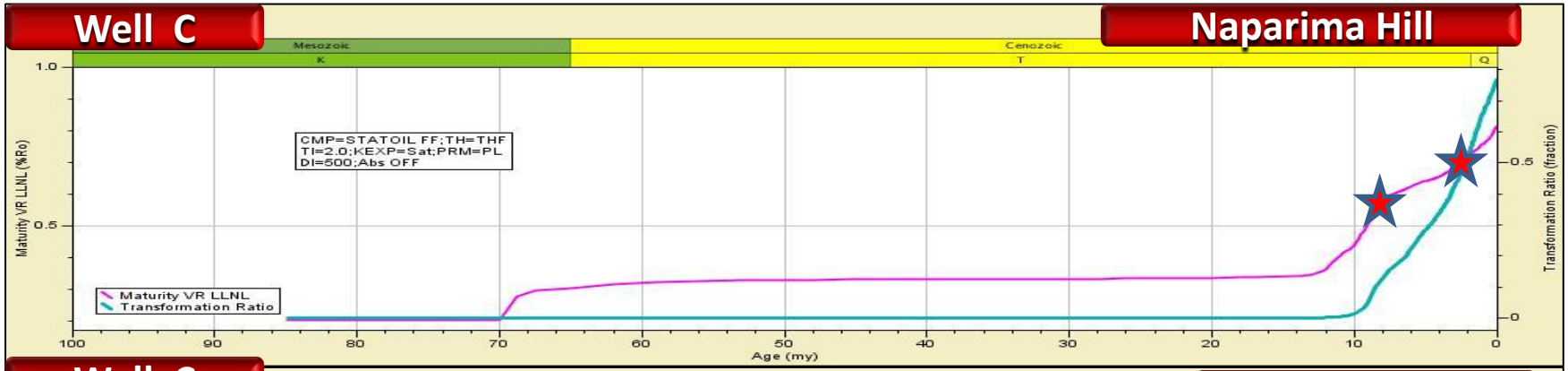
Timing of Source Rock generation Well B

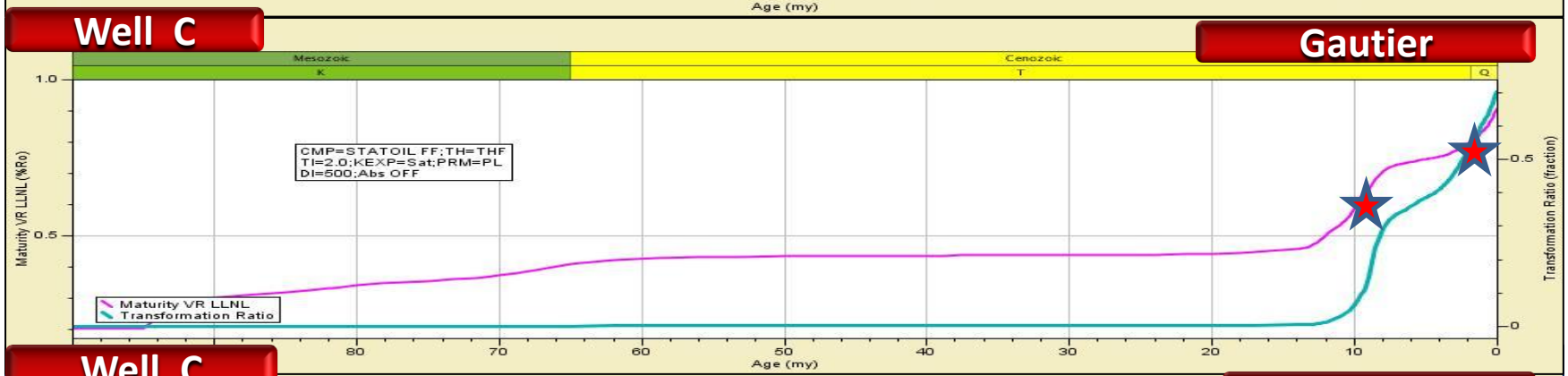
Petrotrin

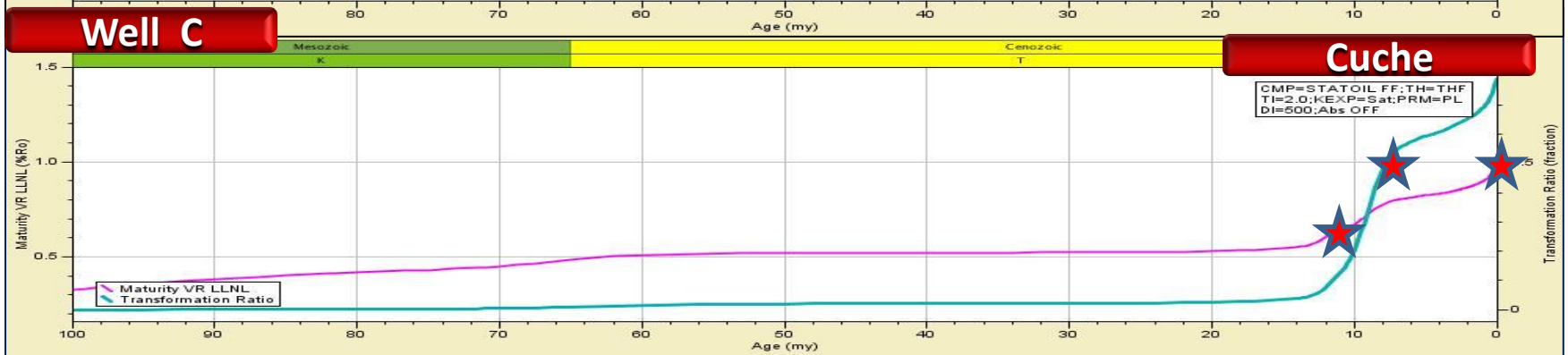


Timing of Source Rock generation Well C

Petrotrin



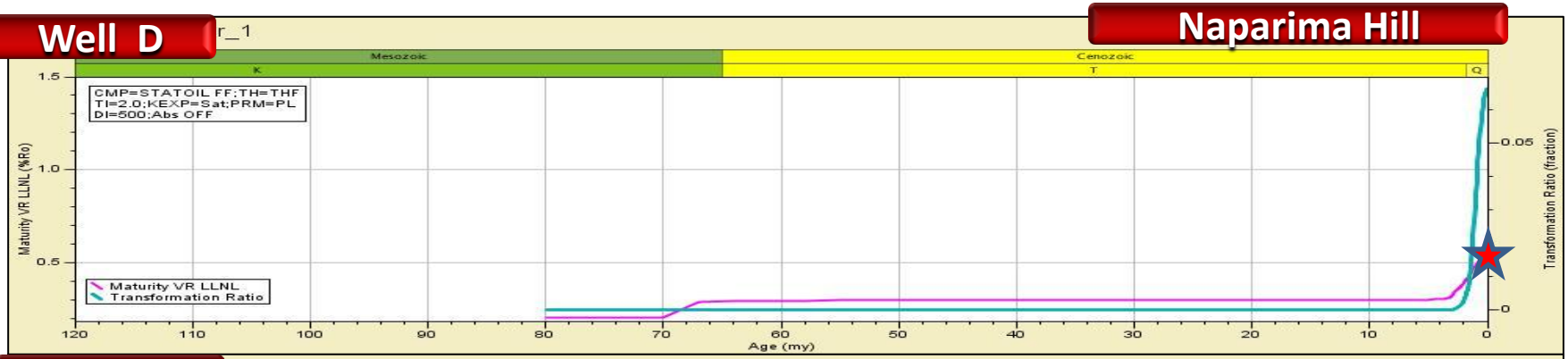




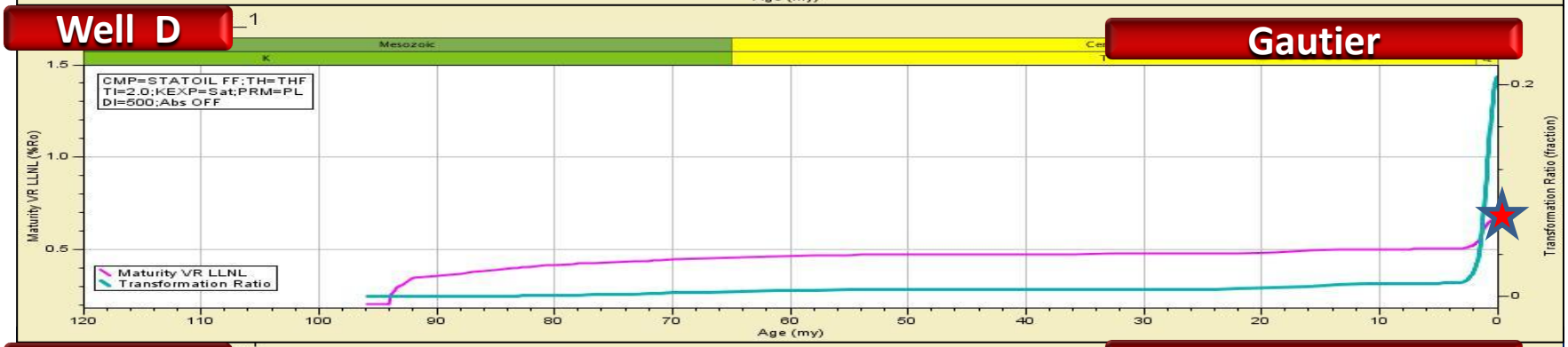
Timing of Source Rock generation Well D

Petrotrin

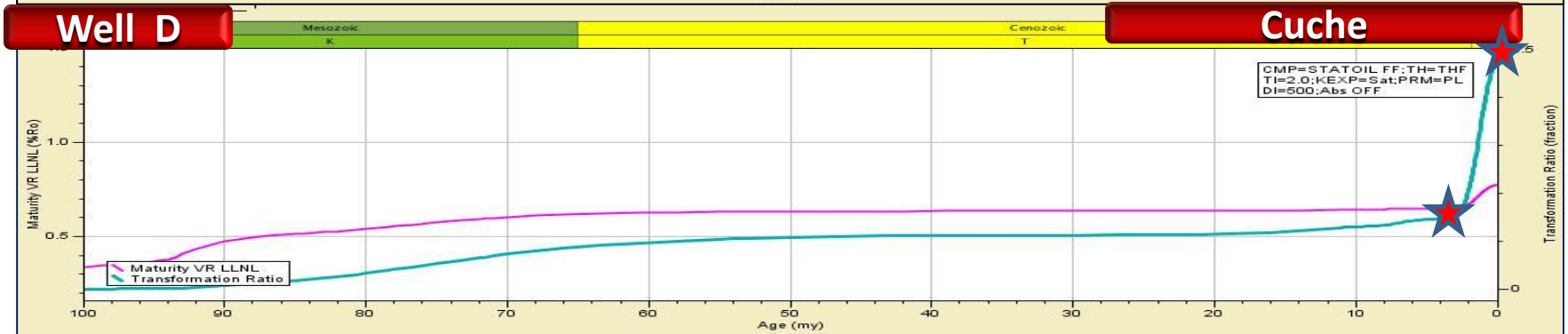
Well D — **Naparima Hill**



Well D — **Gautier**



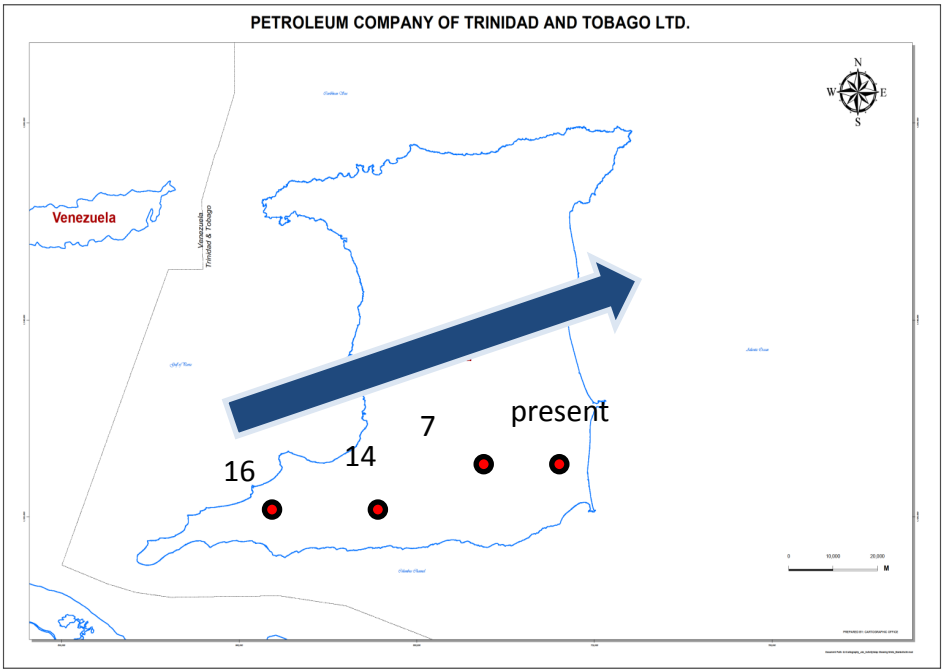
Well D — **Cuche**



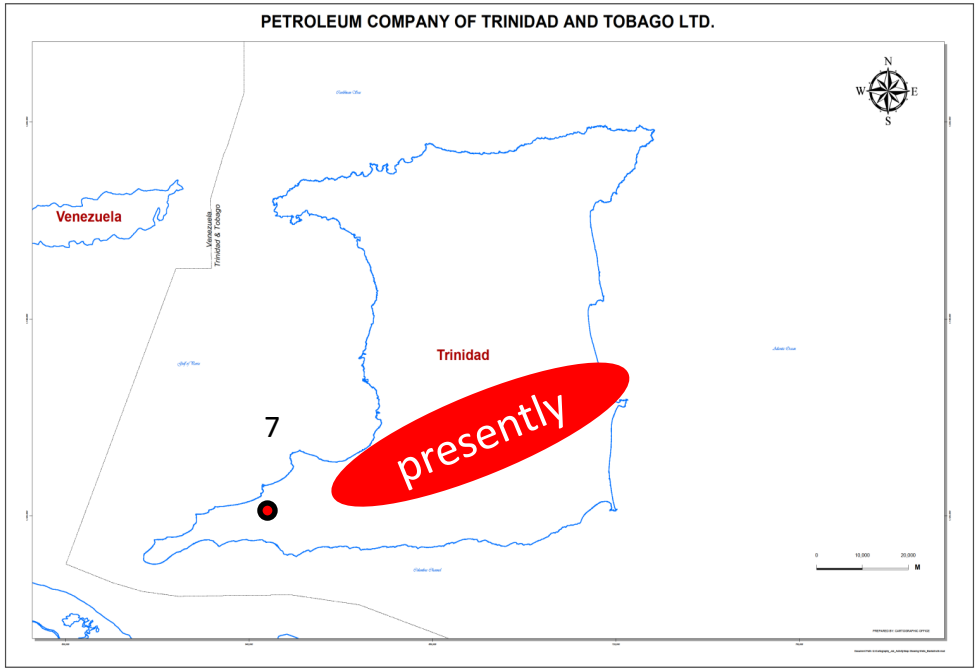
Timing of peak Oil based on Ro%
(Naparima Hill)

Petrotrin

Mature Oil Ro 0.6%

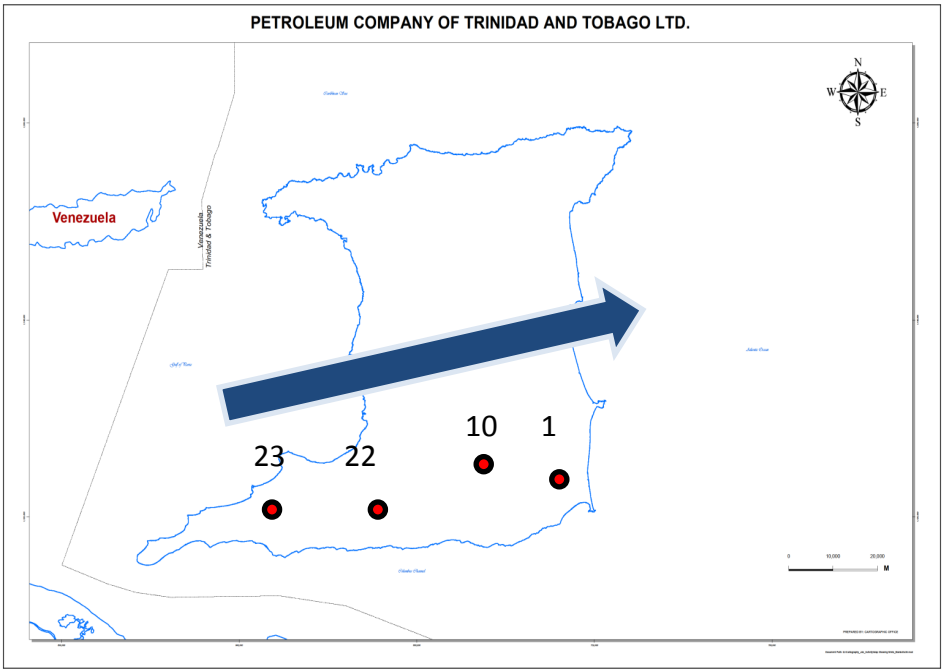


Peak Mature Oil (Ro 0.9 %)

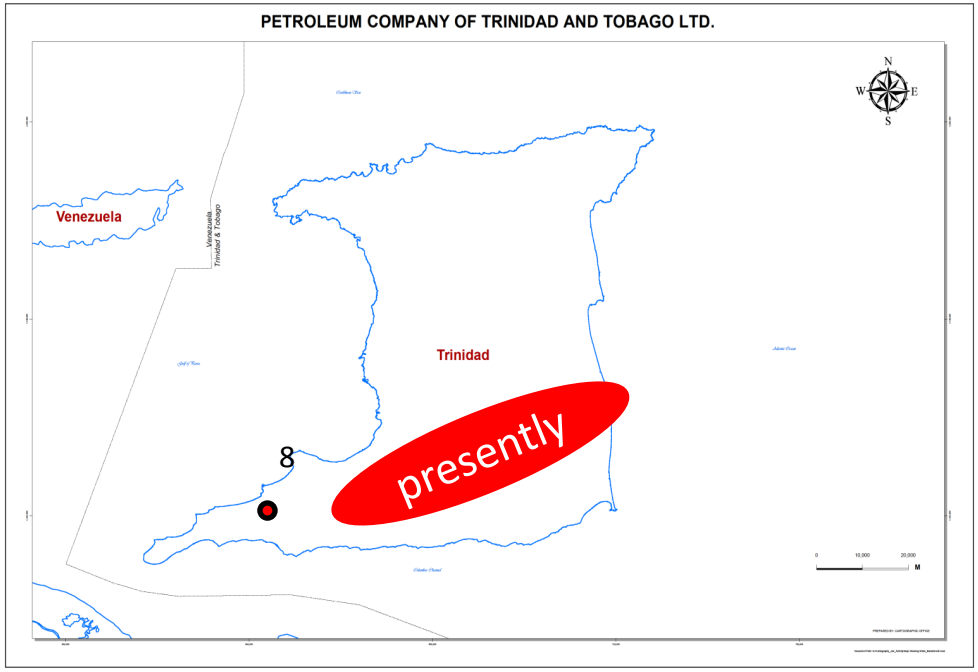


Timing of peak Oil based on Ro% (Gautier Fm)

Mature Oil Ro 0.6%



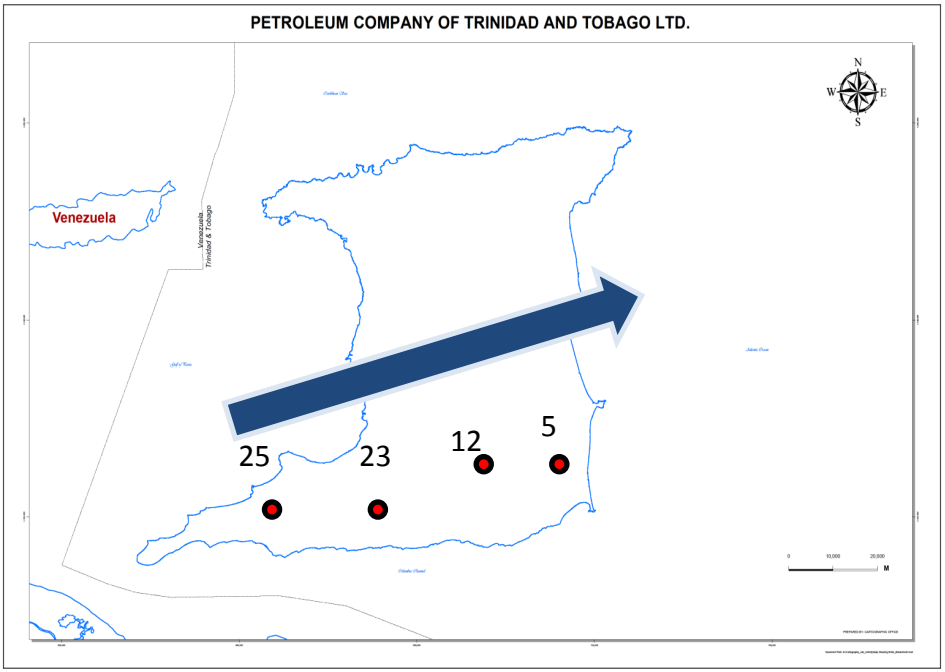
Peak Mature Oil (Ro 0.9 %)



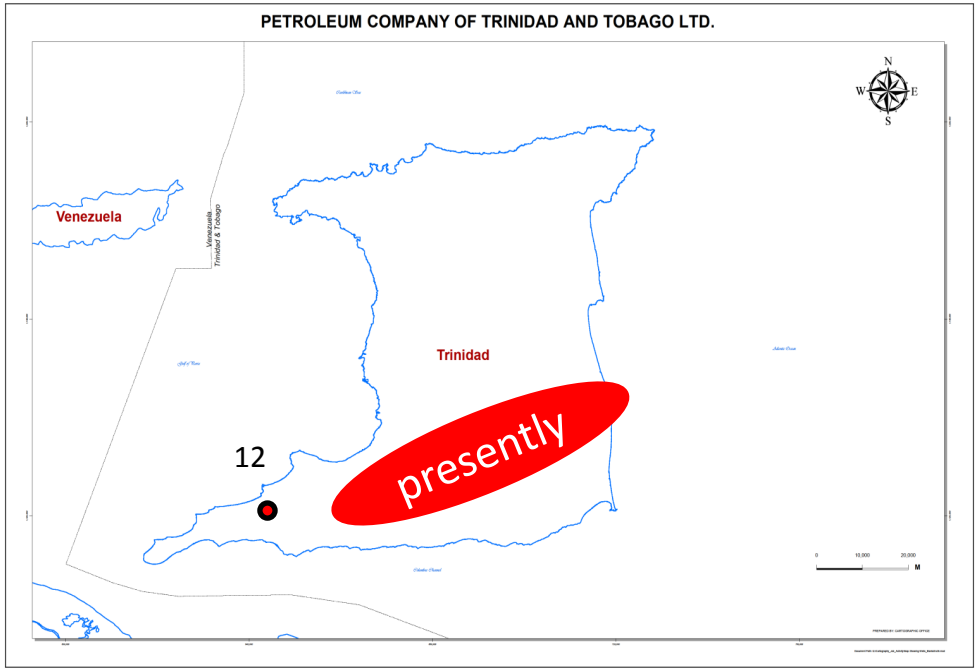
Timing of peak Oil based on Ro% (Cuche Fm)

Petrotrin

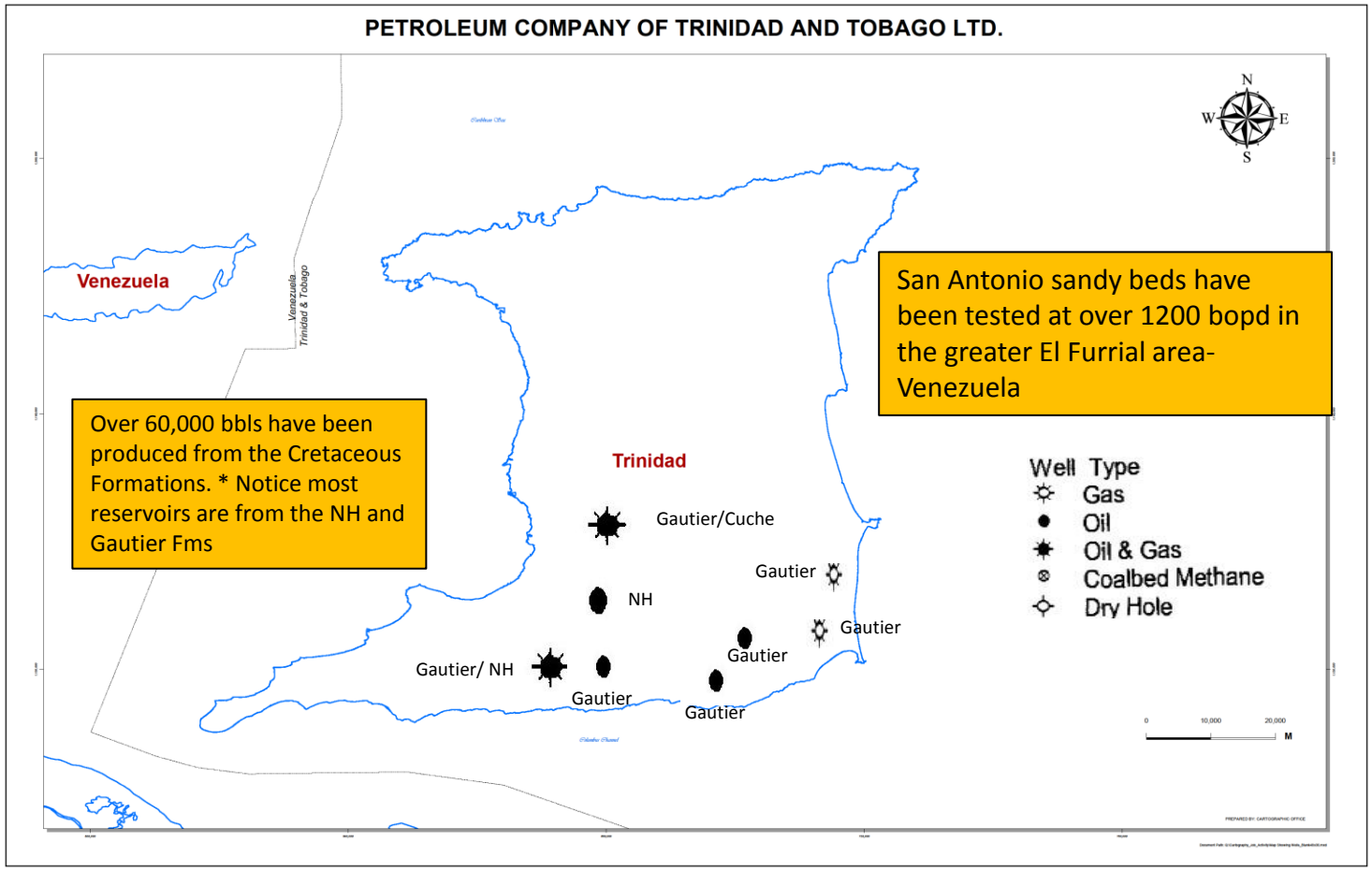
Mature Oil Ro 0.6%



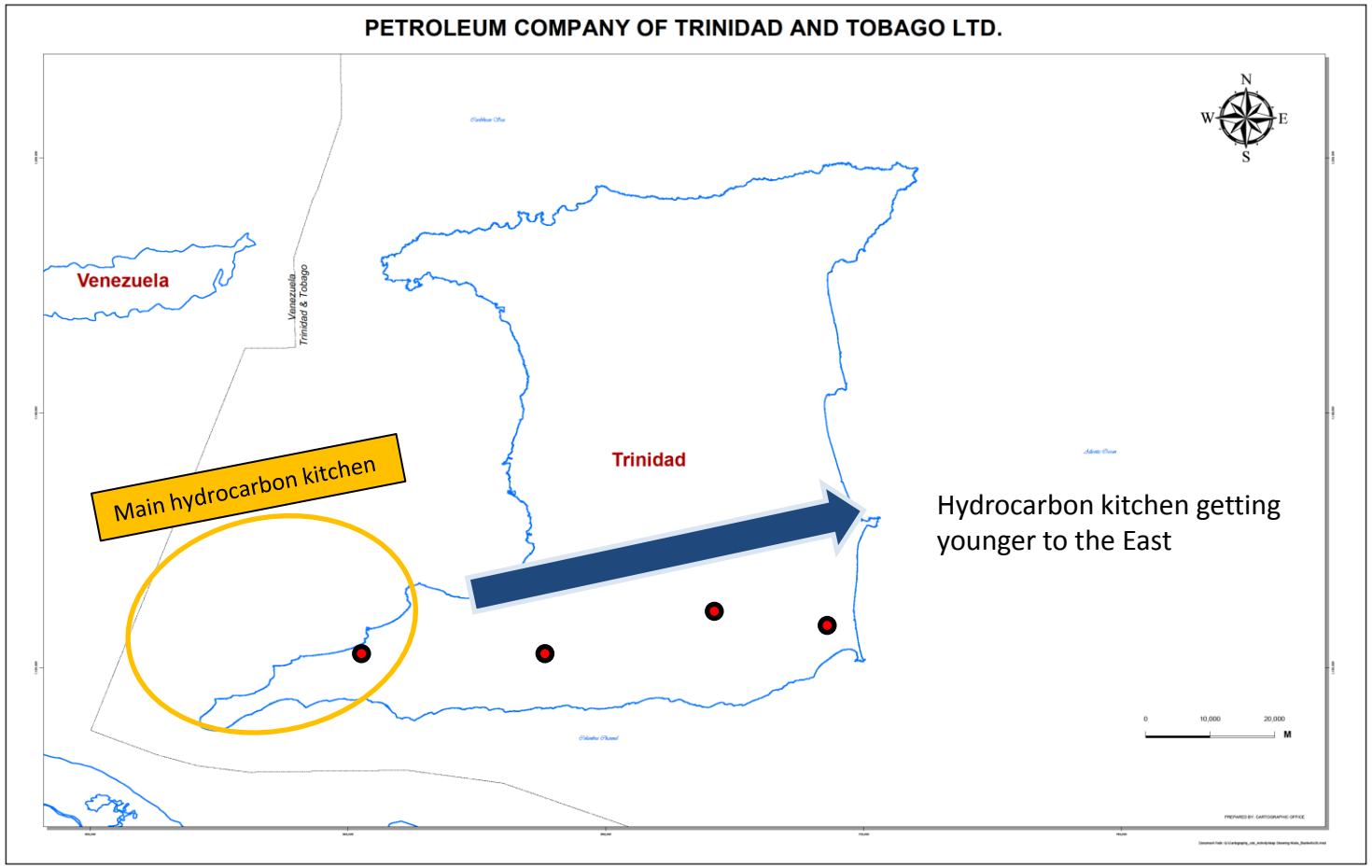
Peak Mature Oil (Ro 0.9 %)



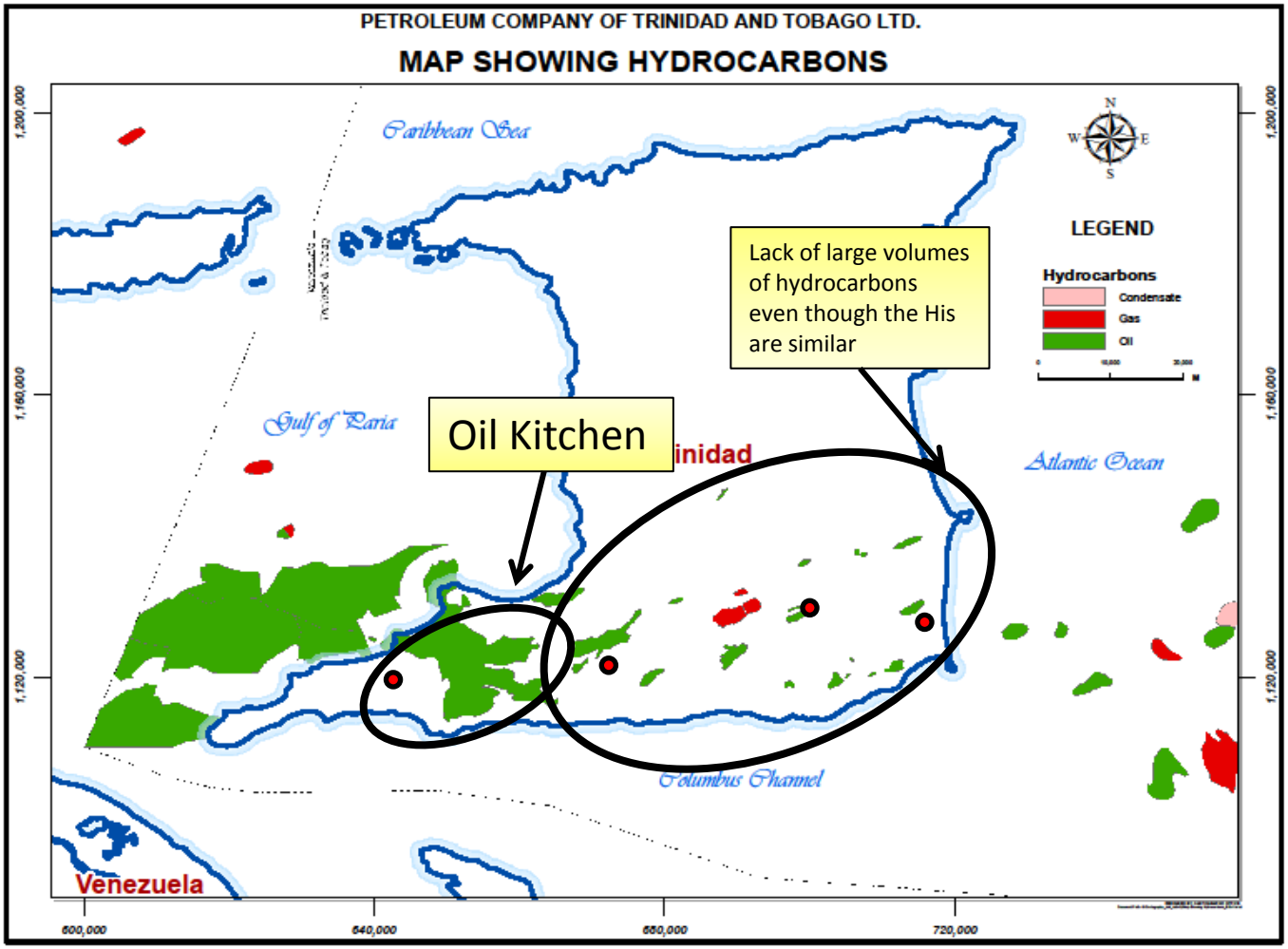
Cretaceous Oil shows and their respective formations



The Southern Basin kitchen



Where have we found Oil?



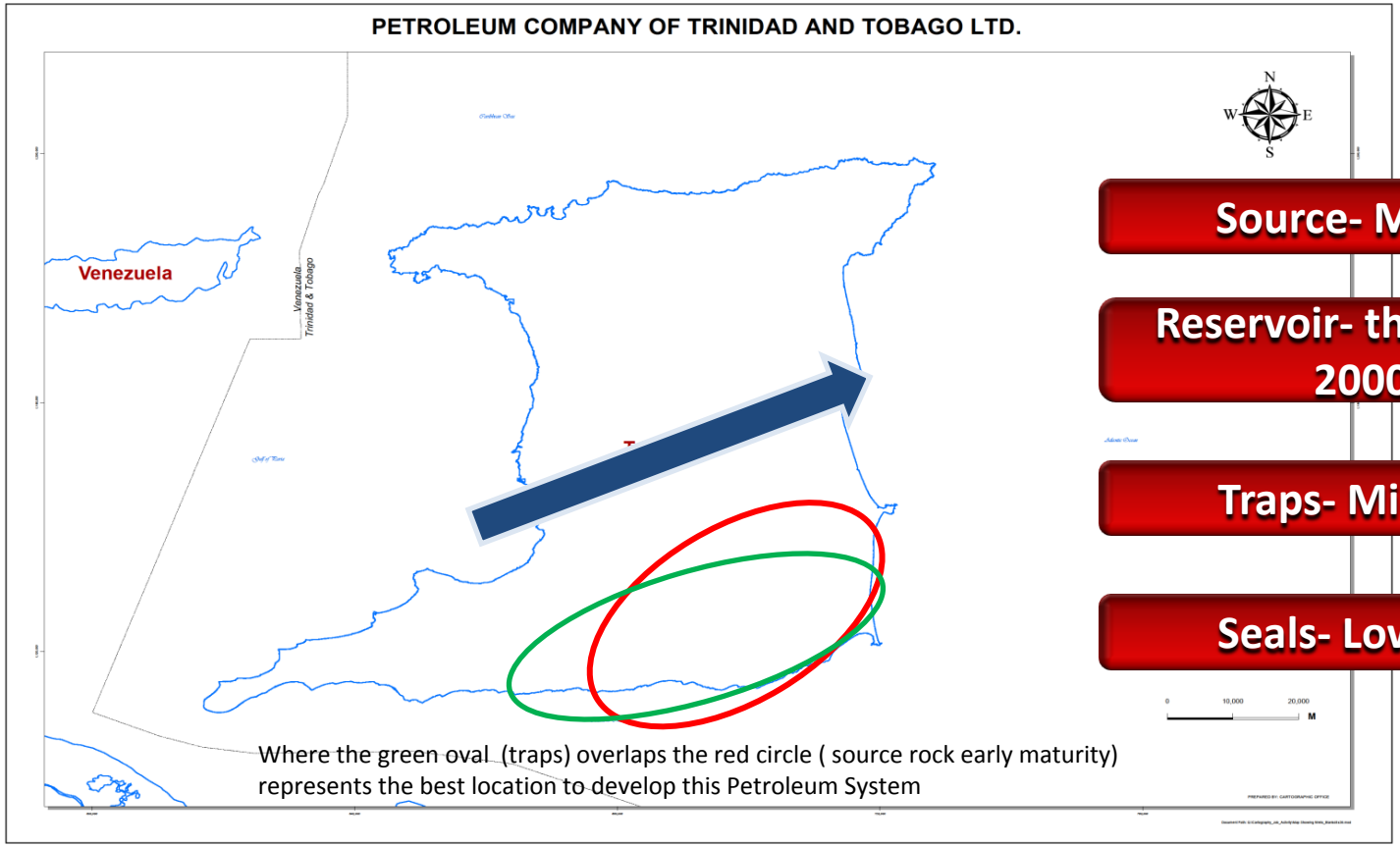
Migration- We're sorry

- Sorry everyone no fancy 3D model here.
- Lets think like a molecule. Where do I want to go???
- Migration into anticlinal traps formed in the Mid Miocene and/ or stratigraphically trapped within the Late Cretaceous sand prone facies.

Proposed System

- Source- Gautier/ Naparima Hill Fms
- Reservoir- Slope fans of the Gautier and Naparima Hill Fms
- Overburden- (Tertiary section)
- Seals - (Intraformational shales)
- Trap- A combination of structure and stratigraphy.
- Generation- ranging from Mid Miocene to Present

Summary



Where the green oval (traps) overlaps the red circle (source rock early maturity) represents the best location to develop this Petroleum System

Source- Mature

Reservoir- thickness – 2000’

Traps- Miocene

Seals- Low risk

Summary

- The Southern Basin onshore Trinidad has an underexplored Cretaceous Petroleum System.
- Onshore Trinidad houses a world class source rock with Hydrogen Indices ranging between 300 to 700 mgH/ g C.
- The Source rocks are the Cretaceous Cuche, Gautier and Naparima Hill Fms.
- The reservoirs are the sand prone facies of the aforementioned formations.
- The overburden is interpreted to be the Tertiary sediments facilitating the maturation process.
- The seals are the intraformational shales of the formations.
- The greatest risk of the Petroleum System is the reservoir deliverability and presence as the reservoirs are not interpreted to be sheet sands and there is great uncertainty with the spatial distribution of the reservoir's permeability.
- One of the key findings of this research deals with the maturation process and the Trinidad "wobble". The source rocks began maturing as early as the Early Mid Miocene in the Erin Syncline , but due to the reduction in the heat flow in the Late Miocene to present , the maturation process was very slow probably facilitating many periods of trap formation and then subsequent breaching leading to large variations in the measured APIs of oils in drilled traps.

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References

- Allen P.A. and J.R. Allen, (2005), Basin Analysis, 2nd Edition: Blackwell Publishing, Malden, MA, p. 349-401.
- Dow W.G., 1977. Kerogen studies and geological interpretations: Journal of Geochemical Exploration 7, 79-99.
- Erlich, R. N., T. Villamil, and J. Keens-Dumas,(2003) Controls on the deposition of Upper Cretaceous organic carbon– rich rocks from Costa Rica to Suriname, in C. Bartolini, R. T. Buffler, and J. Blickwede, ds., The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics: AAPG Memoir 79, p. 1–45.
- Garciacaro. E, Mann.P and Escolana .A (2011) " Regional structure and tectonic history of the obliquely colliding Columbus foreland basin, offshore Trinidad and Venezuela" Marine and Petroleum Geology 28 (2011) 126–148
- Jarvie, Daniel M., Brenda L. Claxton, Floyd "Bo" Henk, and John T. Breyer, 2001, Oil and Shale Gas from the Barnett Shale, Ft. Worth Basin, Texas, AAPG National Convention, June 3-6, 2001, Denver, CO, AAPG Bull. Vol. 85, No. 13 (Supplement), p. A100.
- Lo, H.B (1993) Org. Geochem, v.20 pg 653-657.
- Magoon, L. B., and W. G. Dow, 1994, The petroleum system, in Magoon, L. B, and W. G. Dow, eds., The petroleum system— from source to trap: AAPG Memoir 60, p. 3-24.
- Moonan . X (2011) "4D Understanding of the Evolution of the Penal/Barrackpore Anticline, Southern-Sub-Basin, Trinidad, W.I." available at http://www.searchanddiscovery.com/pdfz/documents/2011/20122moonan/ndx_moonan.pdf.html
- Palumbo et al (1999) "The thermal evolution of sedimentary basins and its effect on the maturation of hydrocarbons" Geophys. J. Int. (1999) 139, 248–260.
- Pearson, D.L., (1990). Pollen/Spore Color "Standard" (Ver. 2): Bartelsville (Phillips Petroleum Co., Geology Branch).
- Peters K.E. and M.R. Cassa, 1994. Applied source-rock geochemistry: in L. B. Magoon and W. G. Dow, eds., The Petroleum System - From Source to Trap: AAPG Memoir 60, 93-120
- Pindell,J.L., and Kennan, L.,(2001), Kinematic evolution of the Gulf of Mexico and the Caribbean, in Fillon, D., ed., Transactions , 21st Bob Perkins Gulf Coast Section Society of Economic Paleontologists and Mineralogists (SEPM) Research Conference: Houston , Gulf Coast Section SEPM Foundation, p 32.
- Pindell and Kennan (2007) " Cenozoic Kinematics and Dynamics of Oblique Collision Between Two Convergent Plate Margins: The Caribbean South American Collision in Eastern Venezuela, Trinidad and Barbados , Transactions of GCSSCEPM 27TH Annual Bob F. Perkins Research Conference pgs 458 to 553.
- Rider, M.H. (1999) "Geologic interpretation of well logs. Whittles Publishing Services.
- Rodrigues, K, (1988) "Oil source bed recognition and crude oil correlation, Trinidad, West Indies. Organic Geochemistry, v. 13, nos. 1- 3, p. 365-371.
- Rodrigues, K.(1990) " Significance of geothermal gradients in Petroleum Exploration in Trinidad" Transactions of the 12th Caribbean Geological Conference , St Croix.
- Wygrala B., 1989, Integrated study of an oil field in the southern Po basin, northern Italy: Berichte kernforschungsamlage, Julich, 2313, p.217