Cretaceous Prospectivity of Southern Trinidad*

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Abstract

This presentation initially outlines the geo-tectonic history of southern Trinidad and its impact on the presence and distribution of reservoirs and source horizons. Based on this framework, the concept of a pre-Tertiary petroleum system is then developed and the existing well and seismic evidence for its presence and extent in the Southern Basin is then reviewed. Finally, we suggest a tool that can be used in developing a play. Most of the four billion barrels of oil extracted from Trinidad in the last hundred years has come from the youngest (mainly Plio-Pleistocene) sediments. About one and a half billion barrels of this have come from the onshore piggy-back Southern Basin and a further billion from its offshore extension westward in the Gulf of Paria. Over one billion barrels of oil and ten trillion cubic feet of gas have come from similar age sediments in the Columbus Basin, part of which extends into the southeastern onshore extremity of Trinidad.

The vast majority of the remainder of the oil production has come from the Mid-Tertiary, Oligo-Miocene age, sediments. The reservoirs are turbidite sands in the Naparima Nariva Fold and Thrust Belt (FTB), which underlies the piggyback Southern Basin, south of the Central Range Uplift and north of the Southern Range Anticline. These deeper Tertiary objectives are only lightly explored in parts of the proven fairway in both onshore Southern Trinidad and in the Eastern offshore. To date there has been no commercial production from the Cretaceous. With regard to the mid-Tertiary and older sediments onshore, complex surface features and a paucity of good quality 3D seismic data have prevented the exploration of the imbricate thrusts known to be present within the Naparima Nariva Fold and Thrust Belt (FTB) which underlies the piggy-back Southern Basin

and onshore portion of the Columbus Basin, south of the Central Range Uplift and north of the Southern Range Anticline. The Cretaceous horizons have as a result been largely un-explored due to their depth of burial and poor imaging.

Focusing on the SW Peninsula where a Cretaceous play is postulated, but where the exploration for the pre-Tertiary is, to be charitable, in its infancy, we will explore the potential for further petroleum exploration and develop a rationale for that work. We will outline the potential petroleum systems present and then suggest the use of full tensor airborne gravity (FTG) which we believe is a tool that can assist in the better delineation and exploration of the basin. Some examples of the successful application of FTG elsewhere in the world are given.

Selected References

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CRETACEOUS PROSPECTIVITY OF SOUTHERN TRINIDAD

by

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and

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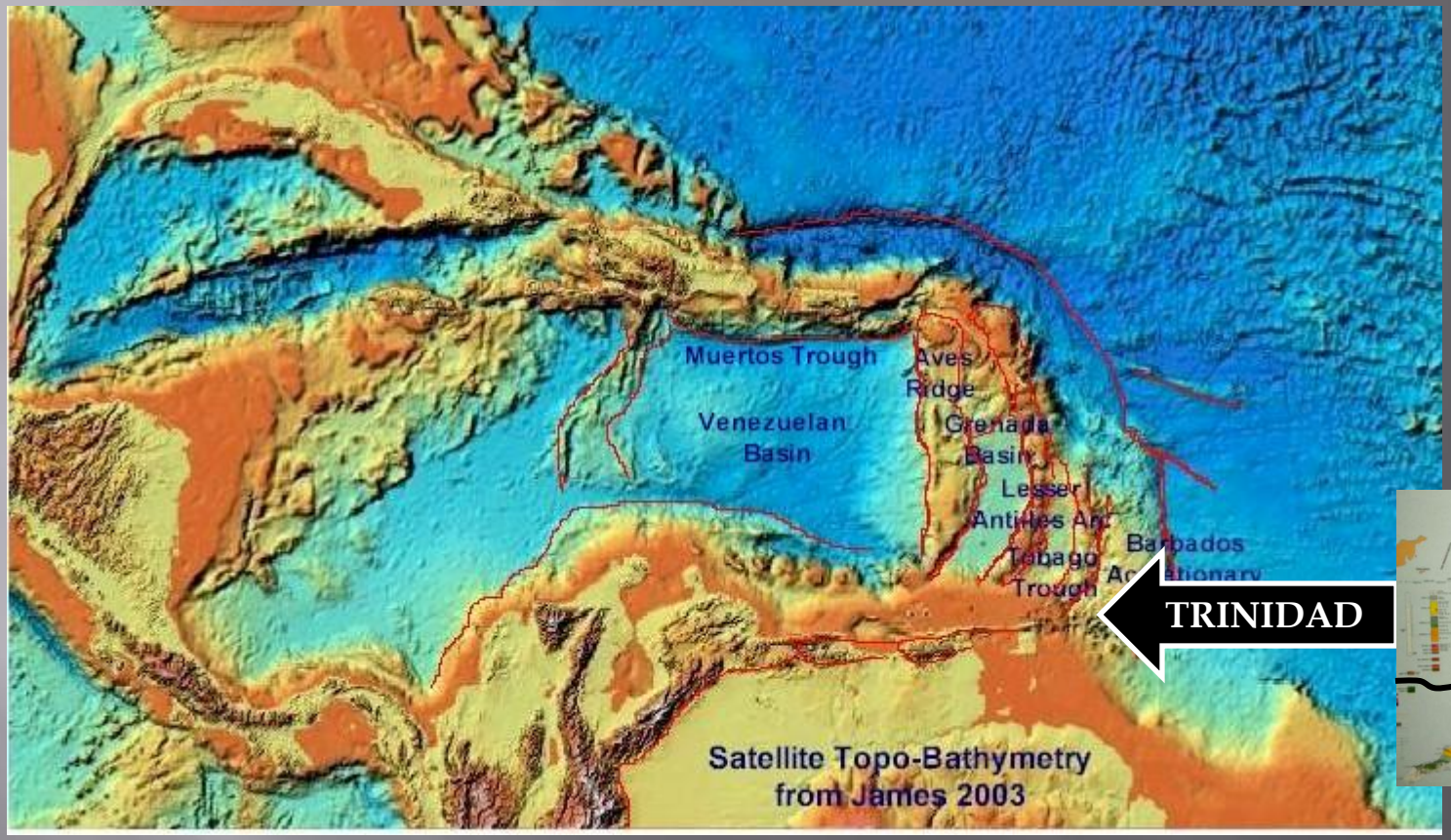
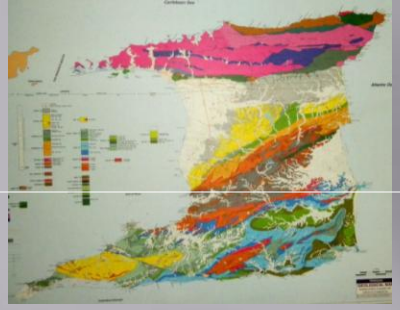


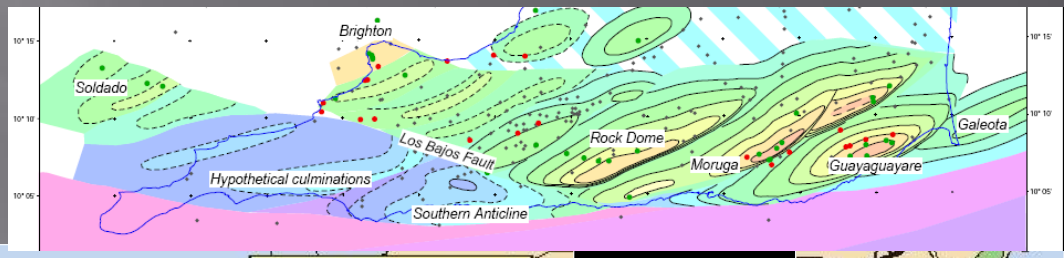
Location Map

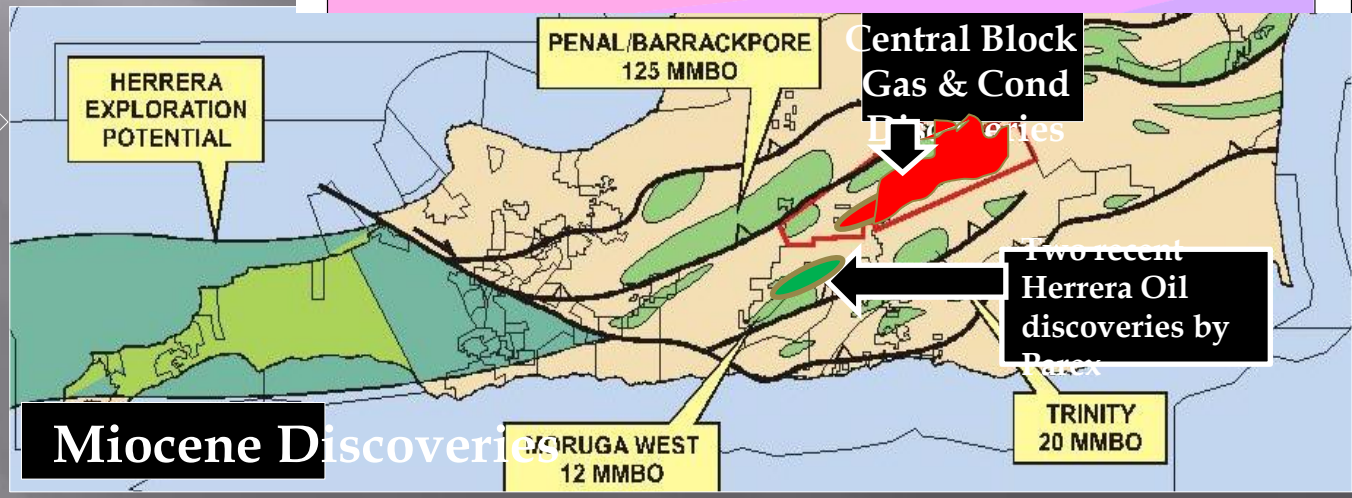
Trinidad is located in the south-eastern corner of the Caribbean plate

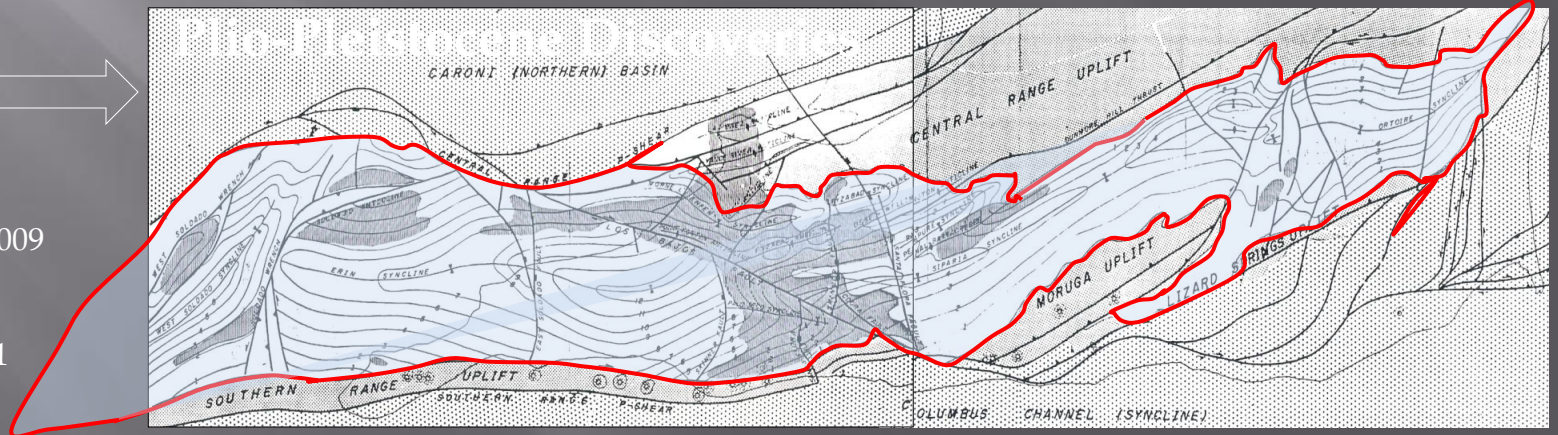
Index map modified after James 2003...Location Map Saunders et al 2009



We will be looking at Southern Trinidad where Tertiary Oil and Gas Discoveries have been made & Cretaceous Highs have been mapped...to look for Cretaceous (and other) Plays







Map Sources
Saunders et al 2009
Pindell 2006
and
Persad et al 2011

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GEO-TECTONIC HISTORY

PRE-TERTIARY PETROLEUM SYSTEMS IN SOUTHERN TRINIDAD

PRE-TERTIARY PLAYS

AIR FTG
USE IN OTHER PARTS OF THE WORLD AND POSSIBLE LOCAL APPLICATION

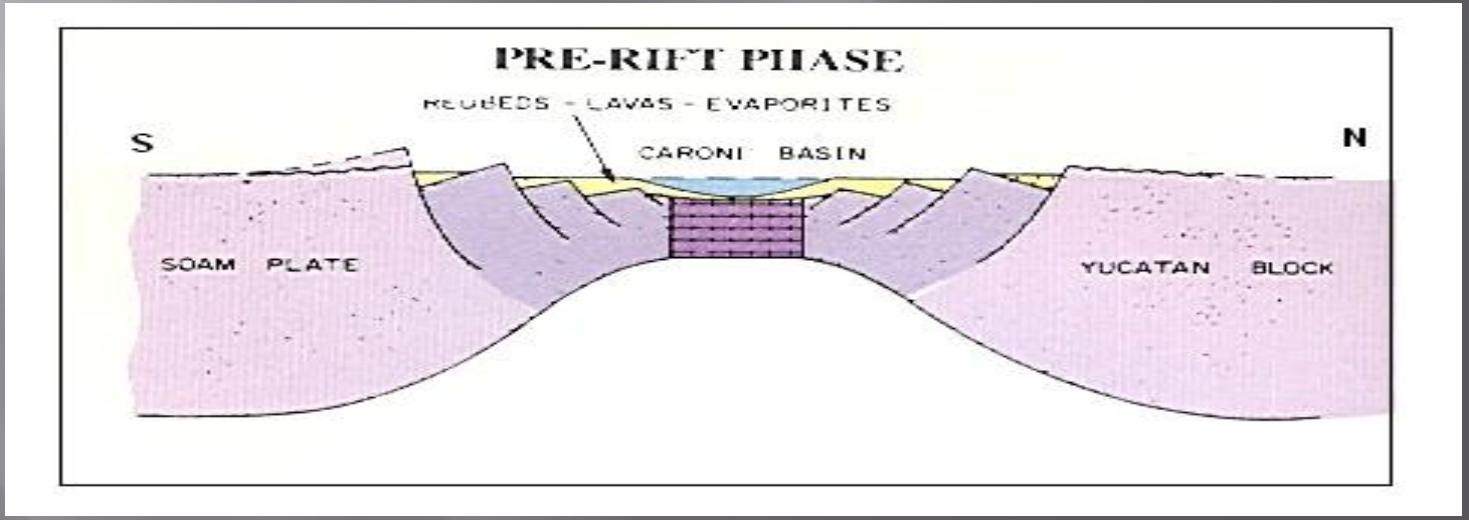
CONTENTS

We have found that a seven stage evolutionary model for the Trinidad area best fits all of the data, as follows:

1 PRE-RIFT, SYN-RIFT and DRIFT (Late Jurassic-mid Cretaceous)
2 PASSIVE MARGIN (Mid -Late Cretaceous)
3 NORTH SOUTH COMPRESSION (Late Cretaceous-Eocene)
4 RETURN TO PASSIVE MARGIN (Eocene-Oligocene)
5 SEQUENTIAL OBLIQUE COLLISION (Late Oligocene-mid Miocene)
6 WRENCH PHASE (Late Miocene-Recent)
7 CONTINENTAL EMBANKMENT (DELTAIC PHASE) (Pliocene-Present)

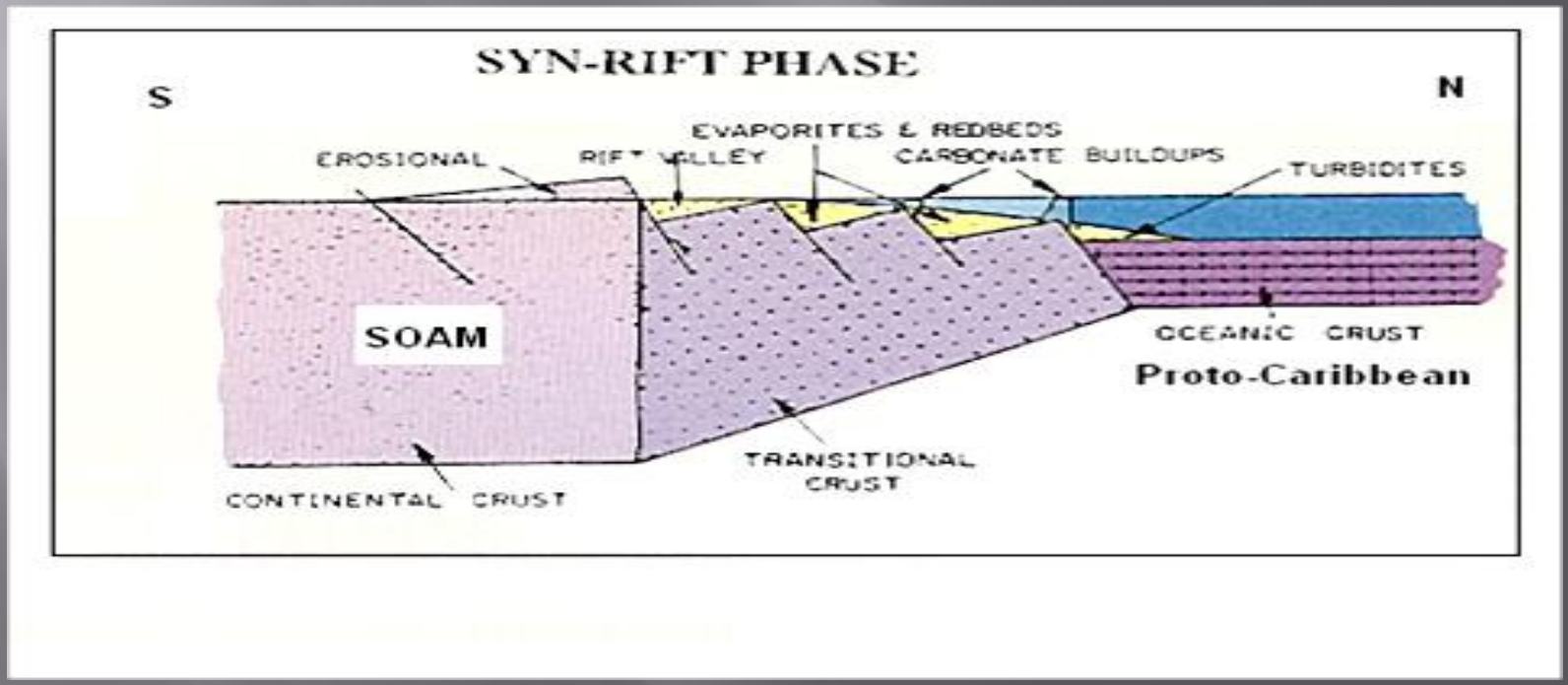
PRE-RIFT, SYN-RIFT and DRIFT (Late Jurassic-mid Cretaceous)

This phase comprises pull apart and sea floor spreading, accompanied by thick suites of sediments, in response to crustal attenuation and cooling.



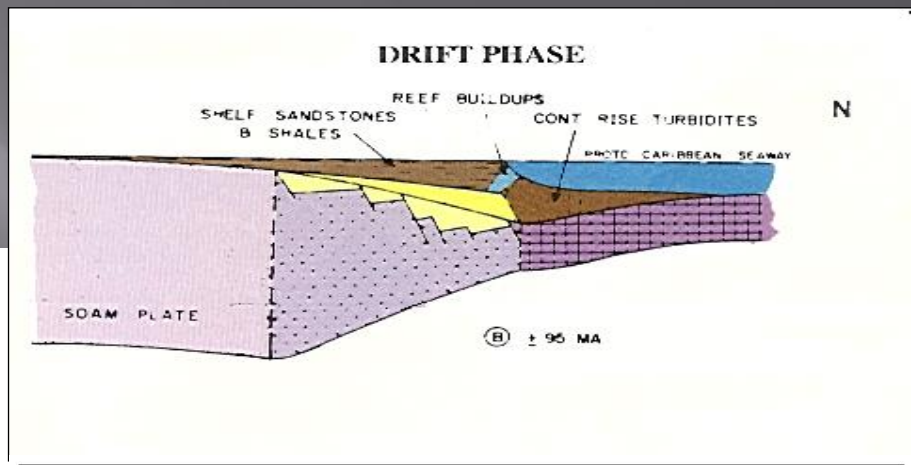
SYN-RIFT PHASE

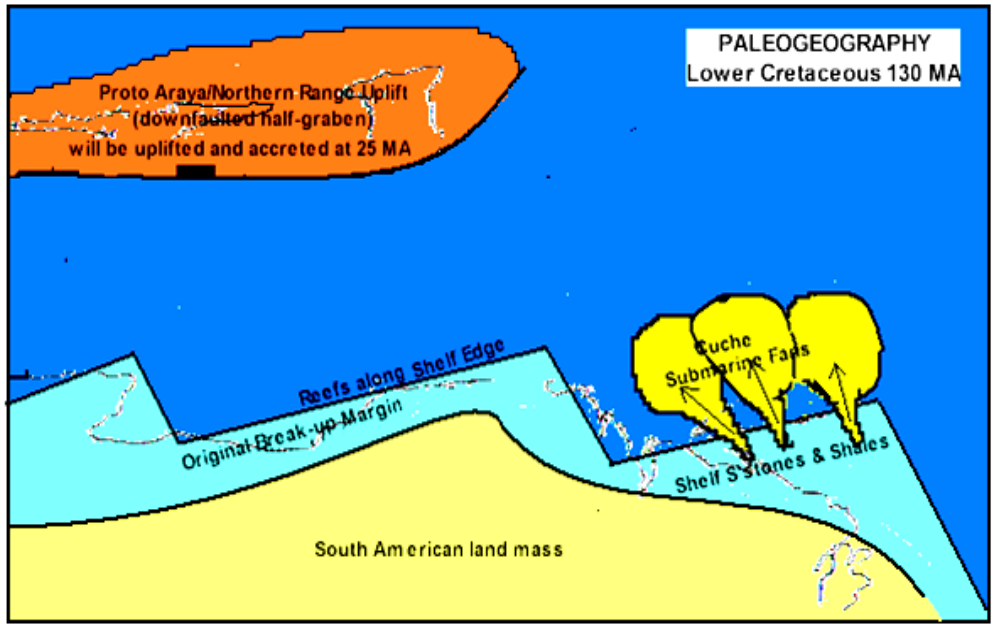
As North America and the Yucatan Block pulled further away evaporite deposition occurred in the proto-Caroni Basin, and extended westward into eastern Venezuela, into an area known as the Espino Graben.
These extensive evaporites could be the mobile rocks on which the older thrust sheets of the fold-thrust belt slid, at least in the Trinidad area.

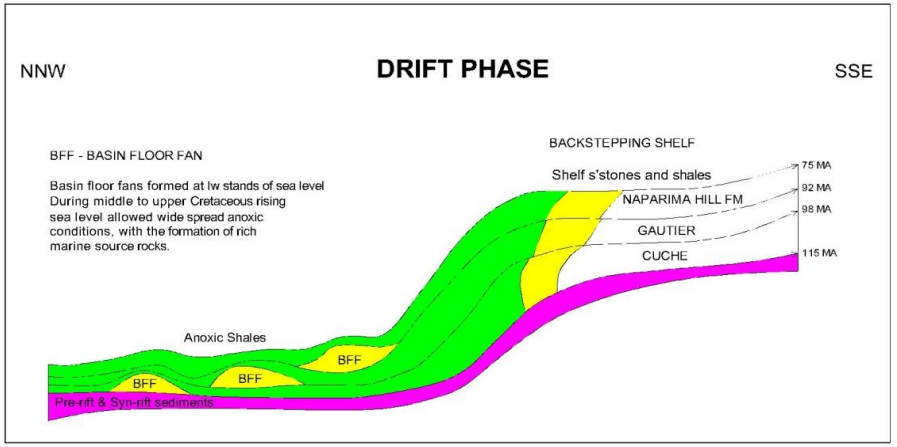


DRIFT PHASE

Continuing separation between the Americas occurred within the proto-Caribbean seaway with the initiation of a SW trending spreading centre between South America and Yucatan
Thick turbidites most likely represent lowstand basin floor and slope fans formed during falling sea level or lowstands of lower Cretaceous times

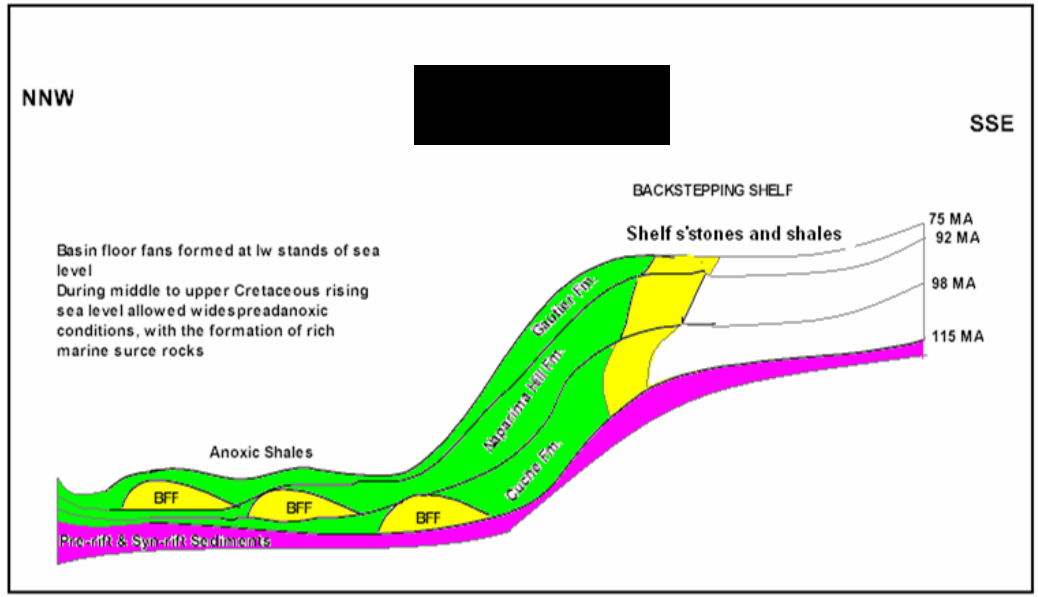


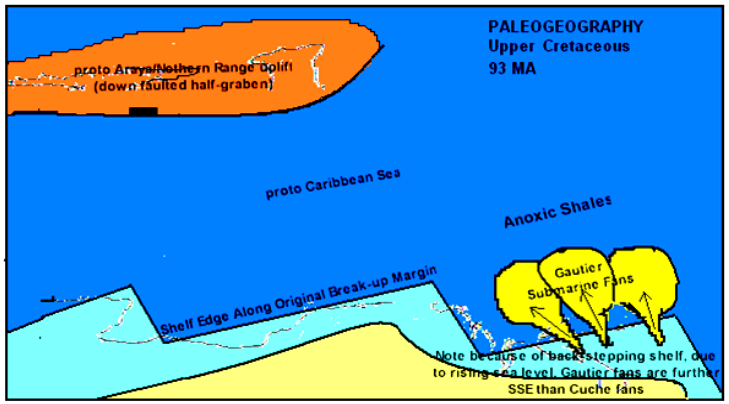




PASSIVE MARGIN (Mid -Late Cretaceous)

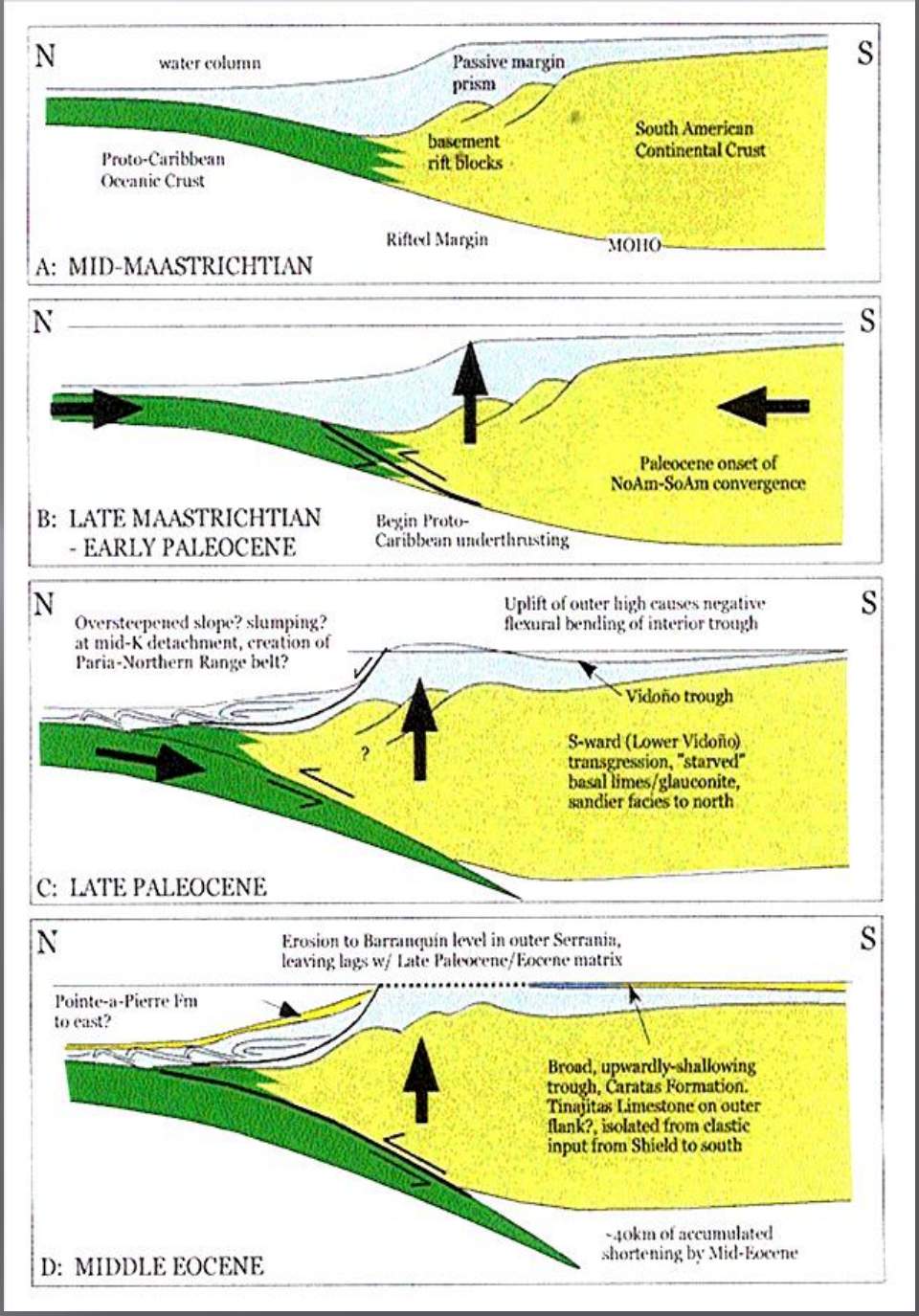
The anoxic shales of the Gautier and Naparima Hill Formations of Upper Cretaceous age, were formed during one of the highest stands of sea levels in earth's history, seemingly accompanied by significant upwelling.





NORTH-SOUTH COMPRESSION (Late Cretaceous-Eocene)

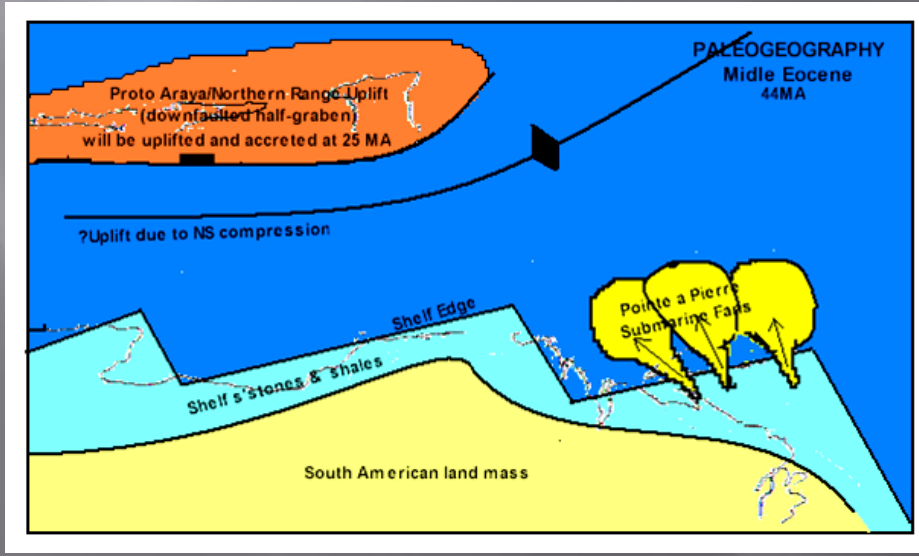
As the proto-Caribbean continued drifting to the north, a spreading center was seemingly initiated. By latest Cretaceous, compression-induced subduction seems to have started on both the northern and southern flanks of the interrupting the passive margin.

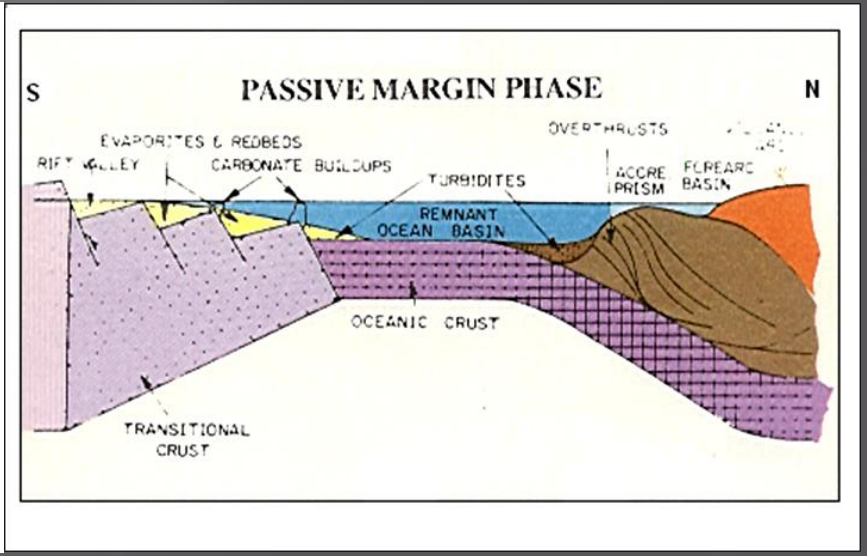


Source: Pindell and Kennan 2007

RETURN TO PASSIVE MARGIN (Lower Eocene-Oligocene)

Oblique convergence between the Caribbean Plate and northern South America started in the west in the Paleocene.
During this period the Trinidad area seems to have been dominated by a return to passive margin conditions, with main sedimentary input still coming from the Guyana Shield area to the south and south-west





SEQUENTIAL OBLIQUE COLLISION (Late Oligocene-mid Miocene)

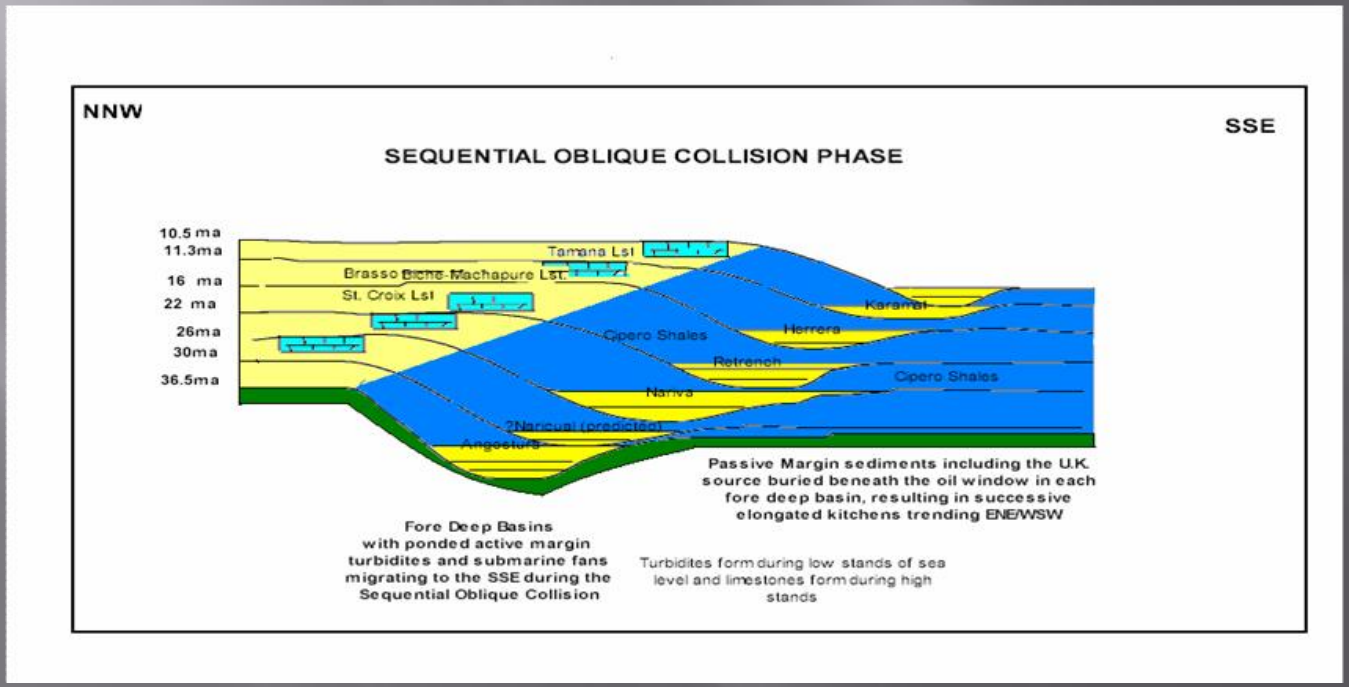
The diachronous oblique collision of the migrating Caribbean Plate with the northwestern extremity of northern South America started in the Paleocene and continued throughout the rest of the Tertiary, moving eastwards with time.

The collision seems to have reached Trinidad in late Oligocene.

The effects of the oblique collision in the Trinidad area were:

1. **Overthrusting of the metamorphic Northern Range Terrane onto the proto-Caroni Basin.**
2. **Development of a series of highly asymmetric anticlines formed within the overthrust ENE/WSW trending Oligo-Miocene detached fold-thrust.**
3. **Downward loading of the crust SSE of the active old thrust belt deforming the remnant ocean basin**
4. **The development of thick sequences of sub-marine fan sediments in the fore-deep basin, trending ENE-WSW, just in front of the leading edge of the fold-thrust belt, which forms the major source of the sediments, also trending, therefore ENE-WSW. The first of the fore-deep basins was probably the Retrench**

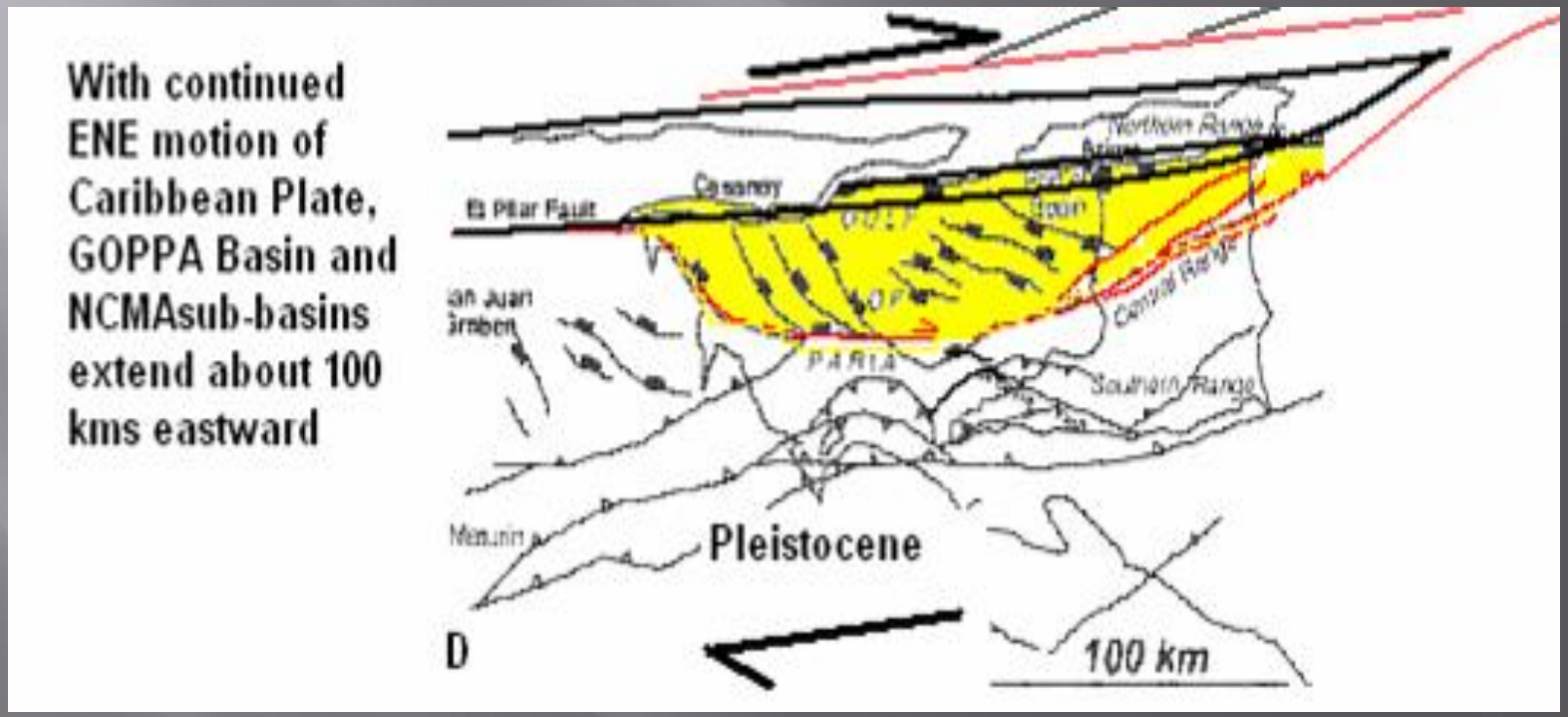
In terms of geochemistry the critical point to make is that it seems that this onset of overthrusting was the start of deep burial of the upper Cretaceous source rocks, with pene-contemporaneous maturation and expulsion
As the collision progressed in an ESE direction, a series of kitchens were formed.
Each kitchen comprised a single phase of maturation and expulsion.
This is the first time that the source rocks did in fact enter the oil window.



GOPPA BASIN

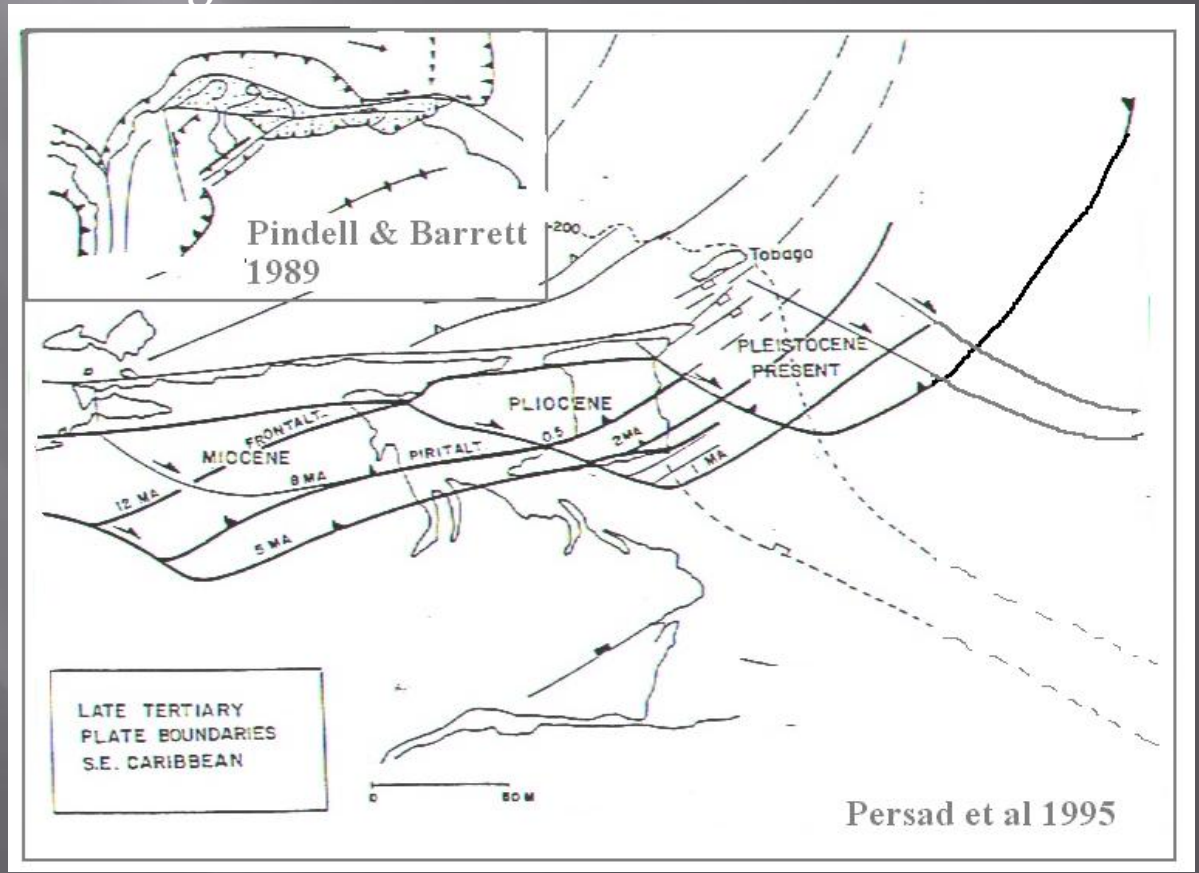
This basin formed in the late Miocene as a result of a step over of the El Pilar Fault to the south and east

As eastward movement continued, the pull-apart basin collided with the Central Range uplift which trends north-east. Along the Central Range Fault transpression resulted in the uplift of the Central Range.



As further eastward motion continued, transpression occurred in the areas to the south and east, starting in the early Pliocene (5ma) and seemingly continuing to the present.

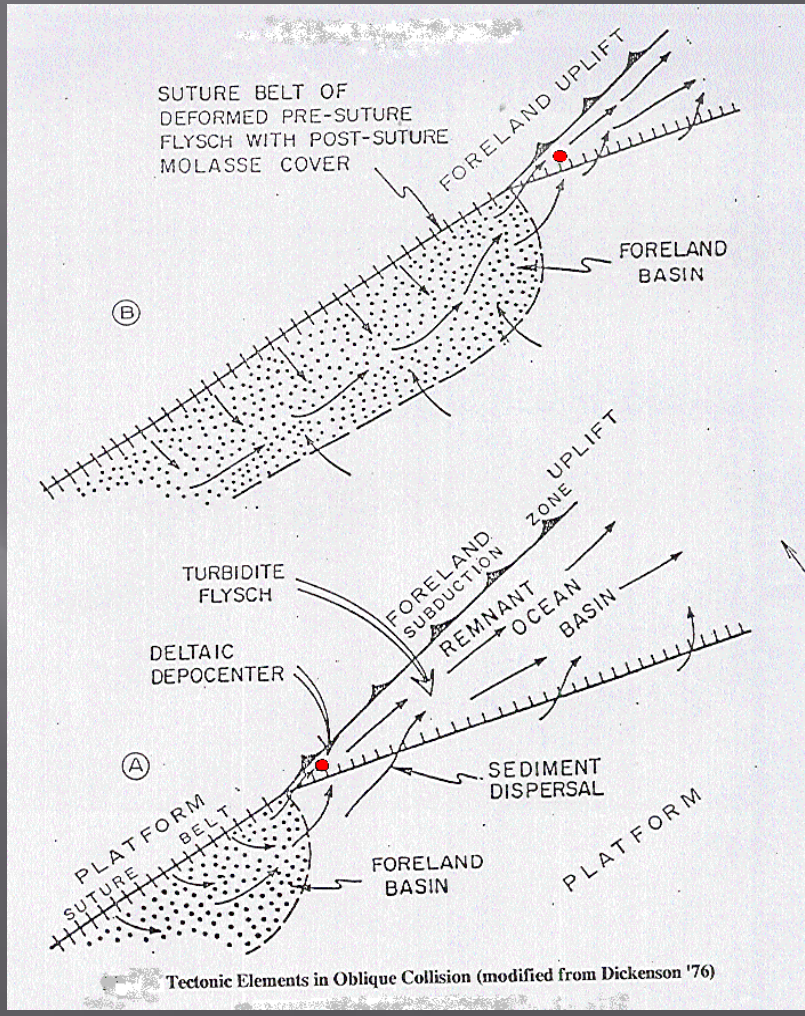
The transpression resulted inter alia in the formation of a series faults like the Los Bajos originally termed (by Persad et al 1989 and 1995) as "wrench-thrust couples" or "Jekyll and Hyde" faults, which are now termed lateral ramps. The overthrust portions join together and coalesce along the southern margin into what is termed the "Southern Range Anticline".



CONT1NENTAL EMBANKMENT CONSTRUCTION (DELTAIC PHASE) (Pliocene-Present)

When the eastward migration of the Caribbean plate started around Eocene times, the eastward flowing Proto-Orinoco deposited deltaic and associated sediments to the east and NE.

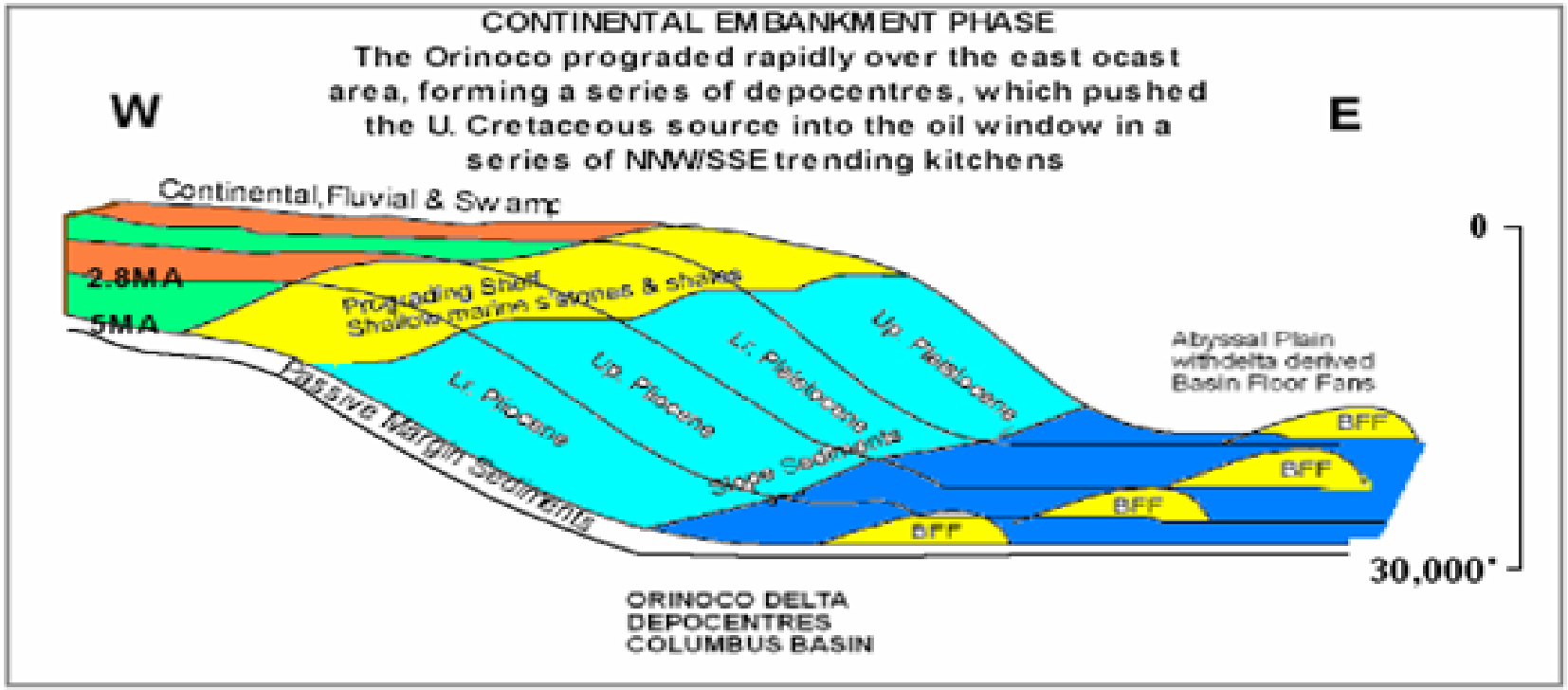
When the Caribbean Plate reached the eastern end of northern South America the main part of the delta pushed eastward into the open Atlantic and deposited massive amounts of sediments brought in by the Orinoco in the Columbus Basin.



Tectonic Elements in Oblique Collision (modified from Dickenson '76)

Eastward progradation of the Orinoco Delta resulted in the migration of a series of depocenters, of which four are recognized, two in the Pliocene, and two in the Pleistocene. During the Pleistocene, the delta probably prograded over the paleo-continental shelf edge onto oceanic crust causing it to overload and hence the very thick Pleistocene section.

Turbidite sedimentation occurred on the continental rise and abyssal plain off the East Coast of Trinidad and Tobago and extended far to the east and to the north, accounting for the very wide Accretionary Prism mentioned earlier.



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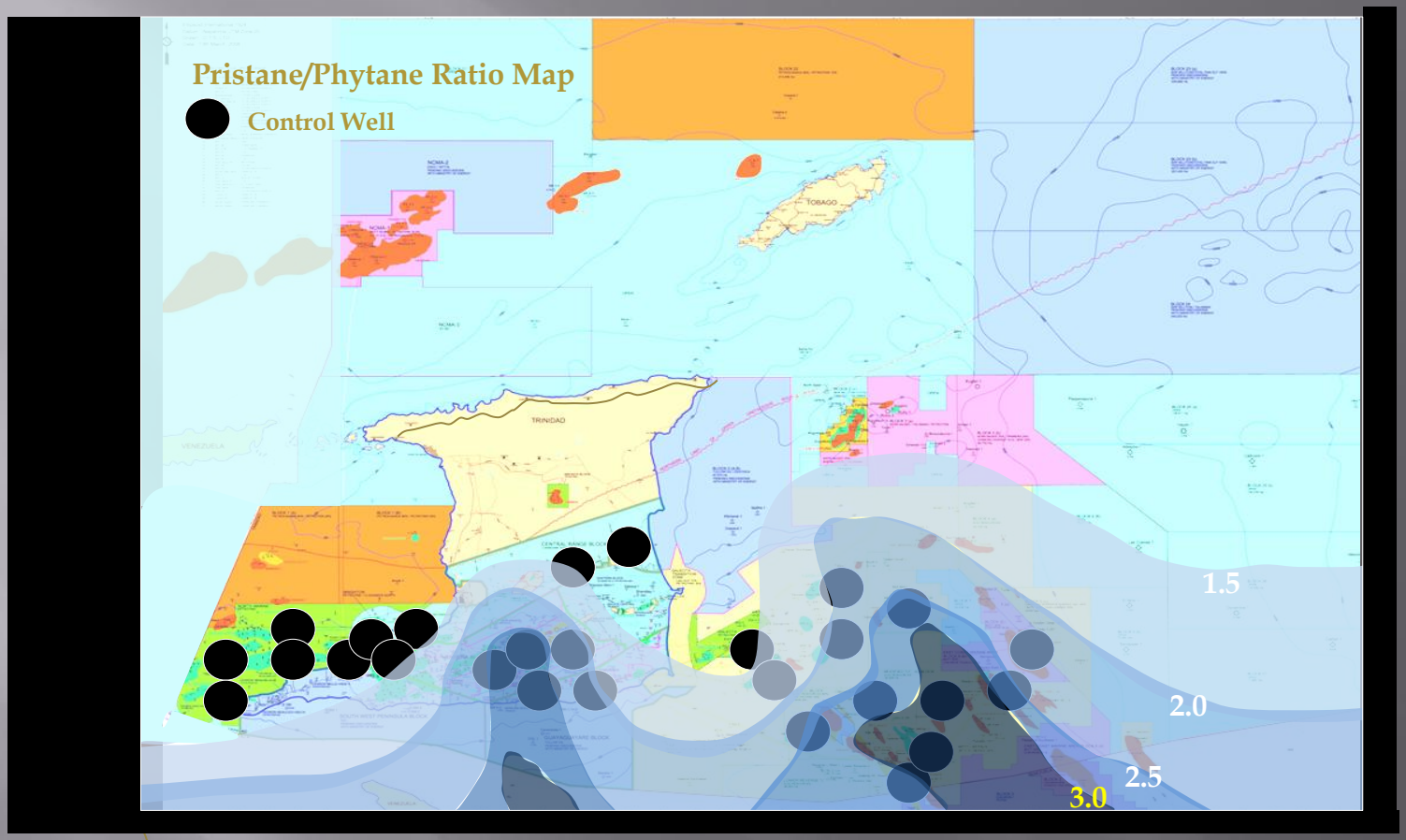
Two petroleum systems are recognised in the pre-Tertiary:

The Gautier/Naparima Hill-Cuche/Gautier/Naparima Hill (.) Petroleum System
The Gautier/Naparima Hill-Cuche/Gautier/Naparima Hill (.) Petroleum System

SOURCE
Both have the Gautier and Naparima Hill formations as the source.

RESERVOIR
The first has Cuche, Gautier and Naparima Hill sandstones as the reservoirs.
The second has fractured Naparima Hill and probably Gautier shales as the reservoirs and form a potential unconventional play

Time does not permit us to describe these systems but they have been described in detail by Persad et al (2011)



SOURCE

Map of Pristane/Phytane Ratios shows the Upper Cretaceous source to be pure marine to the north with terrestrial input to the south in two areas, the southern Columbus Basin and in the Carapal Ridge area onshore (Persad 2003) They have found the Albian age Cuche source rocks to be overmature to at least the gas phase

PETROLEUM ACCUMULATIONS

SUBMARINE FAN RESERVOIRS

To date the only known oil accumulations are the sub-commercial discoveries made in the Moruga East 15 well, which found heavy oil in Gautier turbidites and light oil/condensate in Naparima Hill turbidites in the Rocky Palace 1 well...also in turbidite sands

In addition two wells tested oil in upper Cretaceous sands, S189 in Naparima Hill and

AT 35 in Gautier.

More recently Howler 1 tested gas and condensate in Naparima Hill sands

UNCONVENTIONAL RESERVOIRS

Several wells, including wells in Beach Field and in the northern eastern offshore tested oil from tight naturally fractured Naparima Hill source beds. All wells were vertical.

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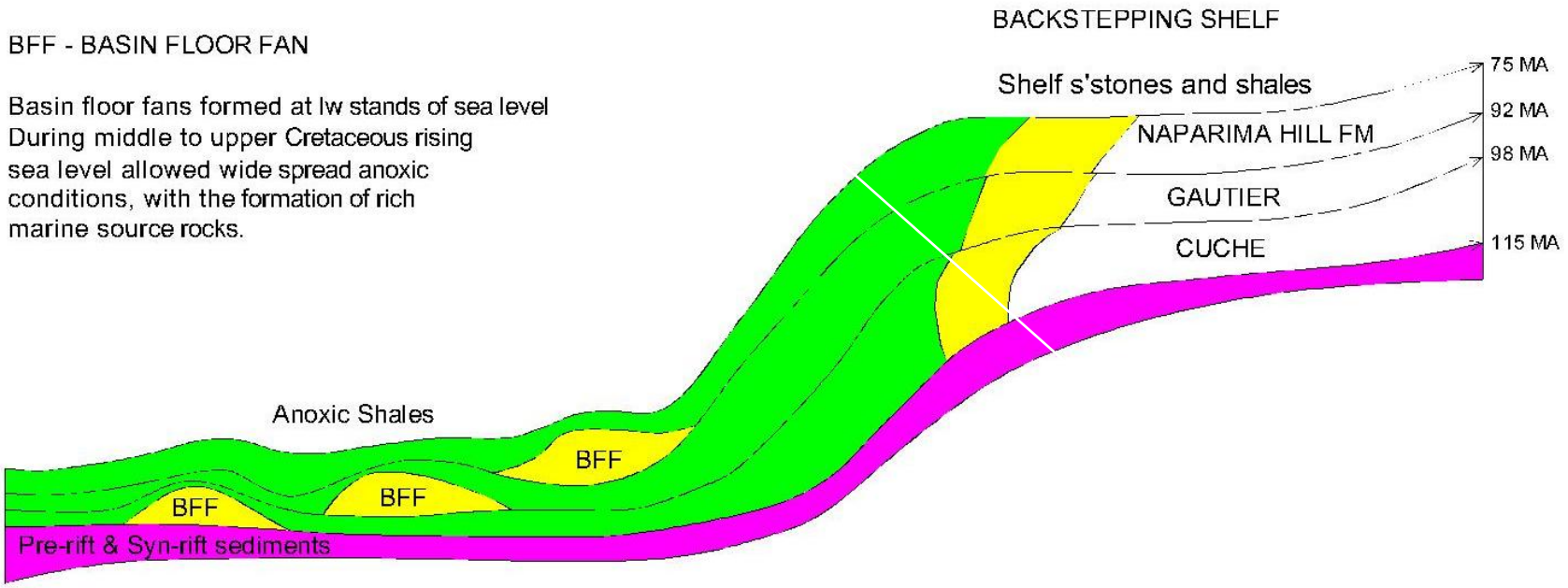
NNW [redacted] SSE

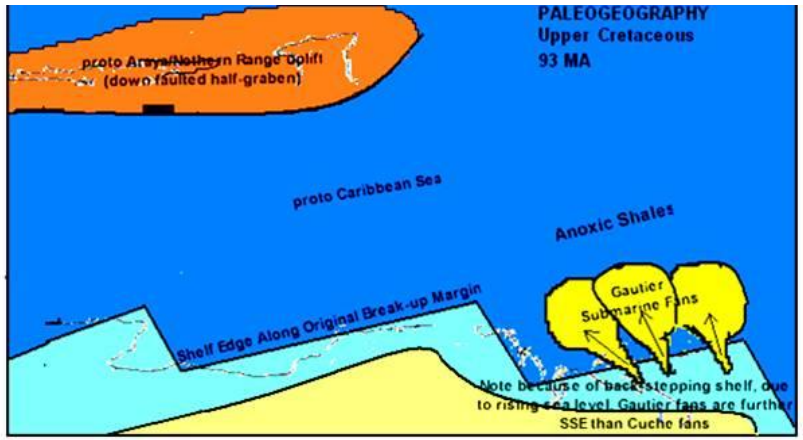
BFF - BASIN FLOOR FAN

Basin floor fans formed at lw stands of sea level During middle to upper Cretaceous rising sea level allowed wide spread anoxic conditions, with the formation of rich marine source rocks.

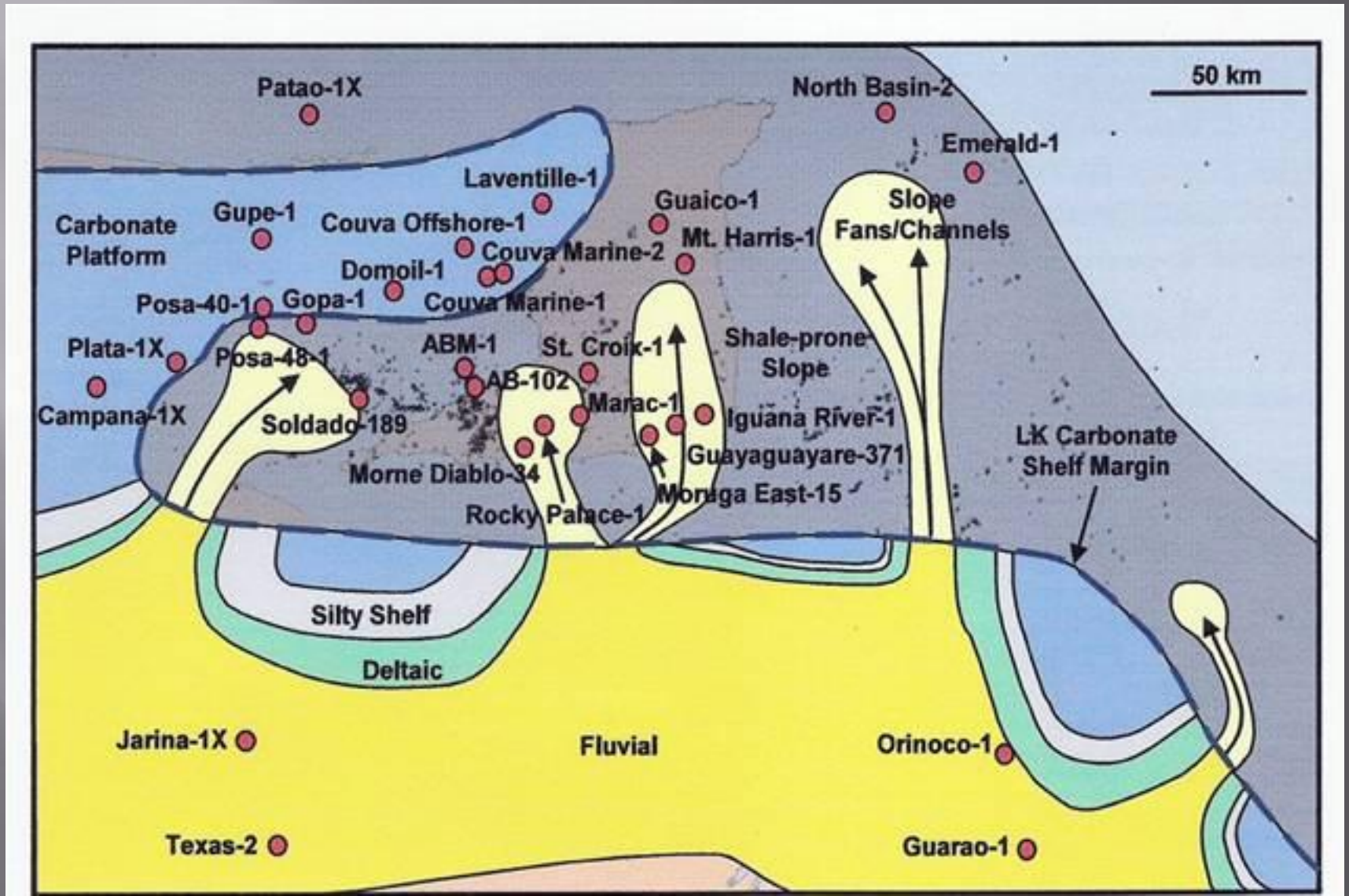


The basin floor fans of Cuche Gautier and Naparima Hill age form potential reservoirs in South Trinidad

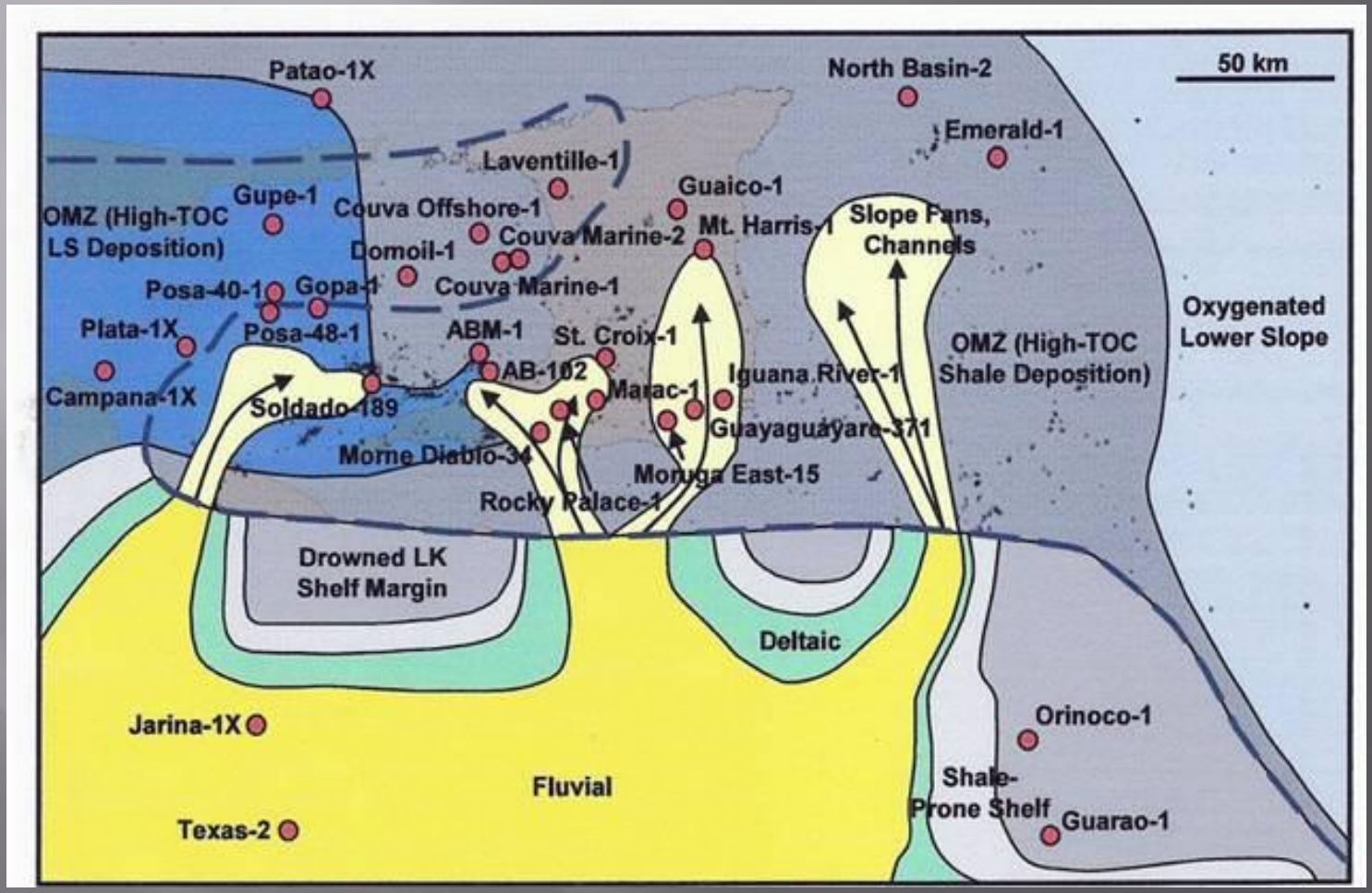
Passive Margin Phase (Persad 2011)

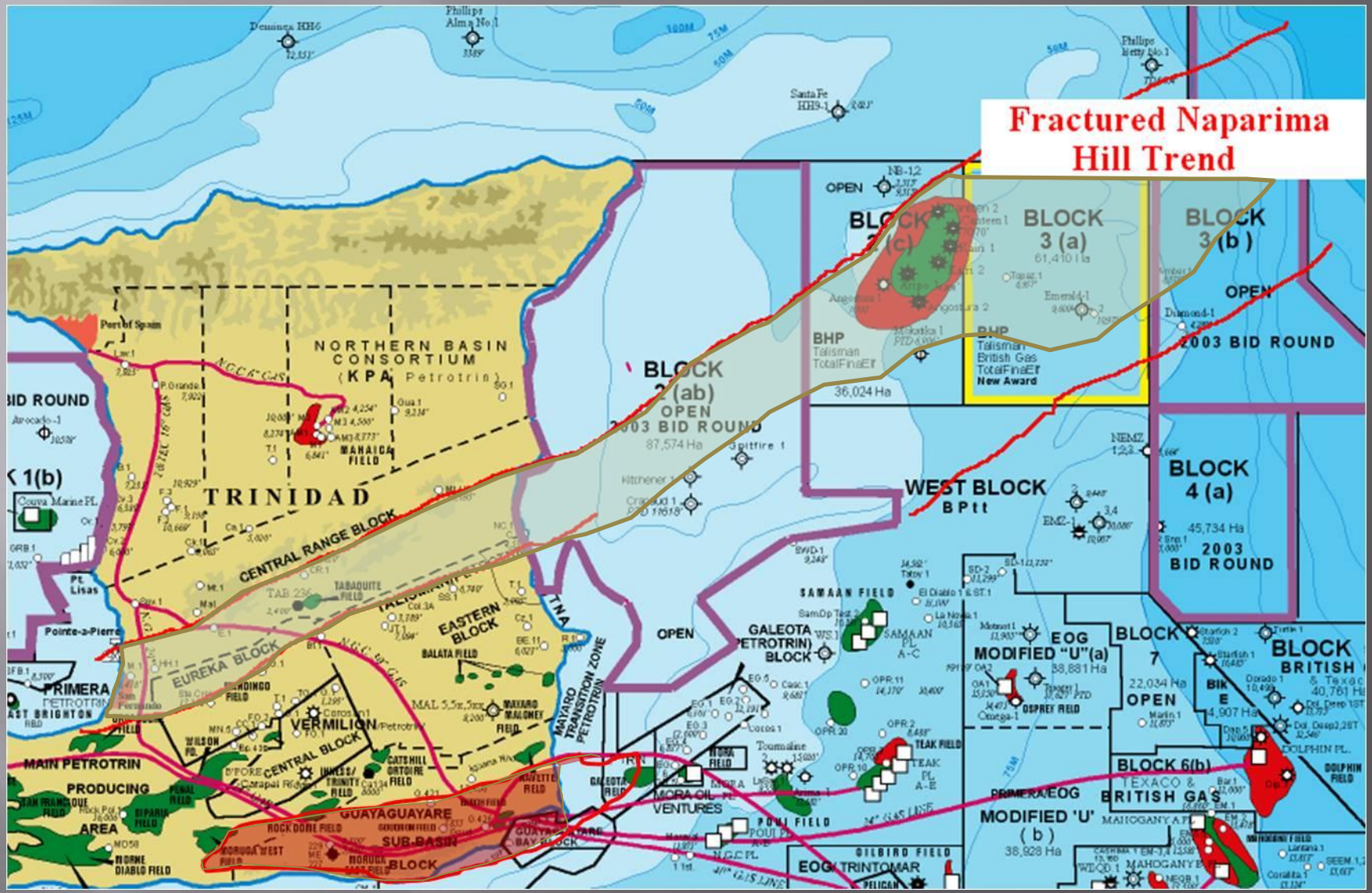


CUCHE RESERVOIRS
SUBMARNE FANS SOURCED FROM THE SOUTH (Map Source Erlich and Keens-Dumas 2007)

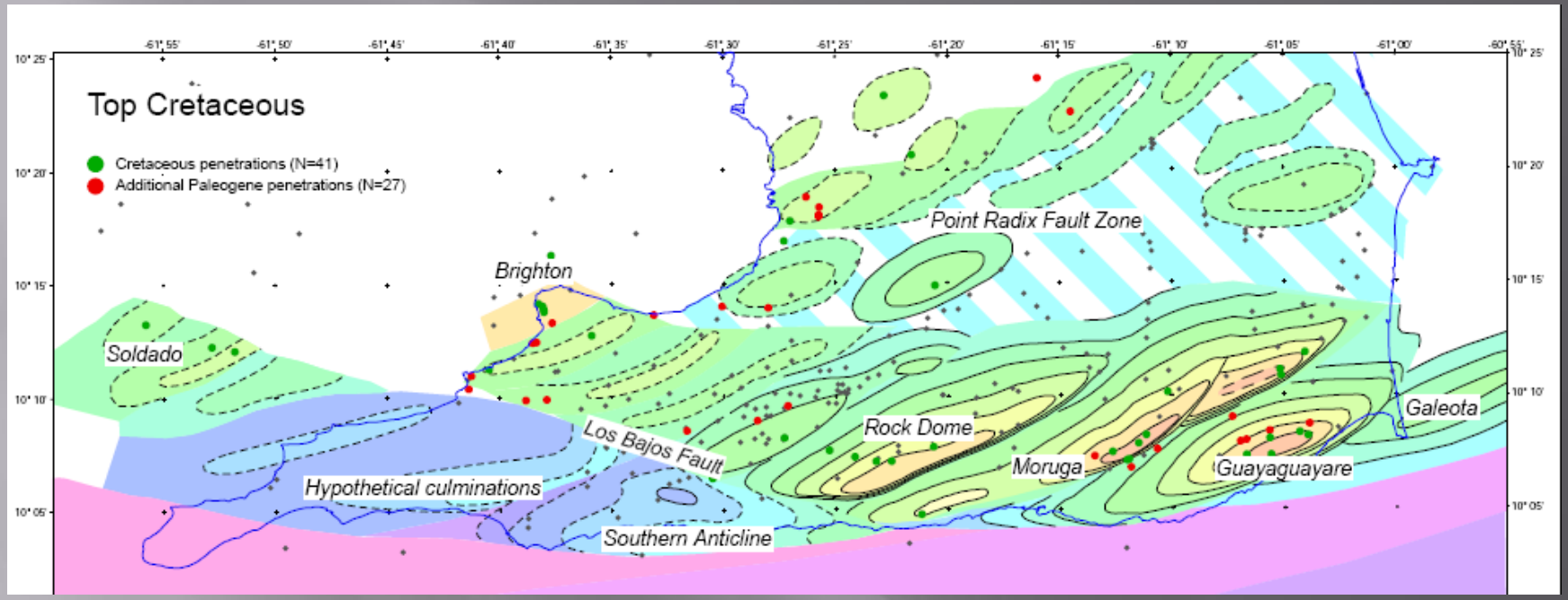


GAUTIER AND NAPARIMA HILL RESERVOIRS
SUBMARINE FANS ALSO SOURCED FROM THE SOUTH (Map Source Erlich and Keens-Dumas 2007)





Persad et al (2011) postulated that Naparima Hill Argillite and possibly Gautier shales could form the target for unconventional oil in South East Trinidad and along the Central Range Transpressive Belt



Naparima Hill Argillite and possibly Gautier shales could form the target for unconventional oil in South East Trinidad and along the Central Range Transpressive Belt

They could also be targets for for conventional oil in areas where reservoirs are found.

Pindell (2006) recognised Cretaceous closures in South and Central Trinidad (see map above)

Persad has mapped some of these closures in more detail

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AIR FTG HAS BEEN USED IN OTHER PARTS OF

THE WORLD WITH SIGNIFICANT SUCCESS

WE WILL LOOK AT WHAT AIR FTG IS

THEN LOOK AT SOME EXAMPLES AND

FINALLY LOOK AT POSSIBLE LOCAL APPLICATIONS

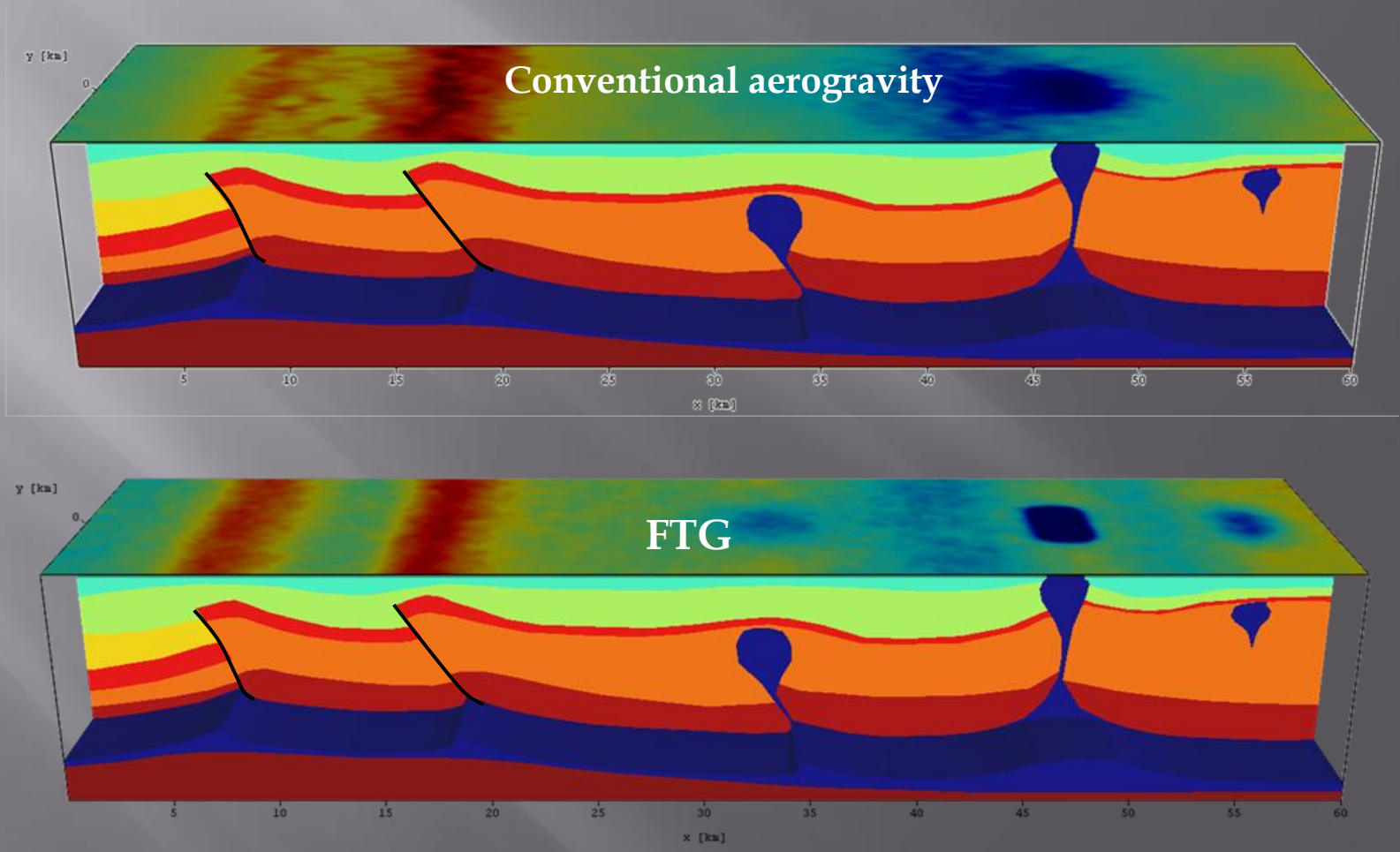
WHAT IS AIR FTG?

FTG is an abbreviation for Full Tensor Gravity.

Air-FTG® is a system that provides high resolution airborne full tensor gravity gradient data

The FTG acquisition system measures minute changes (gradients) of the earth's gravity caused by density differences in the local geology.

The FTG acquisition system gives significantly higher resolution than conventional airborne gravity surveys



WHAT ARE ITS USES IN PETROLEUM EXPLORATION?

When combined with known geologic information and other kinds of data, FTG data is used to interpret geological structures and/or resource deposits including oil and gas

WHERE HAS IT BEEN USED…IN THE ONSHORE?

AUSTRALIA, INDIA, AFRICA and the MIDDLE EAST among others

WE WILL LOOK AT EXAMPLES FROM

WESTERN AUSTRALIA and

UGANDA

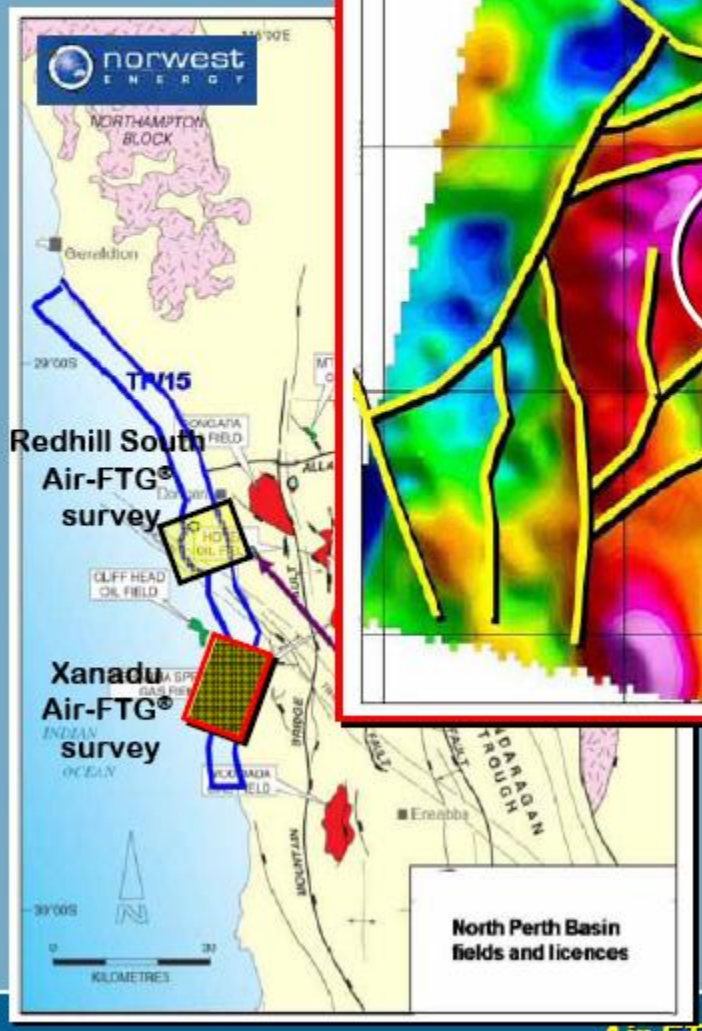
Air-FTG®

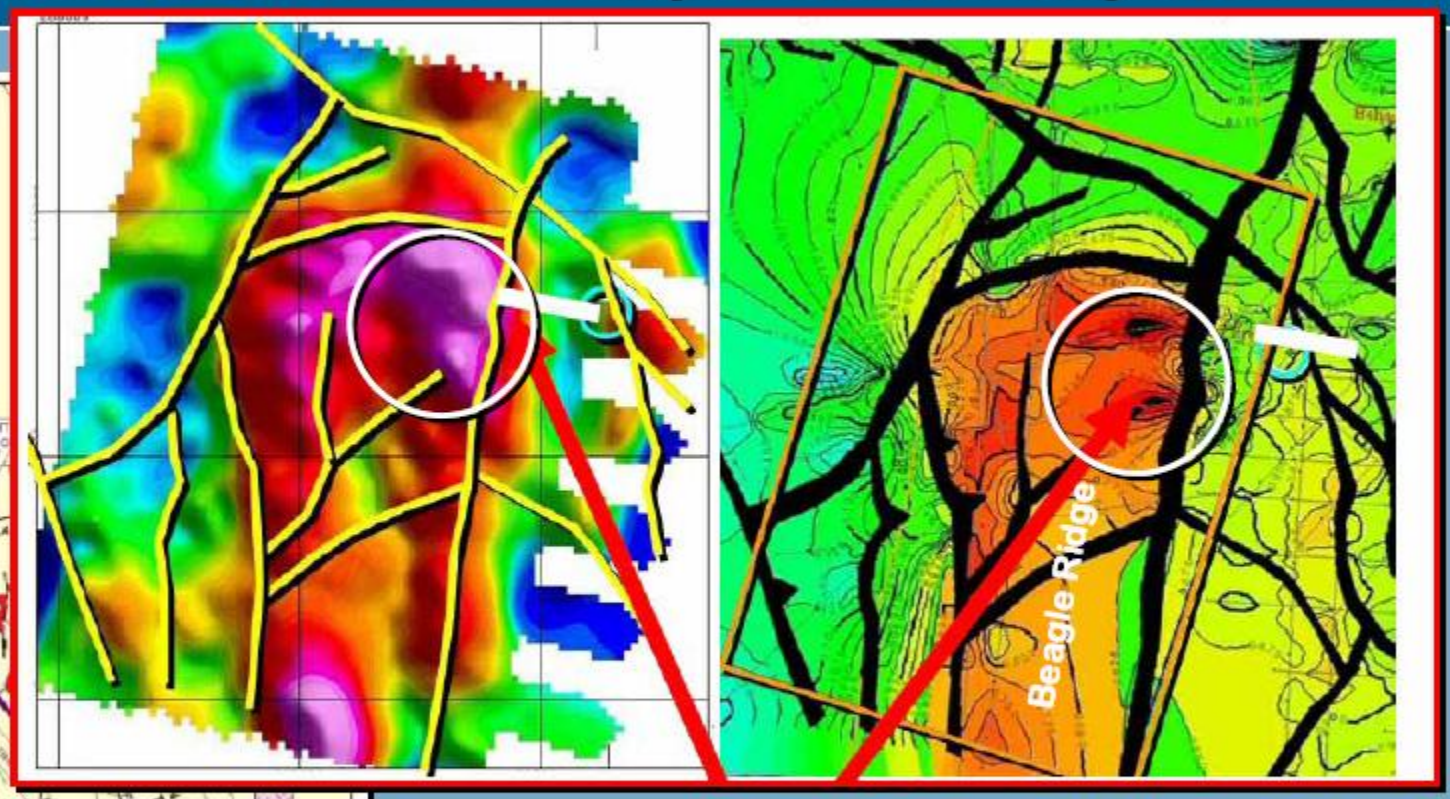
4-Way Structural Closure Exploration Play

North Perth Basin, Australia

FLAT IRONS GEOPHYSICS

4-Way Structural Closure Exploration Play Models:





- FTG Gravity confirms the seismic interpretation map for Top Reservoir detecting the prospective structural closures;
  - 98 MMbbl oil predicted

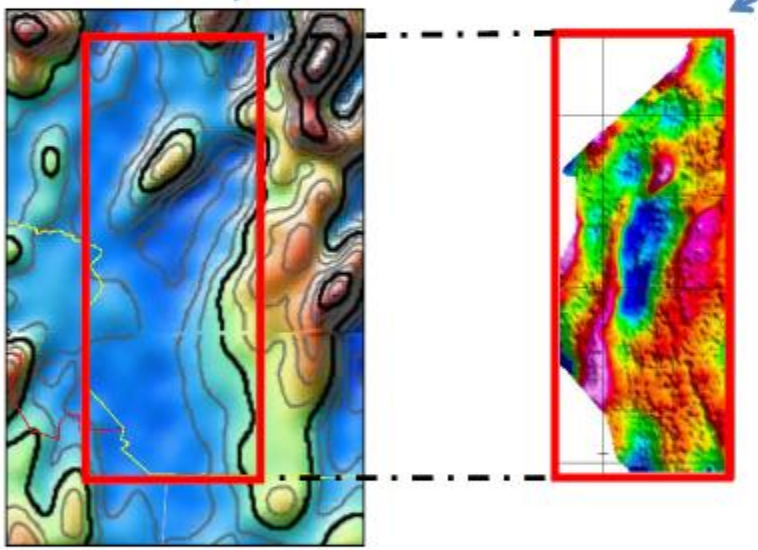
Air-FTG® data shown with permission from Norwest Energy

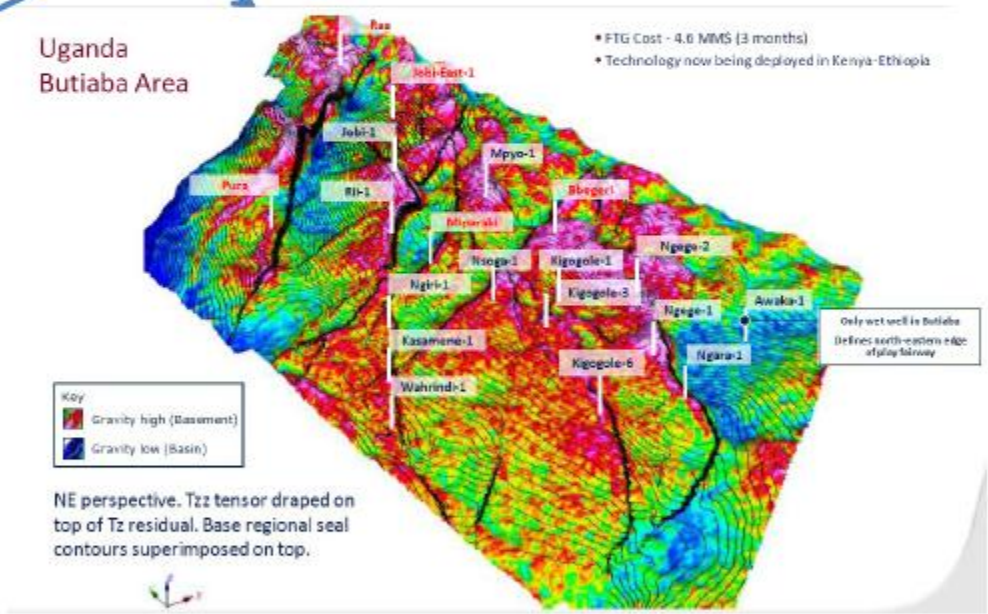
AfricaOil Corp.

Tullow Using New FTG Technology

Traditional Gravity

New Full Tensor Gravity





- New technology developed by Bell Labs for US submarine mapping - released to public in late 90's
- Detailed mapping comparable to 3D seismic
- FTG with seismic unlocks basin potential

Tullow used FTG very successfully in Uganda Albert Graben

2.5+ billion barrels

Source: Tullow presentation

Why acquire FTG data?

Seismic data in a complicated thrust environment is often of poor quality due to :

- Structurally complex geology with very steep dips
- Intense thrusting, faulting and deformation in general
- Frequent velocity inversions
- These problems result in misinterpretations of the seismic data and significant errors on the predicted locations and depths of formations

How can FTG data help?

- Being an airborne technology, it offers fast and complete horizontal coverage
- The FTG (full tensor gradiometer) provides the high resolution that is necessary to properly image the shallow structures
- Cost-effective alternative to further seismic acquisition

Benefits

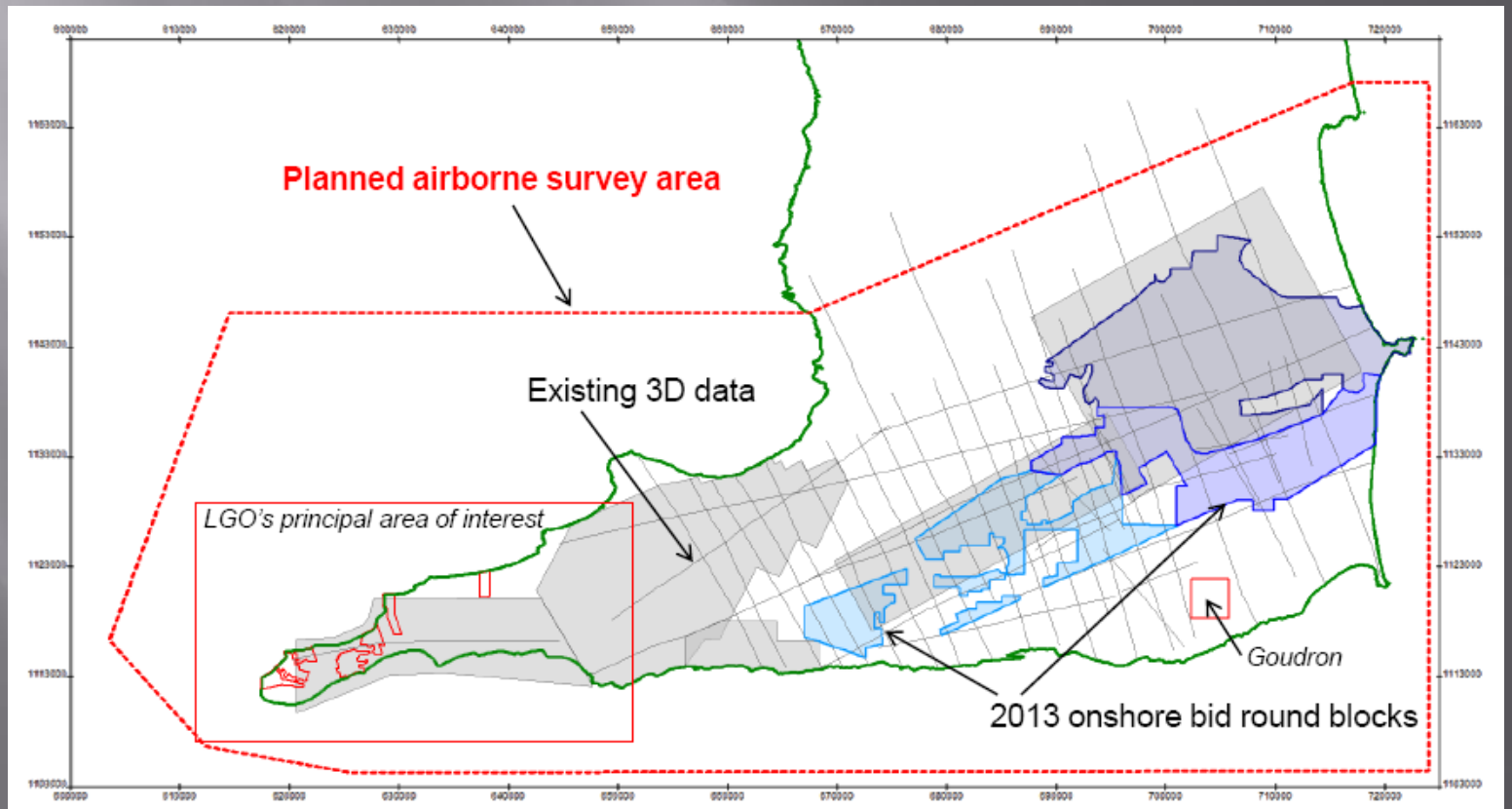
- **Regional exploration**
  - improved definition of the sedimentary basin and internal architecture
  - identification of structural leads which can become the focus for seismic acquisition
  - early seismic in the basin can be calibrated to the FTG and if necessary, the seismic program can be altered in areas of shallow basement or insufficient depth of burial of potential source rocks
  - a fast and efficient way of exploring vast exploration acreage
- **Prospect specific exploration**
  - Exploiting high fidelity of gradiometry data and linkage to seismic to improve seismic imaging

AIR FTG
ADDITIONAL POSSIBLE APPLICATIONS

- IDENTIFY STRUCTURAL HIGHS
- IDENTIFY SHALLOW GAS HAZARDS
- IDENTIFY SHALLOW GAS ACCUMULATIONS(to at least 5,000 feet)
- TRACK SWEEP EFFICIENCY IN GAS FLOODS
- and IN CO2/EOR FLOODS

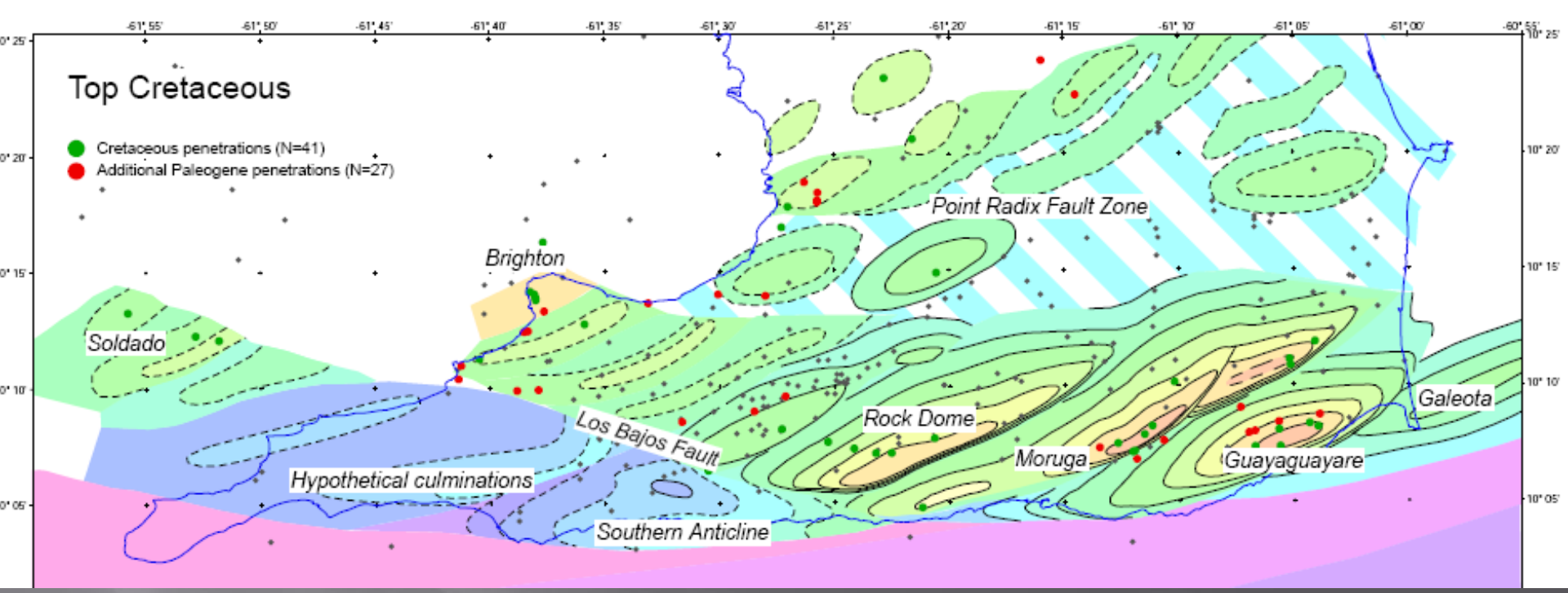
AIR FTG …PLANNED PROGRAMME BY LENI GAS AND OIL

LGO PLANS TO DO AN AIR FTG SURVEY OVER THE ENTIRE ONSHORE SOUTHERN AND CENTRAL TRINIDAD USING ARKEX AS THE CONTRACTOR

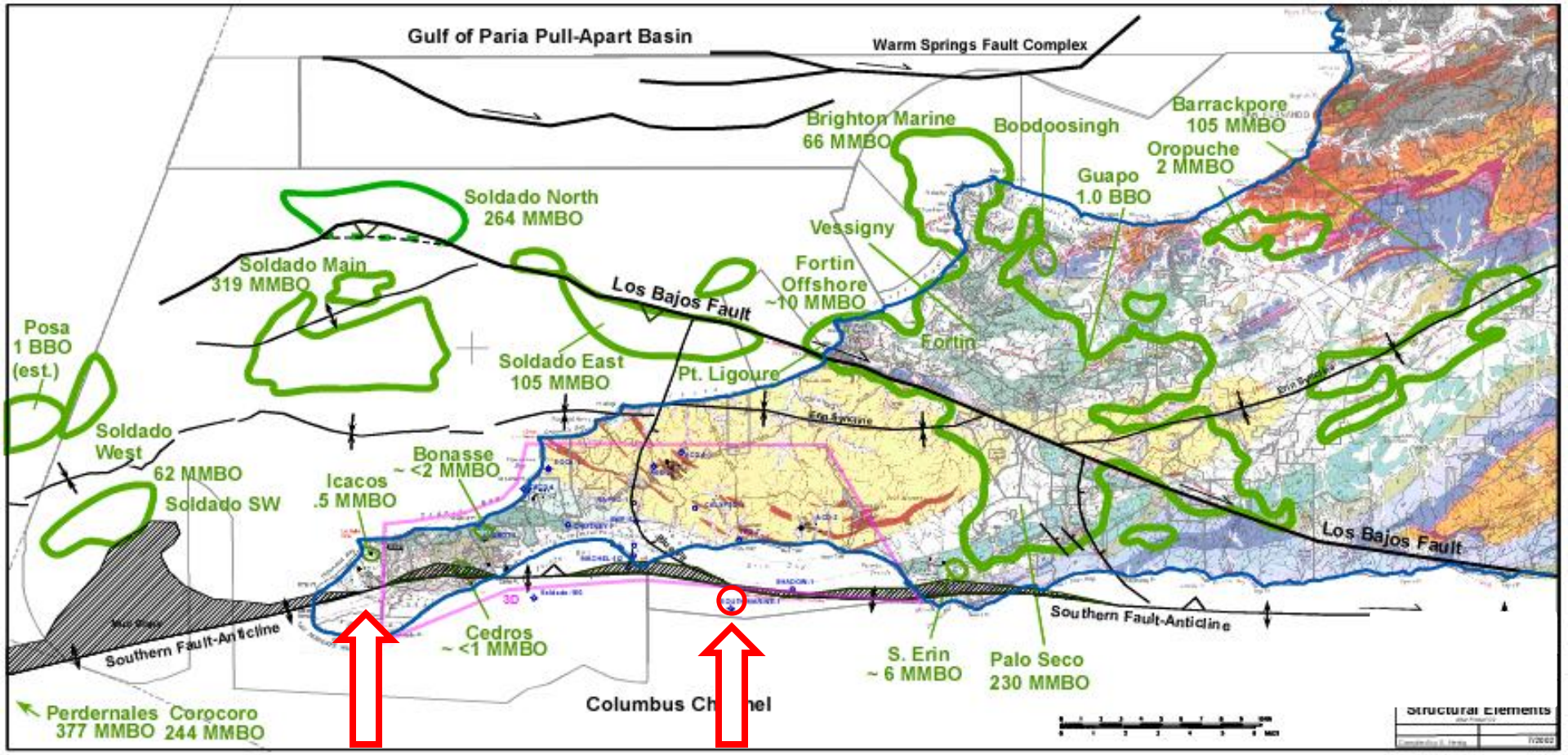


LGO EXPECTS TO IDENTIFY *inter alia*:

- STRUCTURAL HIGHS
- INCLUDING CRETACEOUS HIGHS…this can form basis for further exploration for Cretaceous oil conventional and unconventional



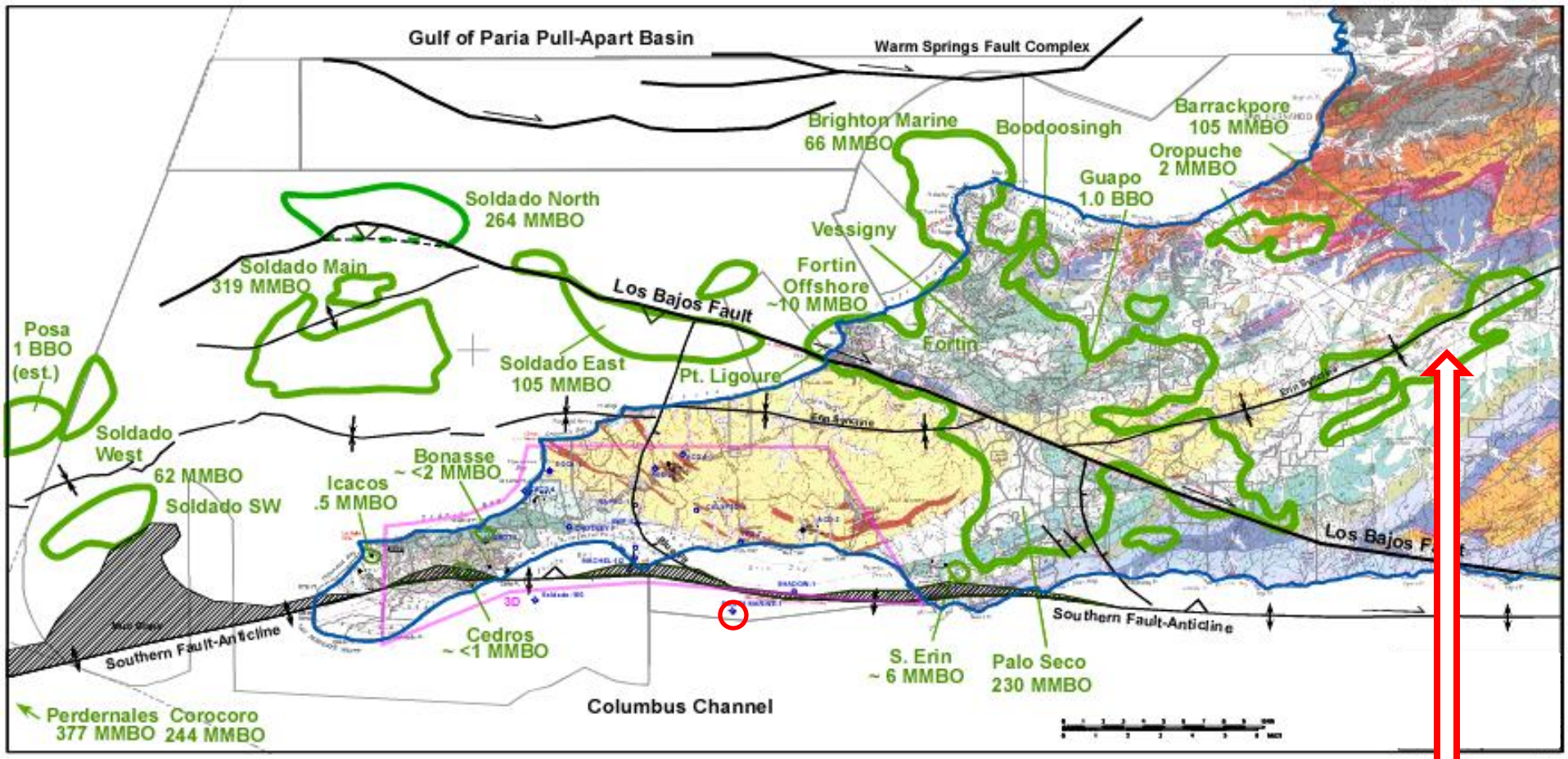
WE ALSO HOPE TO:
IDENTIFY SHALLOW GAS ACCUMULATIONS SOUTH OF THE CENTRAL RANGE IN ONSHORE ACREAGE OWNED BY US (LGO & BOLT) IN THE SWP



GAS POTENTIAL ONSHORE

SM 1
GAS DISCOVERY

WE ALSO HOPE TO:
TRACK SWEEP EFFICIENCY IN A CO2 EOR FLOOD THAT KPAL HOPES TO START SOON IN ITS FARMOUT IN BARRACKPORE



KPAL'S BARRACKPORE FARMOUT

THE END