Exploration for Cretaceous Deep-Water Reservoirs in the Circum-Caribbean Region: Historical Review and Expectations for the Future*

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*Adapted and expanded from oral presentation given at Geoscience Technology Workshop (GTW), Deep Horizon and Deep Water Frontier Exploration in Latin American and the Caribbean, Port of Spain, Trinidad, March 9-11, 2014, and given at Houston Geological Society dinner meeting, Houston, Texas, June 9, 2014

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Abstract

Historical exploration efforts within the Circum-Caribbean region have not typically targeted Cretaceous reservoirs for a variety of technical and commercial reasons. The principal exceptions to this have been exploration efforts along the north coast of Cuba during the 1950's (sporadic since then), some wells on- and offshore Honduras and Nicaragua during the 1930's-1970's (three recent wells in the 2000's), and five wells in the Bahamas during the same time period. Renewed interest in Cretaceous reservoirs began in earnest during the mid-late 1980's, mainly as a byproduct of successful exploration in Eastern Venezuela's Furrial Trend, though these discoveries are concentrated principally within Neogene-Paleogene strata.

Exploration for Cretaceous targets has focused almost exclusively on Trinidad since this time, and results have not been overwhelmingly positive, regardless of whether the objectives were located onshore or offshore. Further interest in the Cretaceous has been generated recently by the discovery of commercial accumulations in slope and basin floor fan/channel complexes, most commonly found along the Equatorial Atlantic margins of West Africa and South America (the "Transform Margin Play"). Despite these recent successes, Cretaceous reservoirs and traps continue to yield unpredictable drilling results, especially along the margins of northern South America.

Significant technical risks include reservoir presence and deliverability, hydrocarbon charge access, and trap/seal integrity. Commercial challenges include hydrocarbon type (gas vs. oil), volumes required for commercial development, development costs (hub and spoke versus stand-alone accumulations; number of development wells and FPSO's needed), and decreasing contractor take. A quick review shows that nearly all successful (?) wells in the trend have been drilled from 5-40 km down depositional dip from the Cretaceous paleo-shelf margin, though the technical factors mentioned above do not guarantee this "sweet spot" will hold up over the long term. While new discoveries in deep-water Cretaceous reservoirs are possible within the Caribbean-northern South America region, significant technical and commercial risks will continue to affect new exploration drilling.

References Cited

Erbacher, J., D. Mosher, M. Malone, M., and O.L.S. Party, 2004, Drilling probes past carbon cycle perturbations on the Demerara Rise: EOS, v. 85, p. 57-68.

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. American Association of Petroleum Geologists Memoir 79, p. 1-45.

Erlich, R.N., and J. Keens-Dumas, 2007, Late Cretaceous Palaeogeography of northeastern South America: implications for source and reservoir development: In Proceedings of the 4th Geological Society of Trinidad and Tobago Geological Conference – "Caribbean Exploration – Planning for the next century", 17th–22nd June 2007, Port of Spain, Trinidad.

Exploration for Cretaceous Deep-water Reservoirs in the Circum-Caribbean Region: Historical Review and Expectations for the Future

Robert Erlich and Francis Inniss

What We Will Discuss

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Part 1

- The nature of “The Cretaceous Play” and its variants
- Where the “fan/channel play” is working and why
  - Examples from Equatorial Africa, northeastern South America, and Trinidad
- Future considerations

Part 2

- A brief historical review of exploration in the Caribbean region, focusing on recent activity
- Summary thoughts

“The Cretaceous Play”

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- Extrapolated/extended from the now classical “West African Transform Margin Play” (next slide)
- Now focuses on any Cretaceous objective, regardless of the petroleum system
- Traps can be stratigraphic, structural, or any combination
- Can be salt-related or not
- Sandstones or limestones

"The Cretaceous Fan/Channel Play"

PanAtlantic

- Also known as the "West Africa Transform Margin Play" (WATM); consists of a series of Upper Cretaceous deep-water slope and basin floor fans and channels within structural/stratigraphic traps, currently being explored along the Equatorial margins of Africa and South America; **Since 2000, >100 wells have been drilled in the play***
- First and second commercial successes: Ghana
  - Jubilee complex (2009): about 700 mmboe recoverable
  - TEN complex (Tweneboa-Enyenra-Ntomme, 2013): about 360 mmboe recoverable
- Next commercial successes: Ghana – Tullow/Kosmos/Anadarko MTA (Mahogany-Teak-Akasa) and ENI (Sankofa/Gye-Nyame); Hess (Pecan et. al) still pending Pre-Dev work; Nigeria? – Yinka Folawiyu (Aje), Afren (Ogo) unclear
- Play contains hydrocarbons in:
  - Africa: Ghana, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Benin, Nigeria (far NW offshore), Equatorial Guinea
  - South America: Brazil, French Guiana, Guyana, Trinidad
- Critical technical risks
  - Access to charge/charge focus and volume
  - Trap definition – where are the potential leak points?
  - Reservoir presence and deliverability
  - Hydrocarbon phase – spotty success with AVO and attributes
- Critical commercial risks: Gas utilization and commercialization; F&D costs; Contractor take, etc.

**Compiled from IHS Data*

Two Commercial Developments, Ghana

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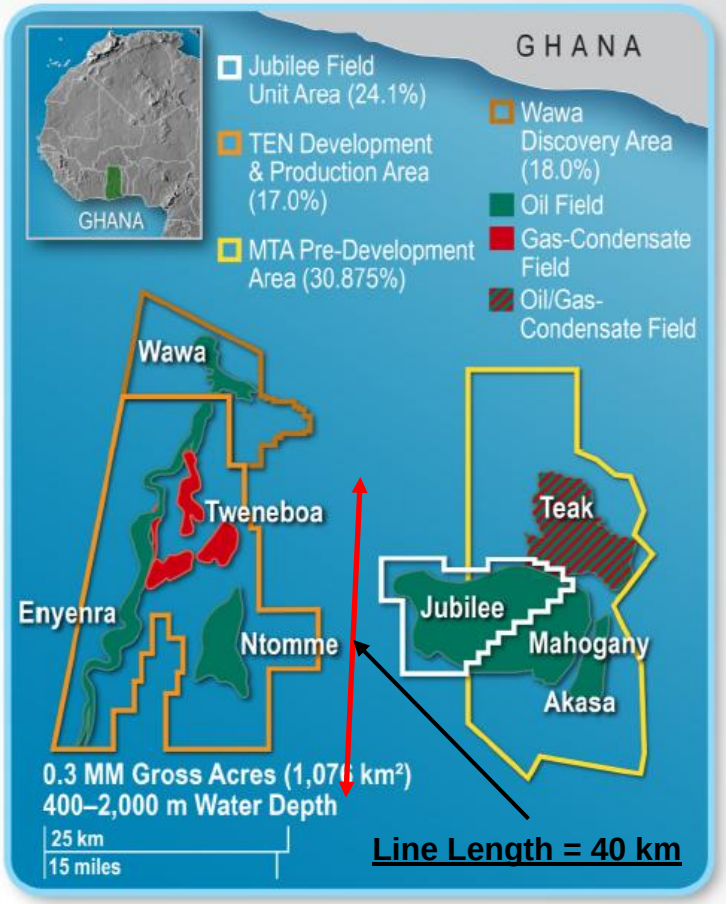
Ghana Discoveries

KOSMOS ENERGY

Kosmos "First Inning" grand slam

- **Opening the Tano Basin**
  - Architect of the basin-opening Jubilee discovery
  - Eight proven hydrocarbon discovery areas
  - High value barrels with 2+ to 4 BBO in place
  - Secures Company as a self-funded explorer
  - Top quartile F&D cost performance
- **Greater Jubilee Area**
  - Jubilee reservoir performance outstanding
  - Several production enhancement opportunities
  - MTA appraisal activity ongoing
  - Plateau-extending, high value barrels in MTA
  - Long-life production plateau of five to seven years
- **TEN Development**
  - Second FPSO-based development in Ghana



From Kosmos Investor Presentation (2014)

"The Cretaceous Fan/Channel Play," Ghana

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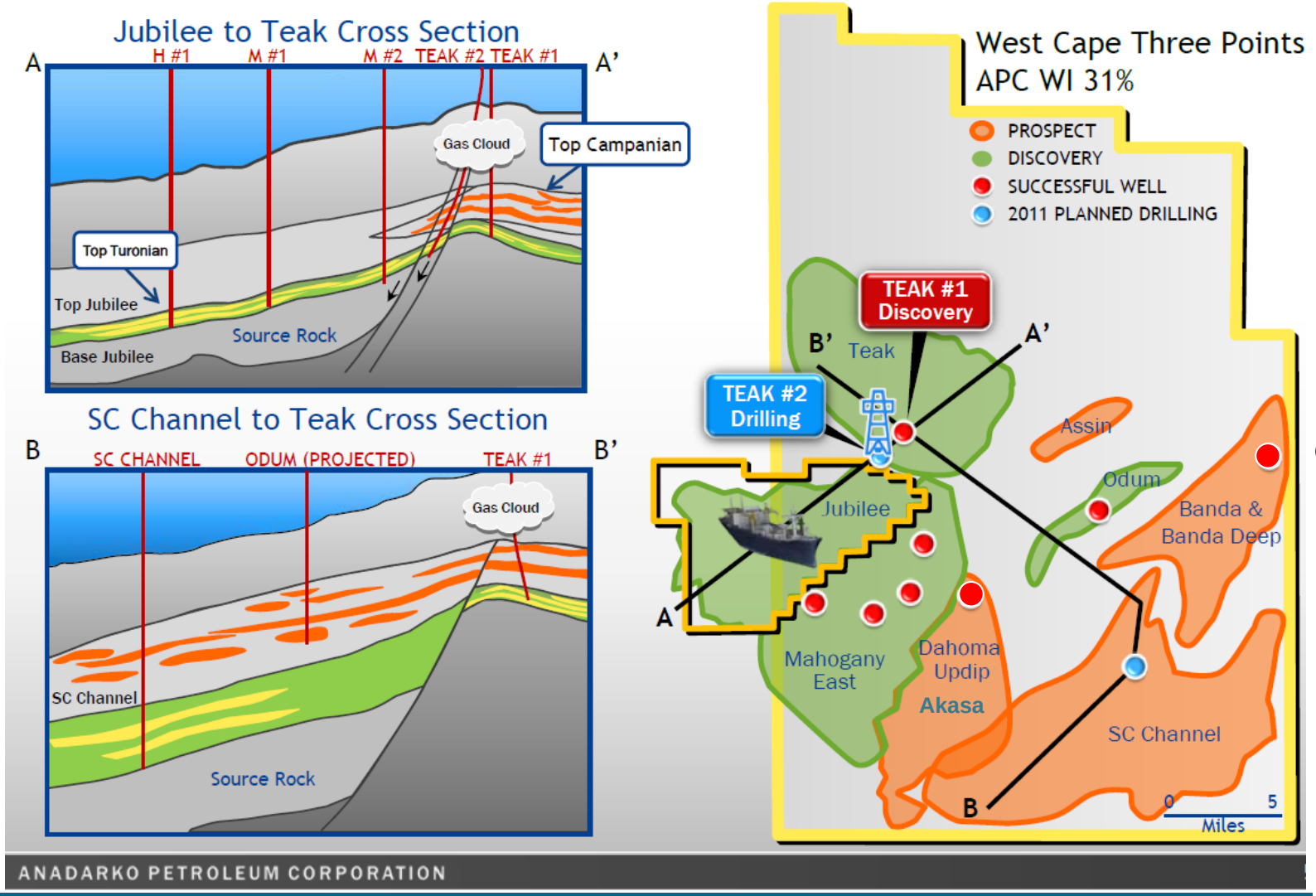
Ghana: Expanding Opportunities



Cenomanian Oil Low Poroperm

ANADARKO PETROLEUM CORPORATION

From Anadarko Investor Presentation (2011)

"The Cretaceous Fan/Channel Play," Ghana

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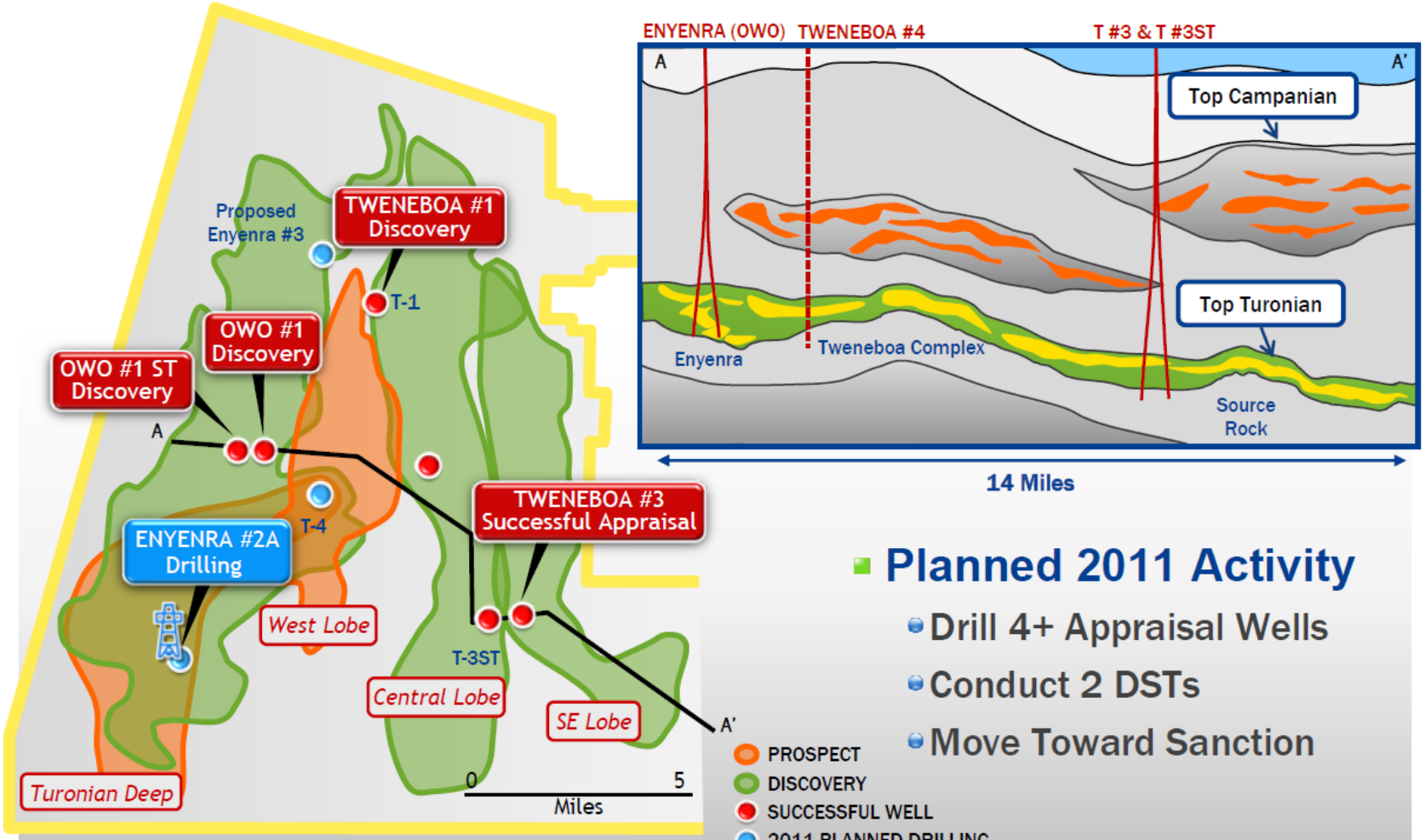
Ghana: Transitioning Tweneboa / Enyenra



- **Planned 2011 Activity**
  - Drill 4+ Appraisal Wells
  - Conduct 2 DSTs
  - Move Toward Sanction

Deepwater Tano APC WI 18%

From Anadarko Investor Presentation (2011)

Regional Drilling Activity and Results, 2005-2014

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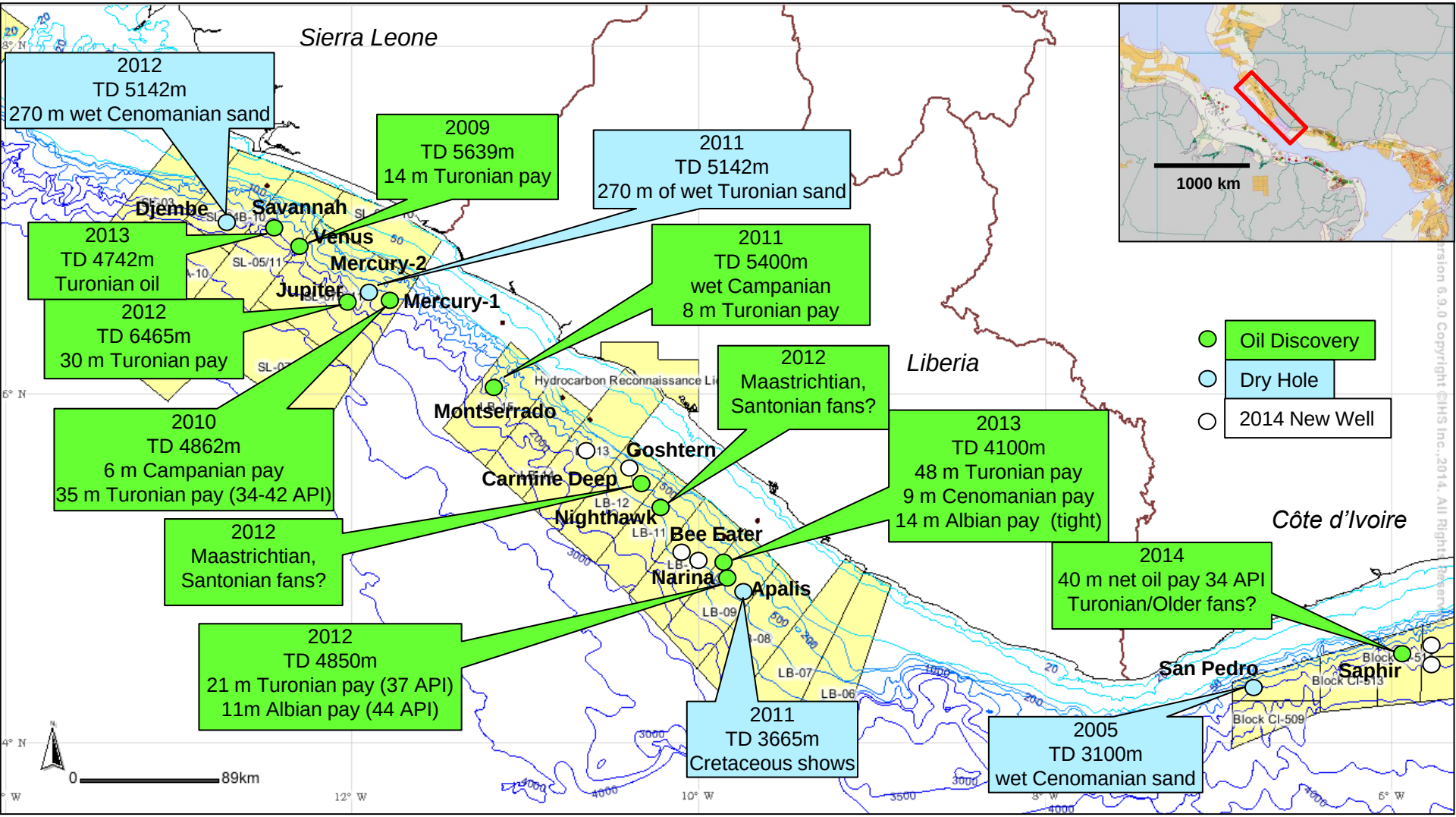

Map and Data from IHS, various public sources

Cretaceous Fan Distribution, Sierra Leone, Liberia

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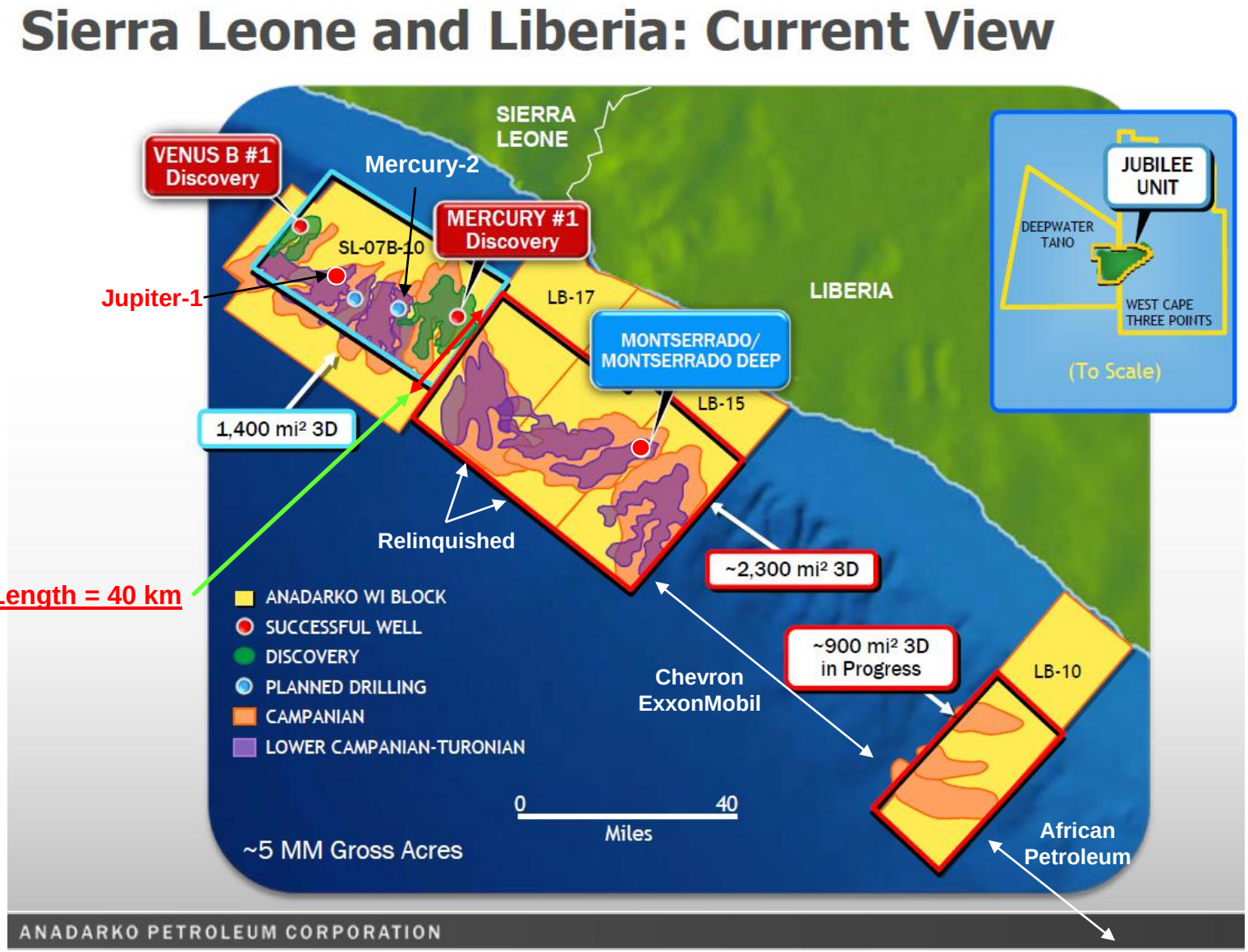

From Anadarko Investor Presentation (2011)

Sierra Leone, Liberia Fan System: Ghana Analogue

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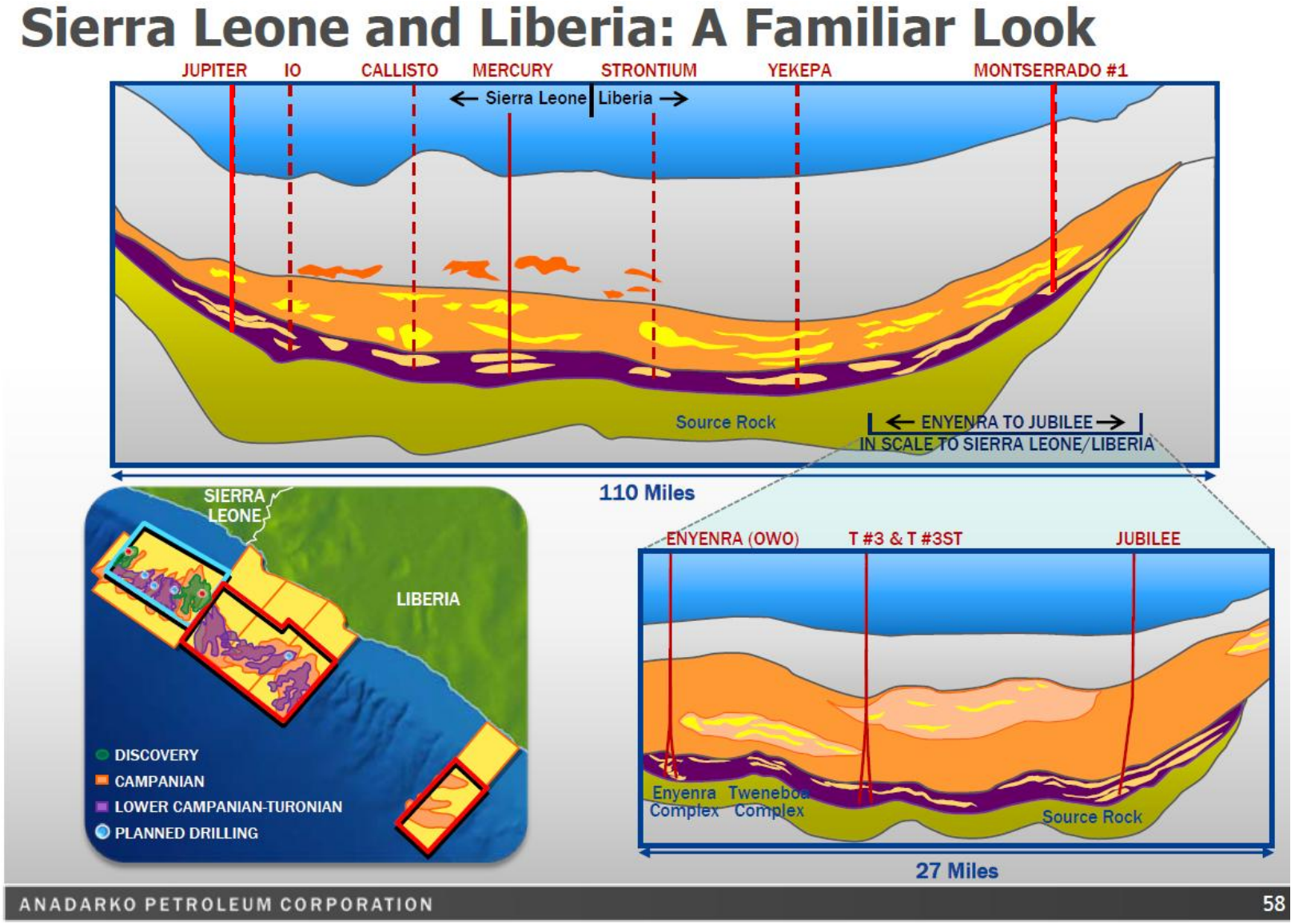

From Anadarko Investor Presentation (2011)

“Bee Eater” Fan System, LB-08 and 09

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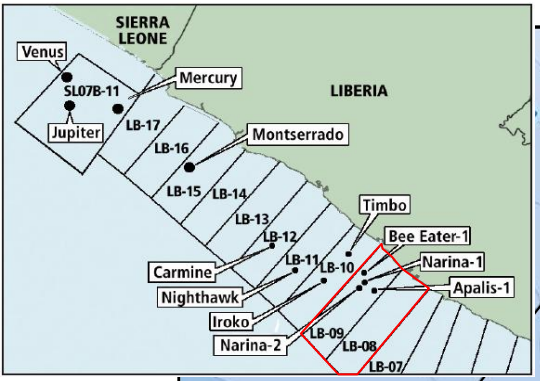

From African Petroleum Investor Presentations (2012-13), Africa Oil and Gas (March 10, 2014)

Liberia Block LB-09: Regional Seismic, Narina-1

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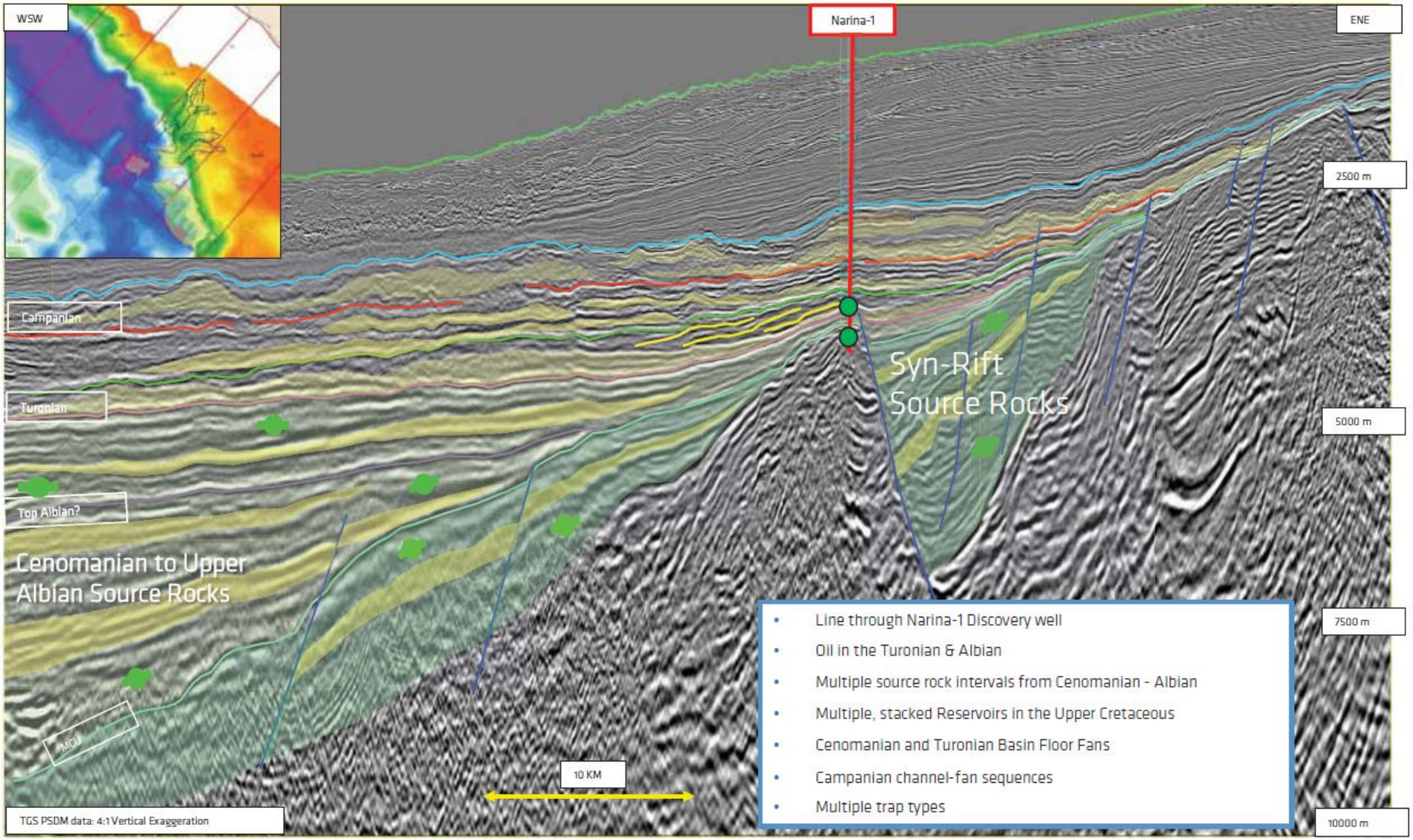

From African Petroleum Investor Presentation (2012)

“Discoveries” vs Distance From Paleo-shelf Margin

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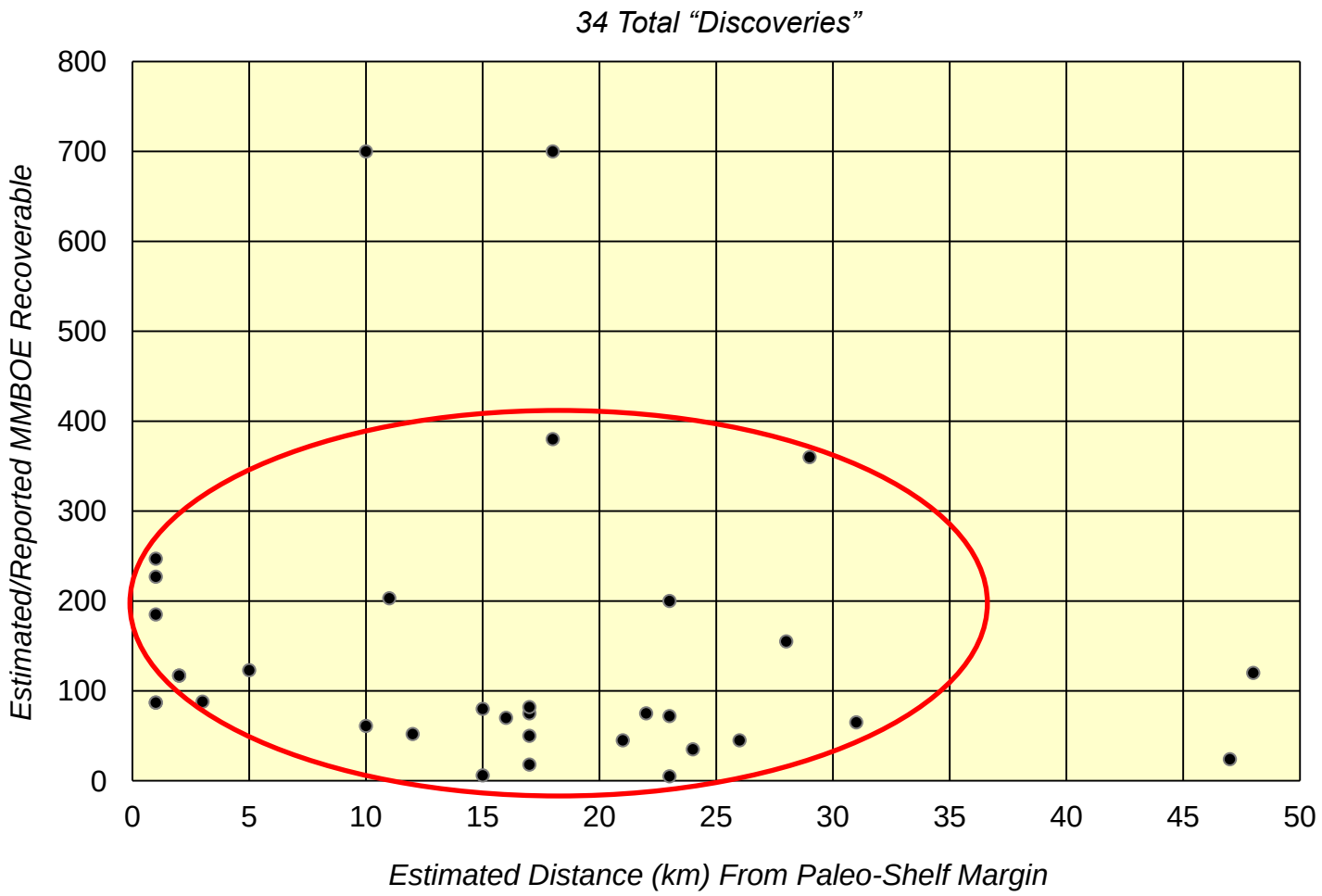

Data From IHS, Various Company Sources

Fan/Channel Play: Summary Observations

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Requirements for the Play to Work

- Little to no structural deformation (secondary folding/faulting)
  - Why? Traps are preserved (not breached)
- Clearly defined traps
  - Why? Multiple seals/trapping points are required for large (commercial) columns
- Direct access to charge/charge focus
  - Why? Complicated migration pathways allow for thief zones in 3D
- Significant sand-dominated river systems with high-maturity sands
  - Why? There is an optimum distance where deliverability impacts commercial rates and column heights

Coincidence or Correlation?

- Most commercial (or pre-commercial) discoveries have been made within 40-50 km of the paleo-shelf margin, with a large percentage within 25 km (there are some exceptions)
- The Turonian works best when the above technical risks have been met
- Younger (Campanian/leaky traps) and older (Albian-Cenomanian/poor reservoirs) units work only under special circumstances
- Can the play work in the central North Atlantic, northern South America, and the Caribbean?

Can “The Cretaceous Play” Be Exported?

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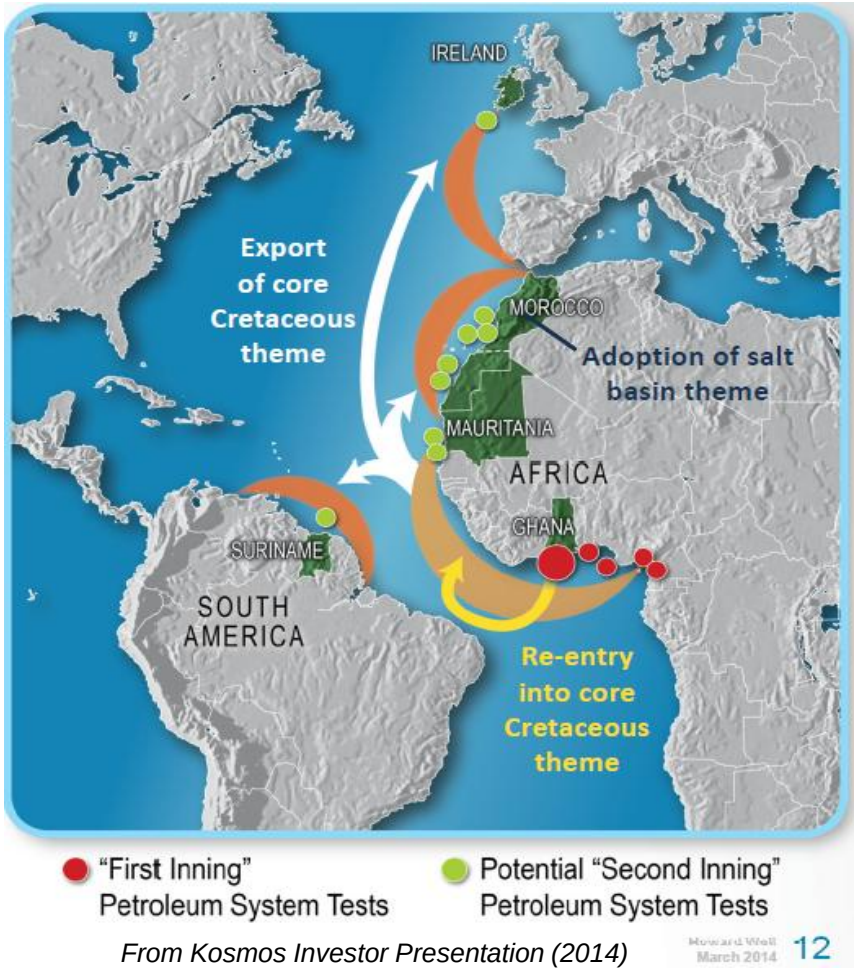
Concerns

- Complicated reservoir architecture/geometry
  - Influence of salt tectonics
- Reservoir deliverability
  - Less mature sands (carbonates)
- Trap and seal integrity
  - Influence of salt tectonics
- Charge access/focus
  - Younger reservoirs are vertically and laterally disconnected from older source horizons
- Overall play and prospect risk
  - Going up, not down



From Kosmos Investor Presentation (2014)

Exporting “The Cretaceous Play” to Northwest Africa

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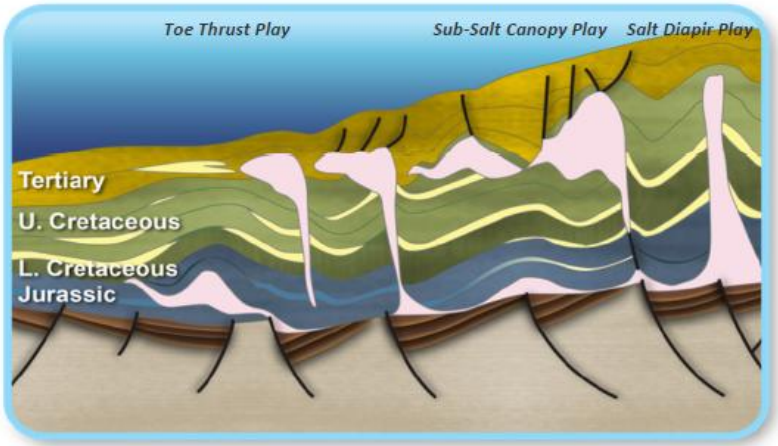
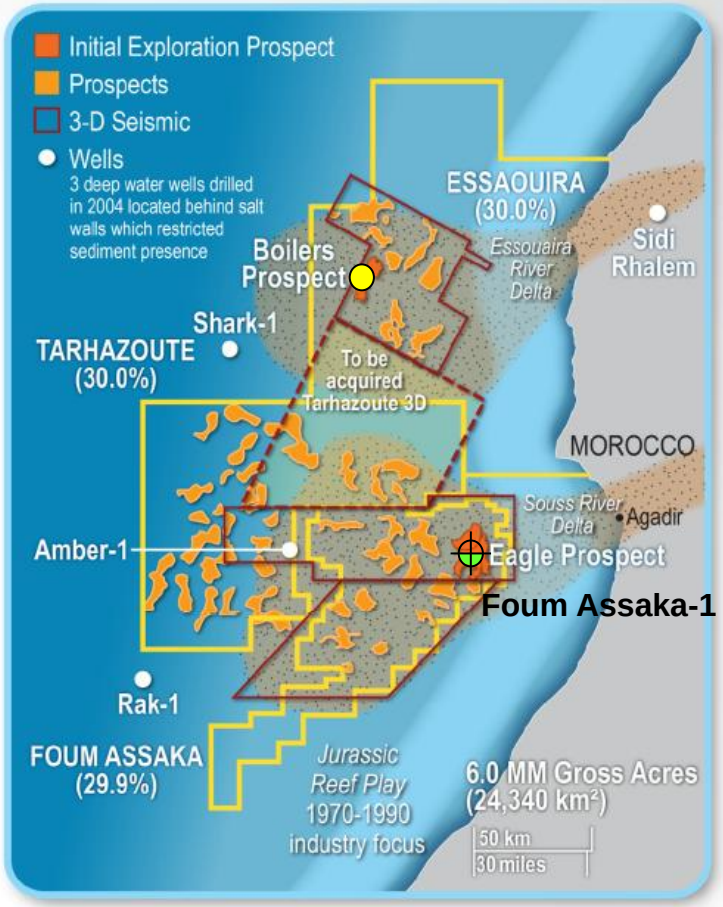
Offshore Agadir Basin Petroleum System

KOSMOS ENERGY

One of the last undrilled salt basins along the Atlantic Margin

- **An Unexplored Salt Basin**
  - Salt-related structures similar to Gulf of Mexico
  - Evidence of a working petroleum system
  - Play diversity and prospect dependency
  - Multiple exploration wells planned
- **Multiple Prospects Defined for Drilling**
  - Prospect size range up to 500+ MMBOE
  - Initial exploration well underway





From Kosmos Investor Presentation (2014)

FA-1 Well Cretaceous Target

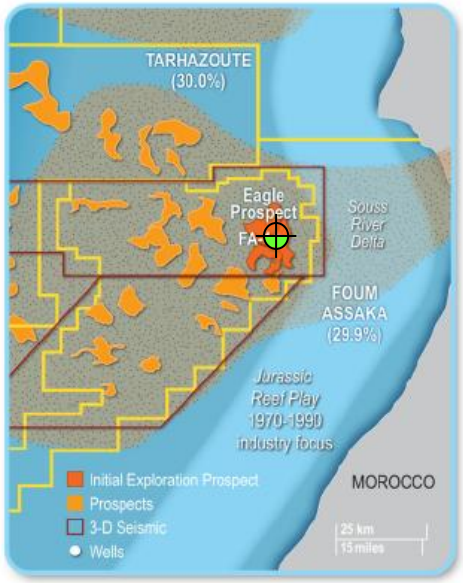
PanAtlantic

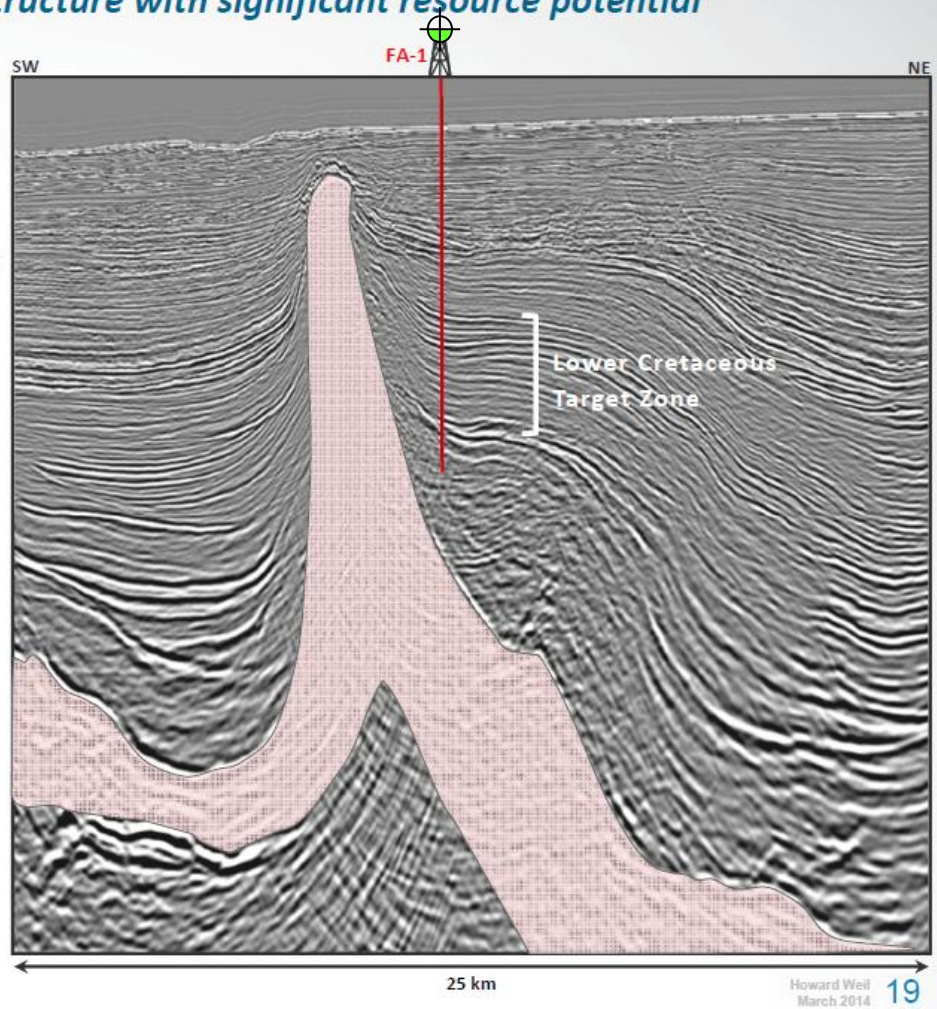
Foum Assaka Block – FA-1 Well

KOSMOS ENERGY

Eagle prospect is a large, salt-cored structure with significant resource potential

- **FA-1 Summary - Pmean 360 MMBOE**
  - Formally Eagle-1 well
  - Drilling operations ongoing
  - Targeting Lower Cretaceous reservoirs
  - Multiple deepwater reservoir objectives
  - Water depth ~600 meters
  - Planned well TD ~4,000 meters





From Kosmos Investor Presentation (2014)

“The Cretaceous Play”: Central and North Atlantic

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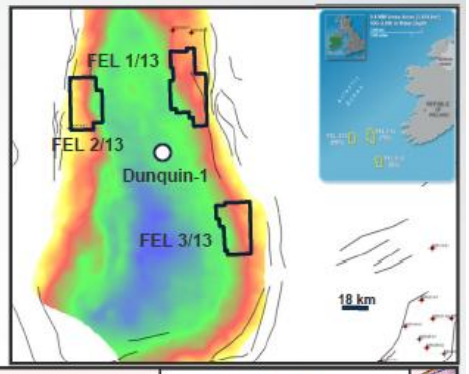
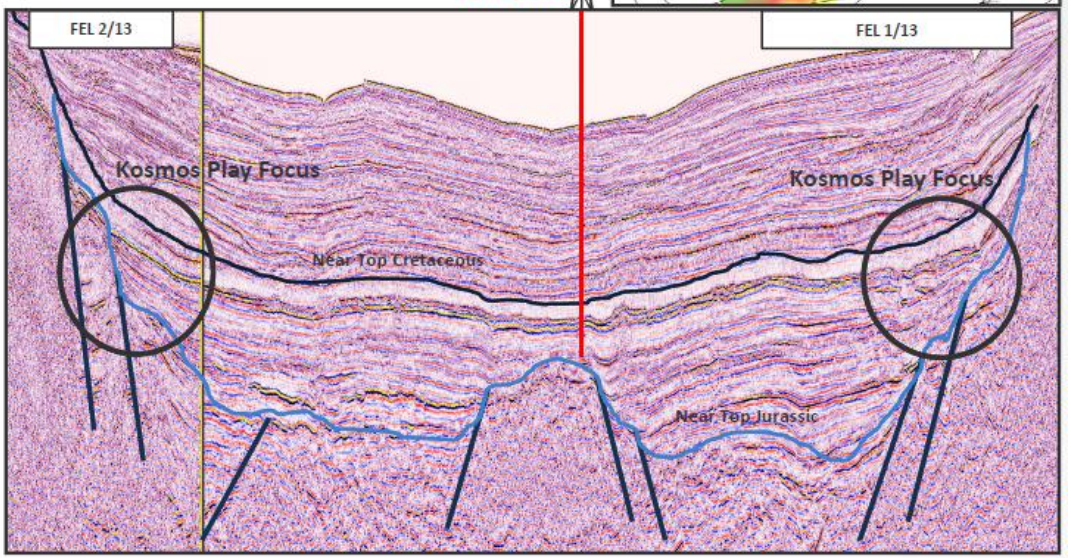
Ireland – Porcupine Basin

KOSMOS ENERGY

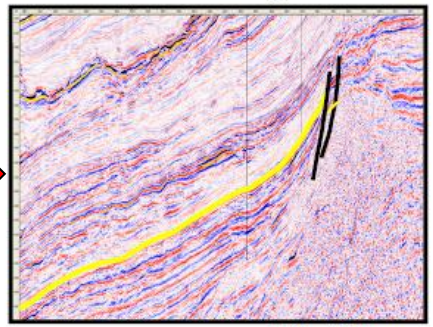
Exploring the North Atlantic with a South Atlantic perspective

- **Premier Basin-flank Acreage Position**
  - Under-explored basin with existing nearby discoveries
  - Up-dip of a working oil kitchen
  - Potential for multiple source rocks
  - Overlooked Cretaceous combination plays
  - Large upside, fiscal terms commensurate with risk
  - Accelerated 5,000 km^2 3D seismic program completed 2013
  - First well targeted in 2016





Ghana Analogy



Jubilee / Mahogany

From Kosmos Investor Presentation (2014)

“The Cretaceous Play”: Caribbean and SOAM

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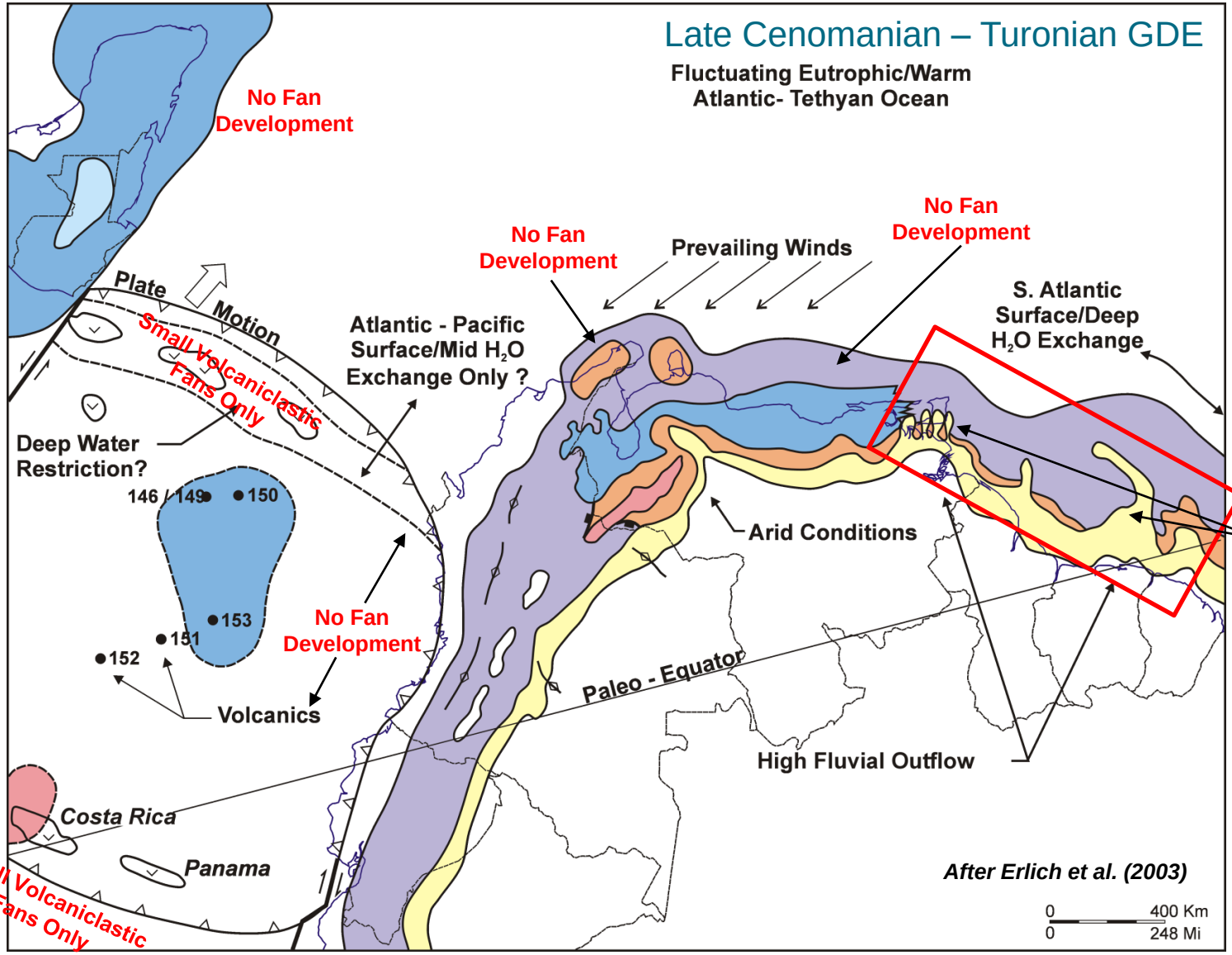

Play Opener: Zaedyus-1, French Guiana

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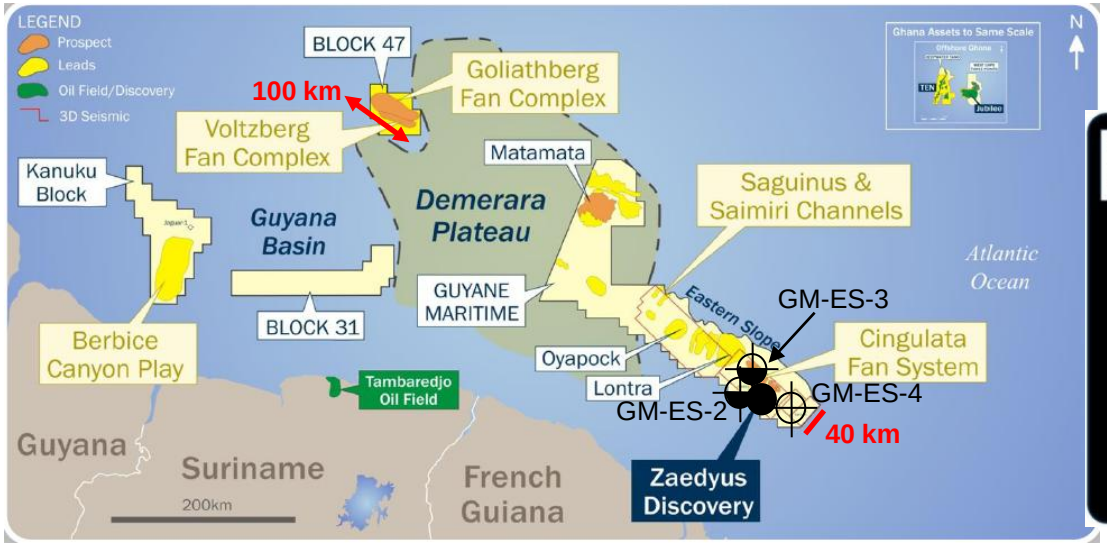

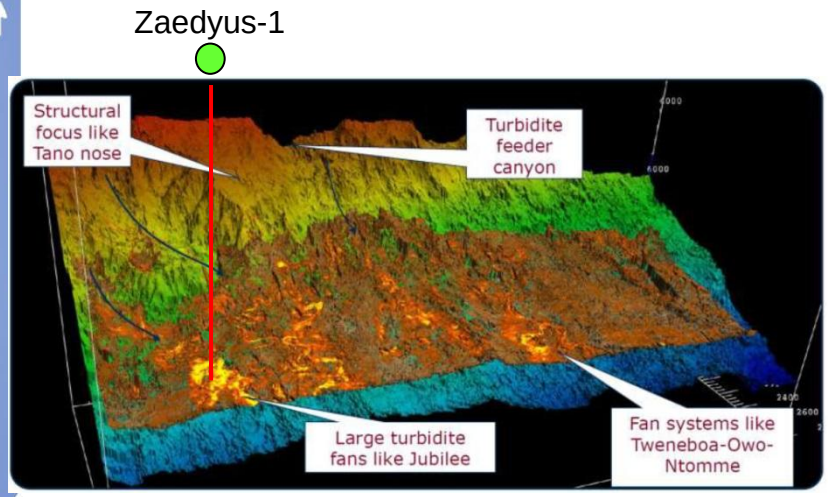

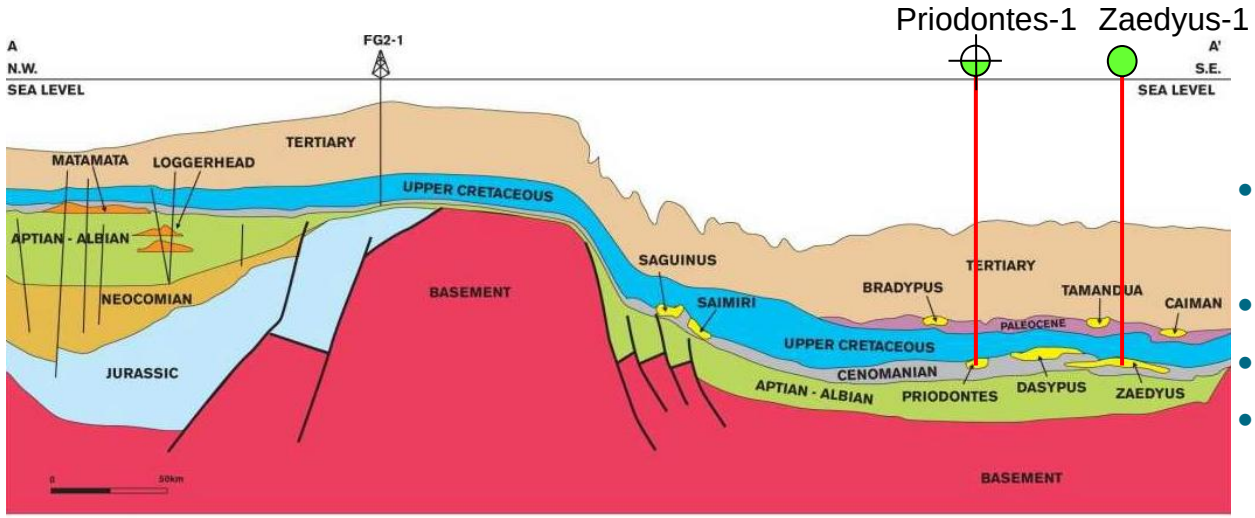

Zaedyus-1 (GM-ES-1)

- 72 m net oil pay (Cenomanian-Turonian?)
- 39 m main sand with light oil
- Original P10 = 700 mmbo
- Follow-up wells dry or non-commercial

From Tullow Mid-year Update (2013), Wessex De Profundis (2011)

Guyana-Suriname: Cenomanian-Santonian GDE

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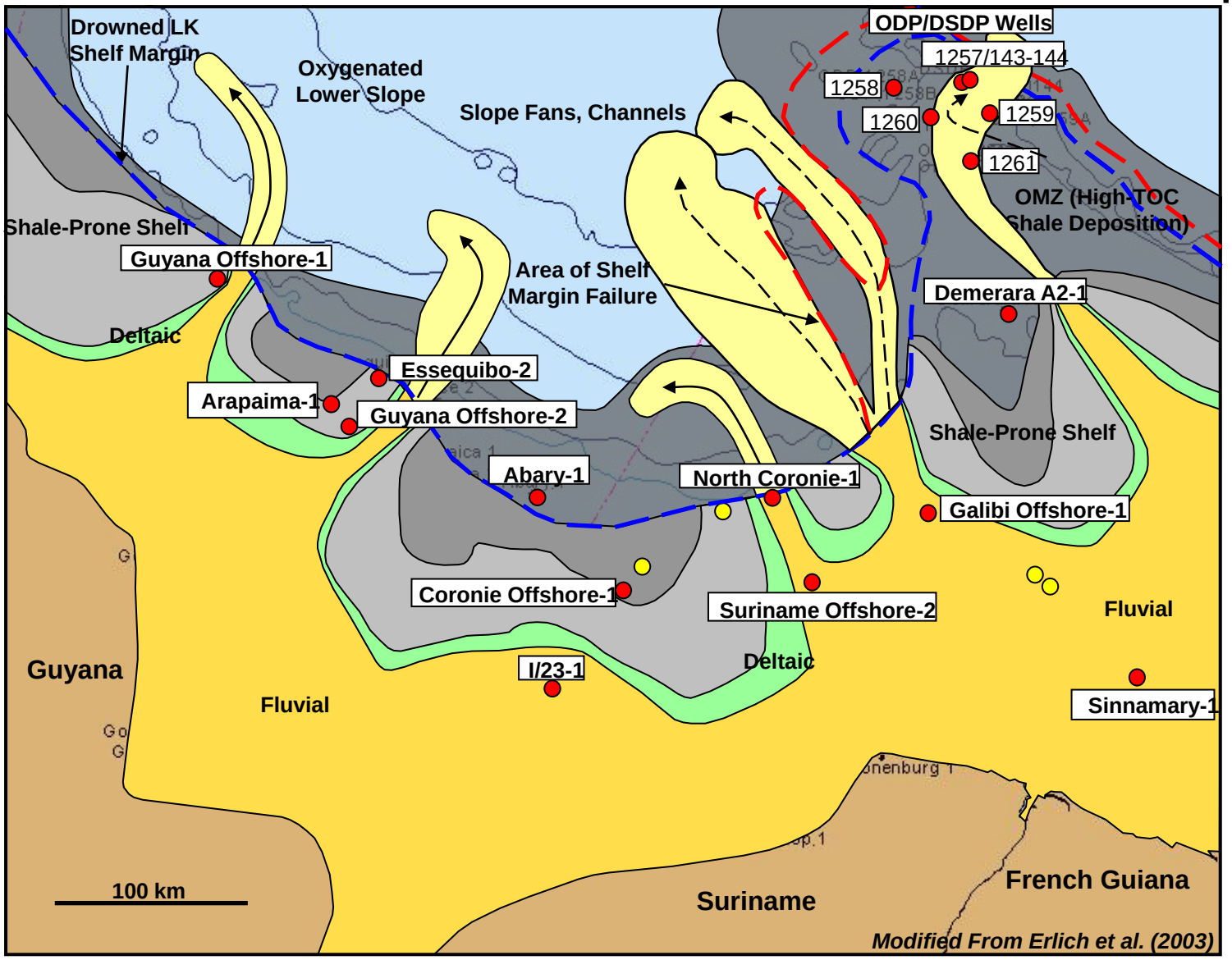

Block 47 Cretaceous Submarine Canyon and Fans

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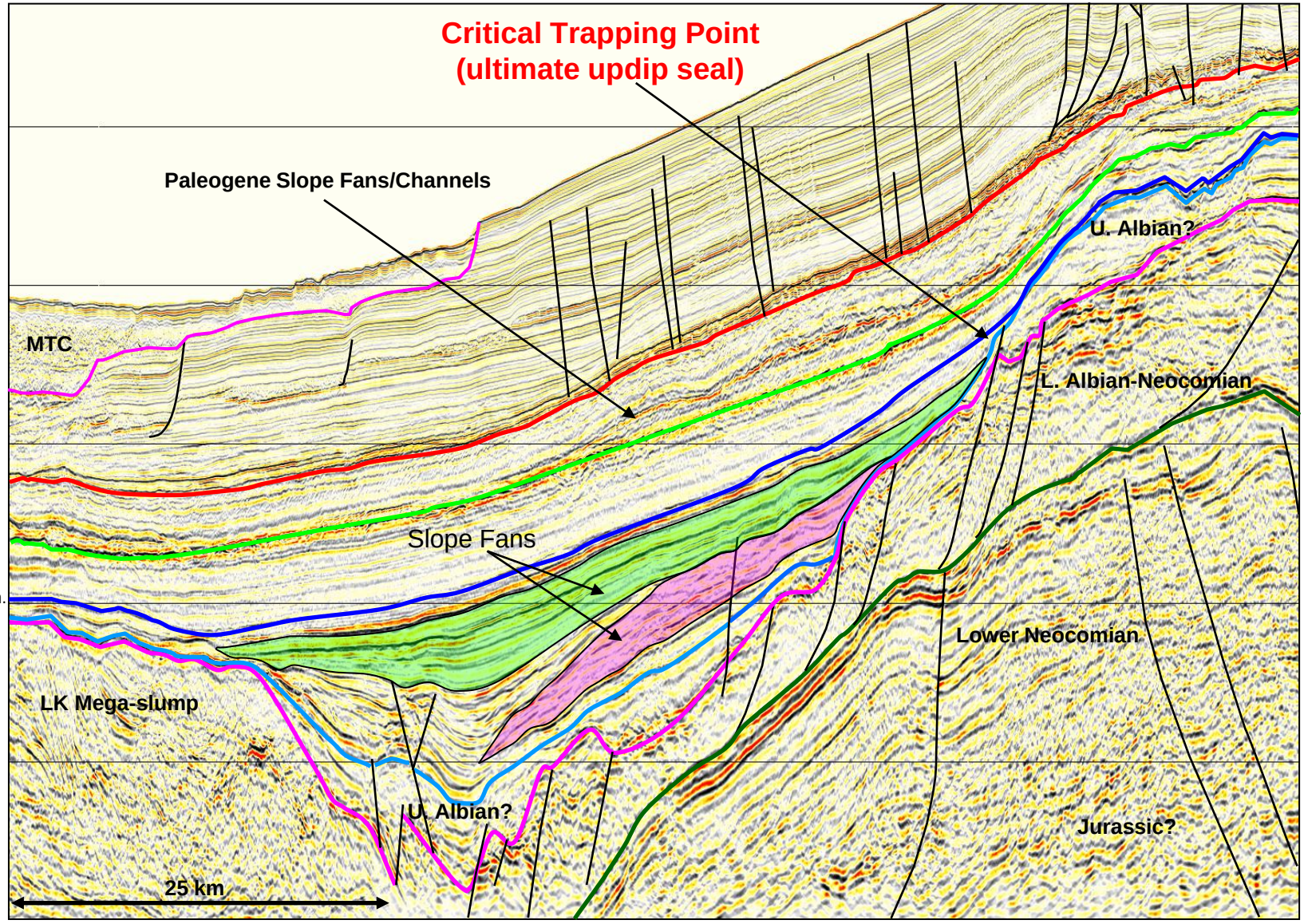

Seismic Data Courtesy of Staatsolie

Adapted From Erlich and Keens-Dumas (2007)

Tullow Geologic Model, Block 47 Fan System

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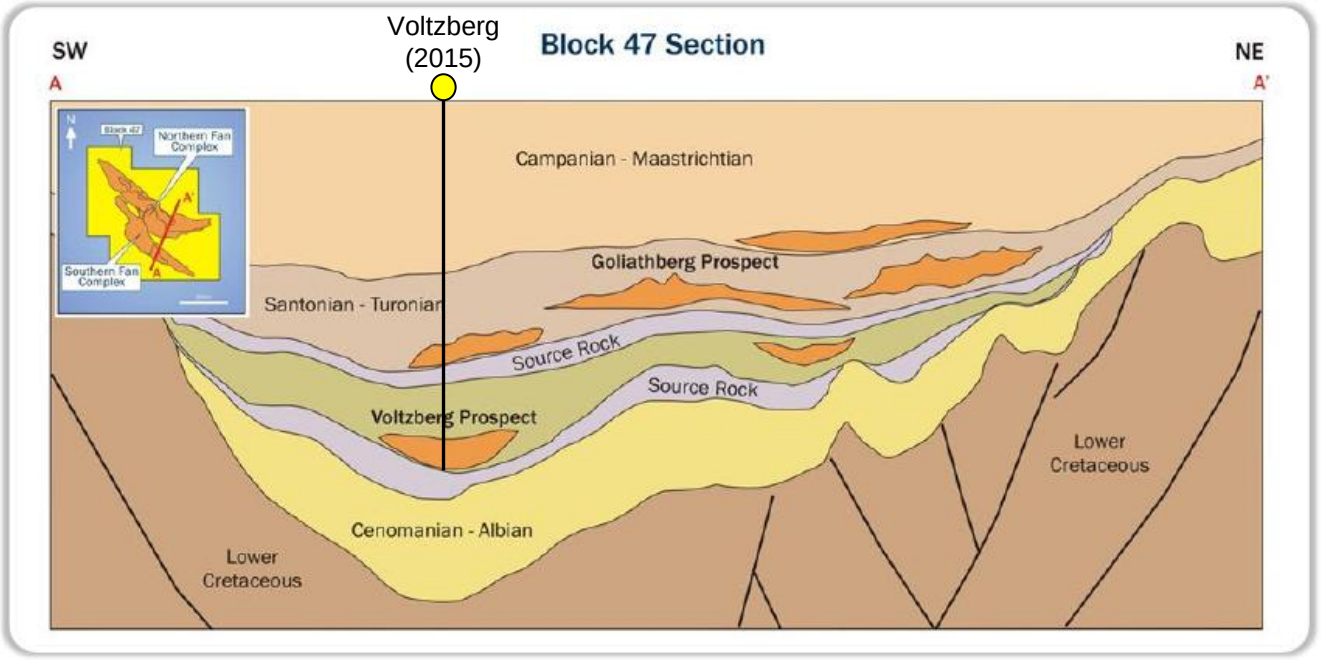
November 2013 Overview Presentation

Focus on Suriname operated exploration for Jubilee play

TULLOW OIL plc



Critical Prospect Risks

- Updip Trap
- Lateral Seals
- Reservoir Deliverability

- Jubilee play campaign continues across the Atlantic, after Tullow's successful Zaedyus-1 basin opener
- Multiple Ghana-scaled prospective fan systems overlying Ivorian-style Albian fault block plays
- New 3D seismic surveys reveal exciting material stacked drilling targets in our Suriname Block 47
- Tullow 70% operated position, provides control over direction & execution of exploration strategy

From Tullow Investor Presentation (2013)

Trinidad: Cenomanian-Santonian GDE

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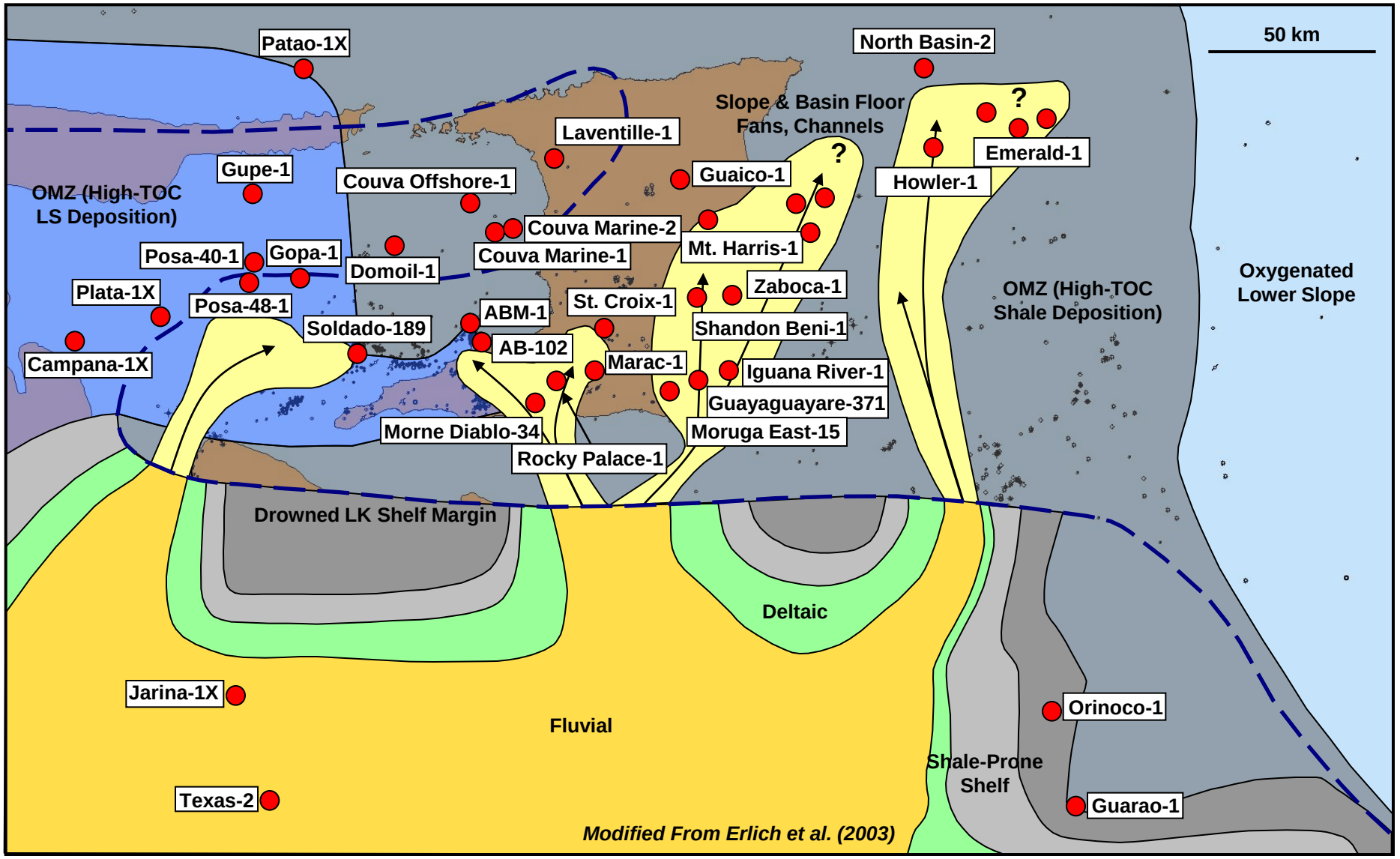

Upper Cretaceous Submarine Fan/Channel System

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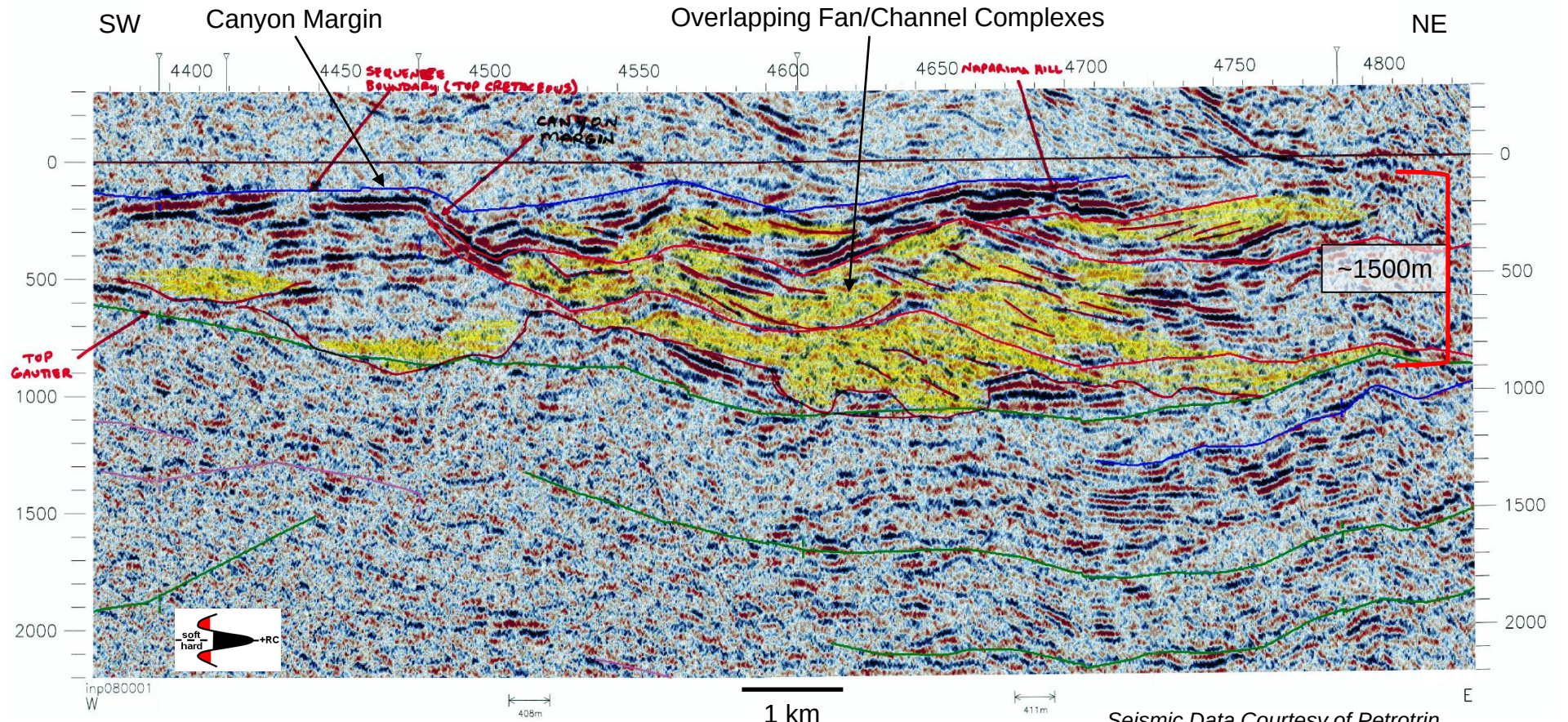
Flattened near the Base of the Oligocene Detachment



Seismic Data Courtesy of Petrotrin (interpretation and comments, 1999)

MD-34 Slope Channel System

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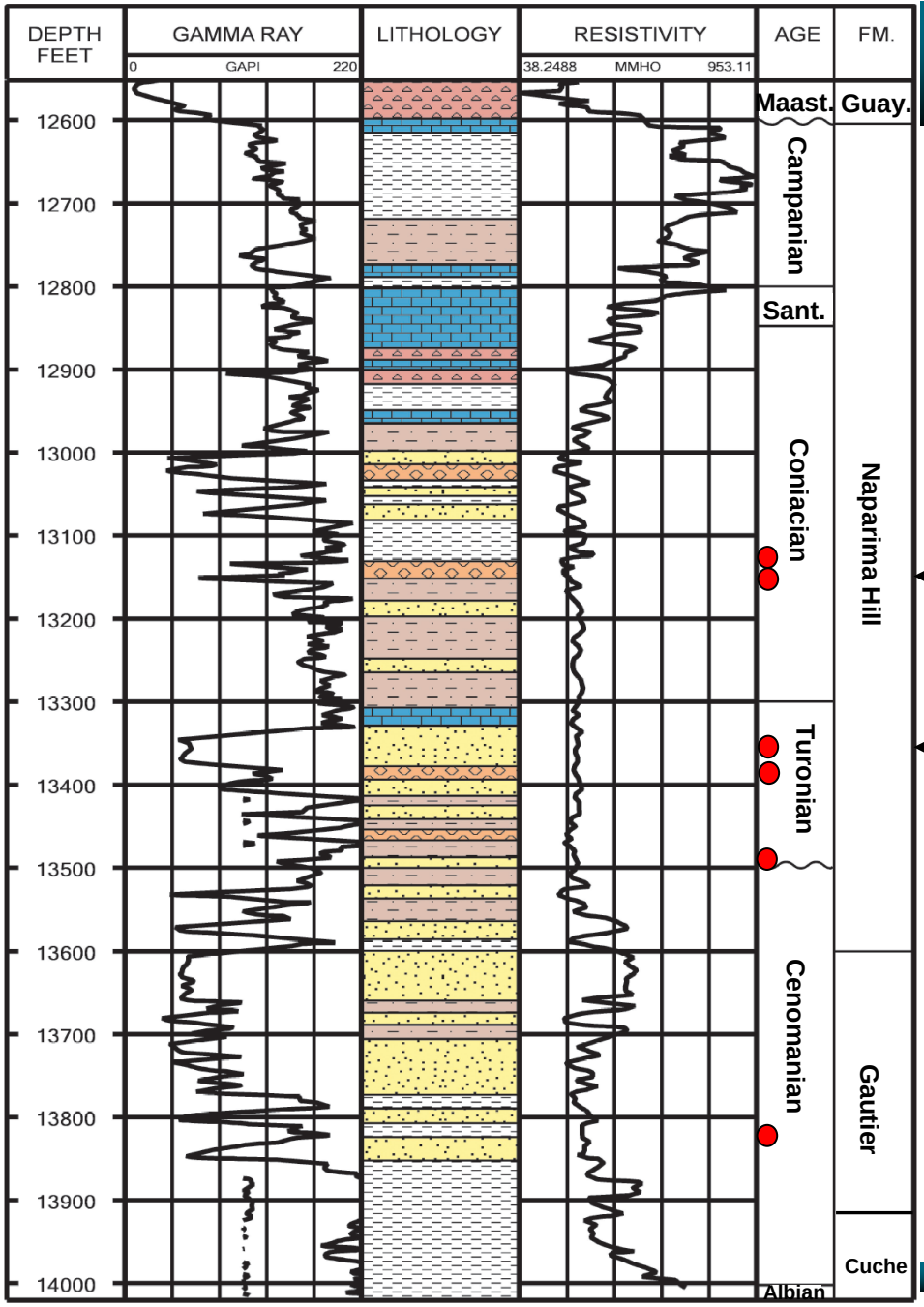

Interpretation: Slope Channel Lag Deposits

Interpretation: Slope Channel

Adapted From Erlich et al. (2003)

Restored View, Possible Maximum Extent of Cenomanian-Turonian Source/Reservoir System

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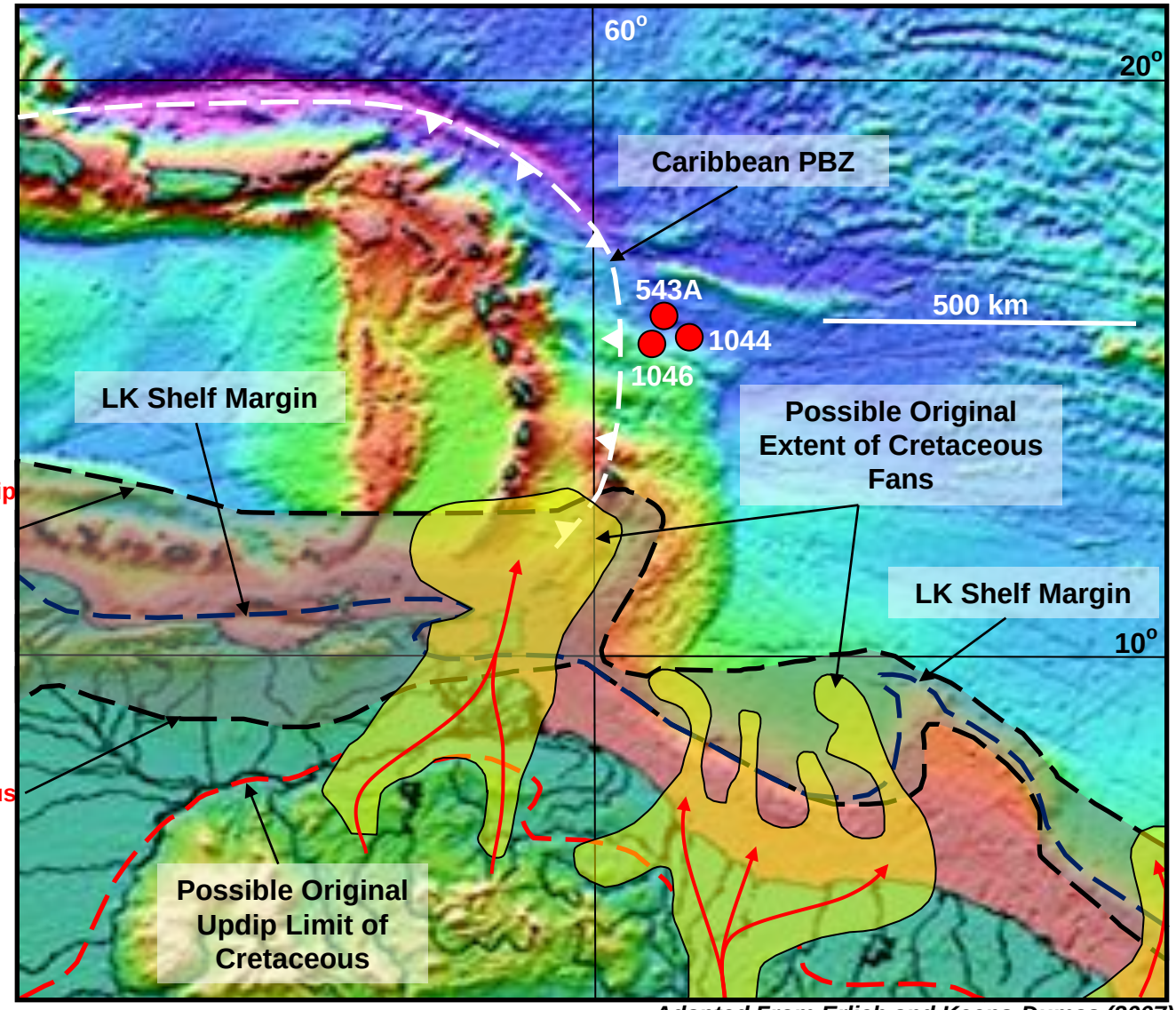

Original Downdip Limit of Viable Cretaceous Source

Updip Limit of Viable Cretaceous Source

Adapted From Erlich and Keens-Dumas (2007)

The slope fan/channel play likely will only work within 40-50 km of the paleo-shelf margin; the basin floor systems have not been tested

Fan/Channel Play: Summary and Conclusions

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- Cretaceous fans have been drilled on both sides of the Equatorial Atlantic margin and contain hydrocarbons, however, commercial success has been elusive to date

- Our understanding of the play has changed through time; nevertheless, the basic play elements are grounded on proven geological concepts

- The fan/channel play may work on a technical and commercial basis in some geographies, while in others it will be very risky or likely will not work on a commercial basis

- There are some fundamental differences in the fan/channel play between the Equatorial Atlantic margins and the central North Atlantic/Caribbean that negatively impact the POSg and POSc in those areas

- The play concept is valid and may work for other geologic intervals; for example, more emphasis should be given to the exploration for Pliocene-Eocene fan/channel complexes offshore in other geographies: Trinidad, Colombia, Venezuela (e.g.,Corocoro Field), and Panama (northern arc)

Exploration in the ROC*, 1970-Present: Review

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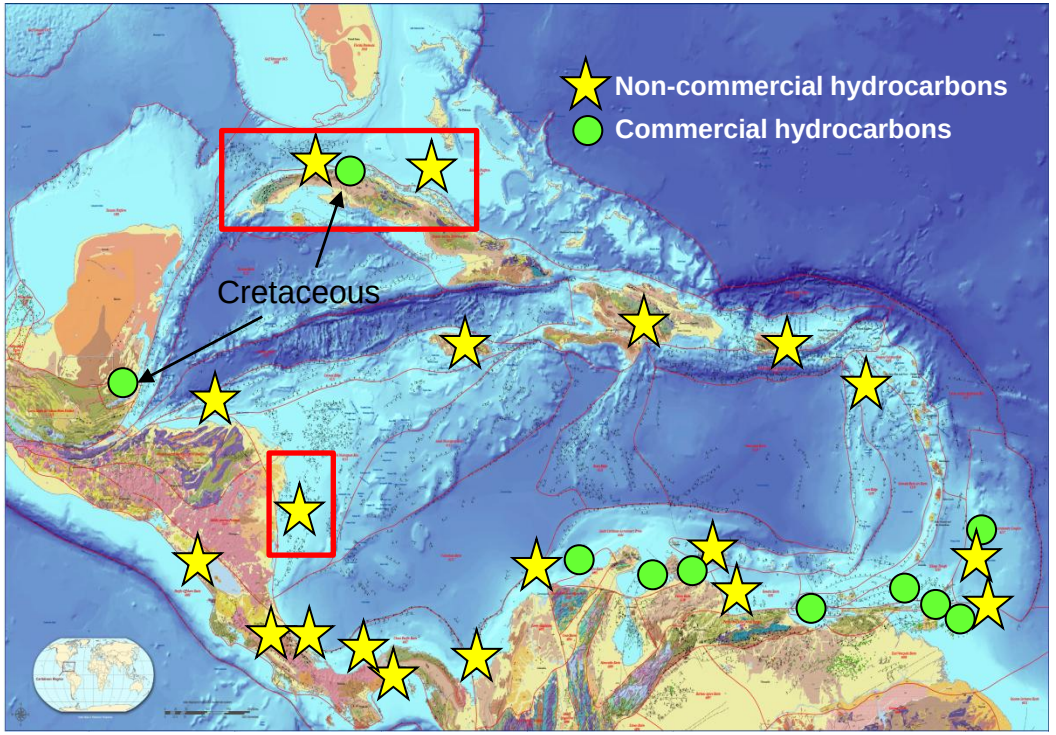
*Rest of the Caribbean



Since 1970, where has exploration worked?

- Trinidad – Onshore (Carapal Ridge); Offshore: north (West Tobago) and east coast offshore
- Colombia – Chuchupa, Ballena Fields
- Venezuela – Paria (Gulf and offshore northern peninsula), Plataforma Deltana, Gulf of Venezuela (Perla)
- Cuba – northern coastal zone
- Barbados – Woodbourne extensions
- Belize – Spanish Lookout

Since 1970, where has it failed?

- Most of the Caribbean region

Why? What Prevents Success?

- Wrong geologic concept (play risk)
- Old/poor technology or application of technology, lack of key data
- Economics/price environment
- Politics
- Exploration philosophy

Cuba: Active Leases, 2012

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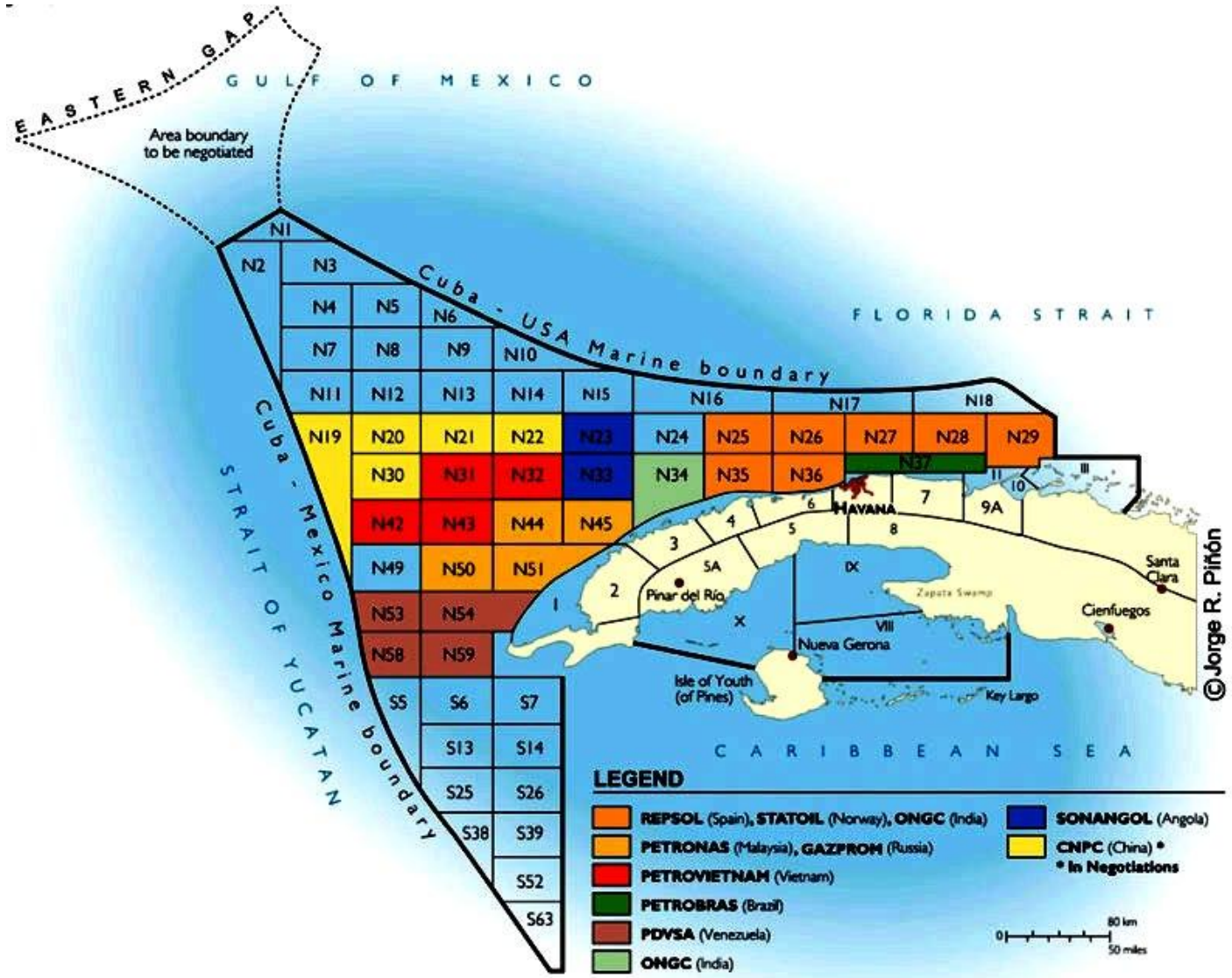

Cuba: Active Leases, April 2014

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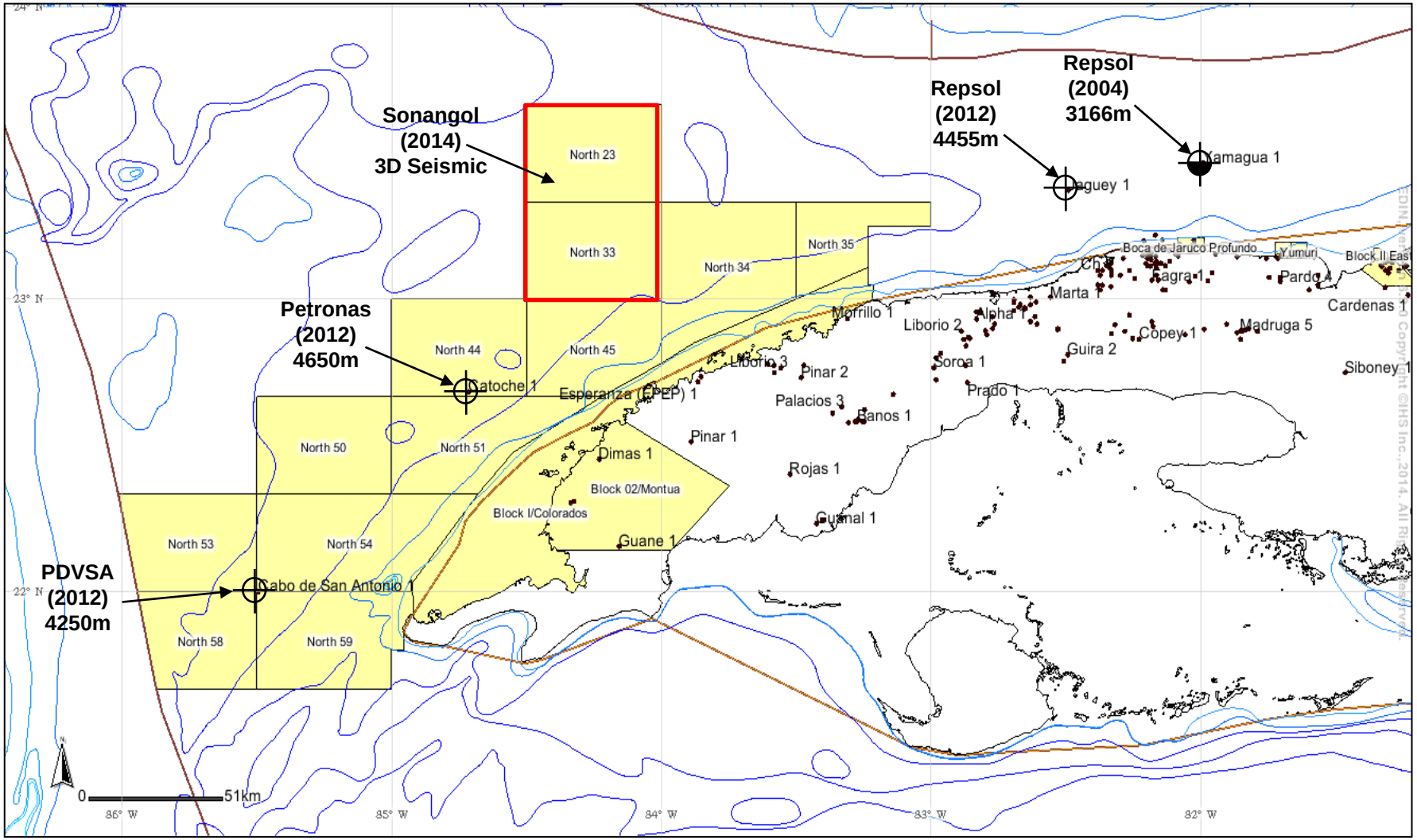

Map and Data from IHS

Geoseismic Models, Cuban North Coast

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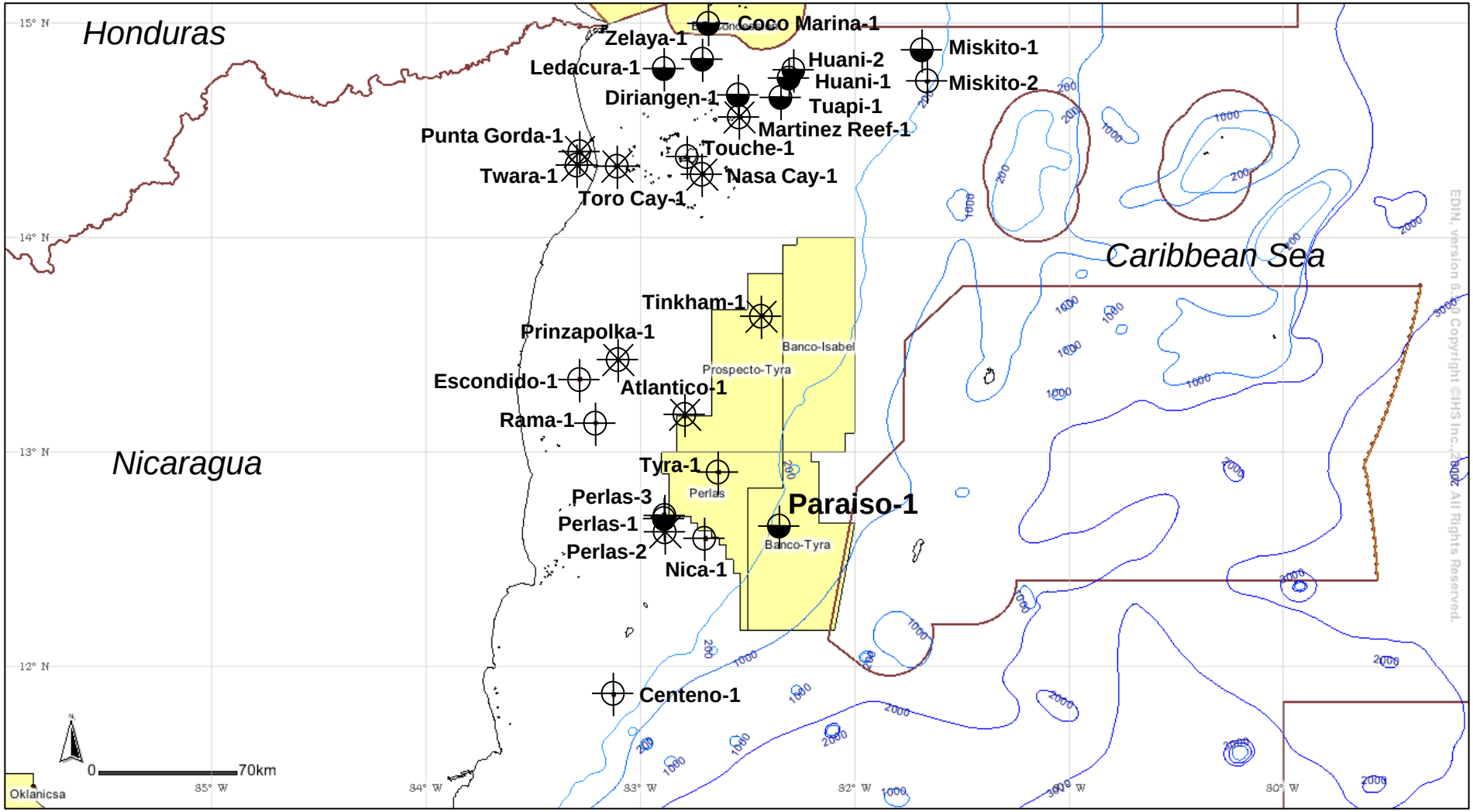
Courtesy of CUPET

Nicaragua: Well Control

PanAtlantic



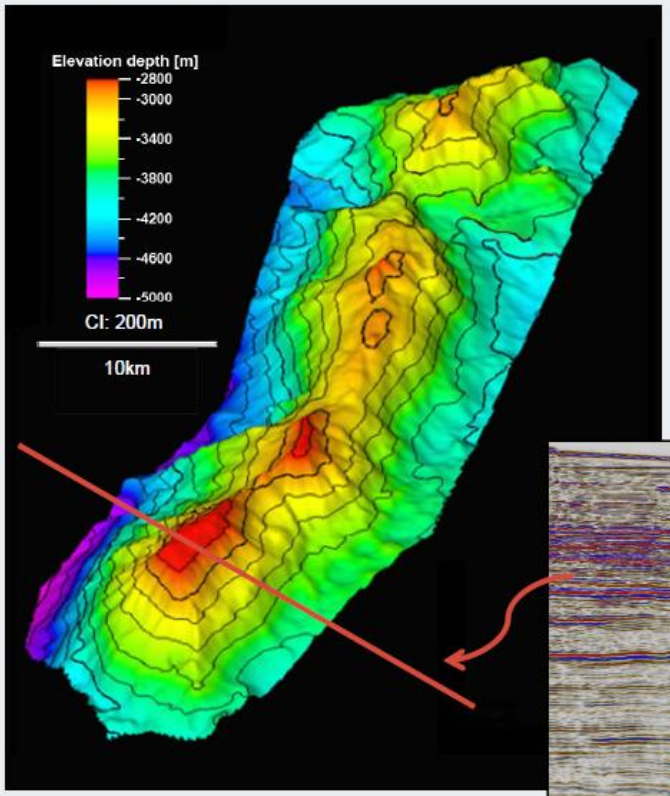
Map and Data From IHS

Noble Energy Nicaragua: Current View

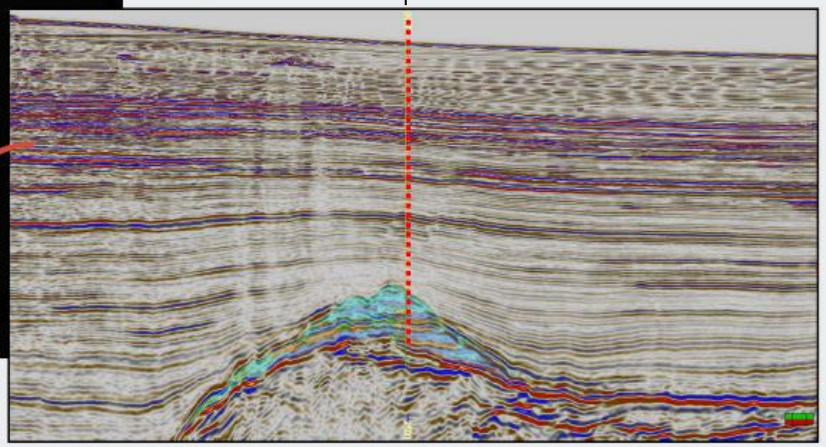
PanAtlantic

Offshore Nicaragua – Paraiso Prospect

Drill-ready world-class opportunity



- Carbonate Reservoir Target
- Gross Unrisked Mean Resources
  - 210 – 1,220 MMBoe (P75 – P25)
- 25% Geologic Chance of Success
- Drill in 2013



NBL

From Noble Investor Presentation (December 2012)

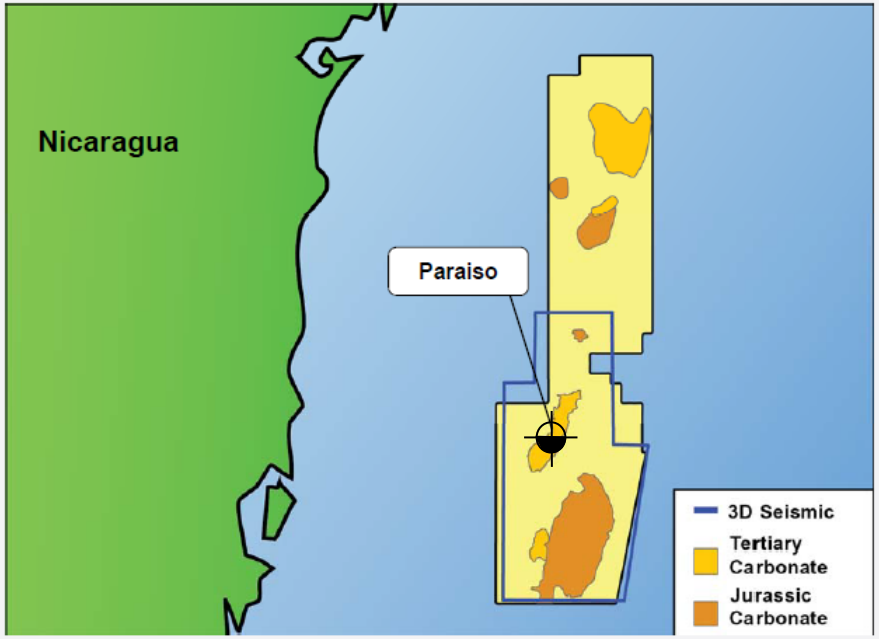
Noble Energy Nicaragua: Current View

PanAtlantic

Nicaragua

Integrating well results and assessing next steps

- **Paraiso Results**
  - First deepwater well testing frontier concept
  - Found Tertiary age reservoir
  - No hydrocarbon accumulation
  - Likely failure: containment or source
- **Analyzing Future Potential**
  - Fully evaluate well data and samples
  - Re-assess geologic model for further prospects and leads
  - Decision additional 3D seismic
  - Continue to mature deeper Cretaceous and Jurassic potential
  - 2.8 BBoe gross unrisked resource potential



1.9MM Total Gross Acres

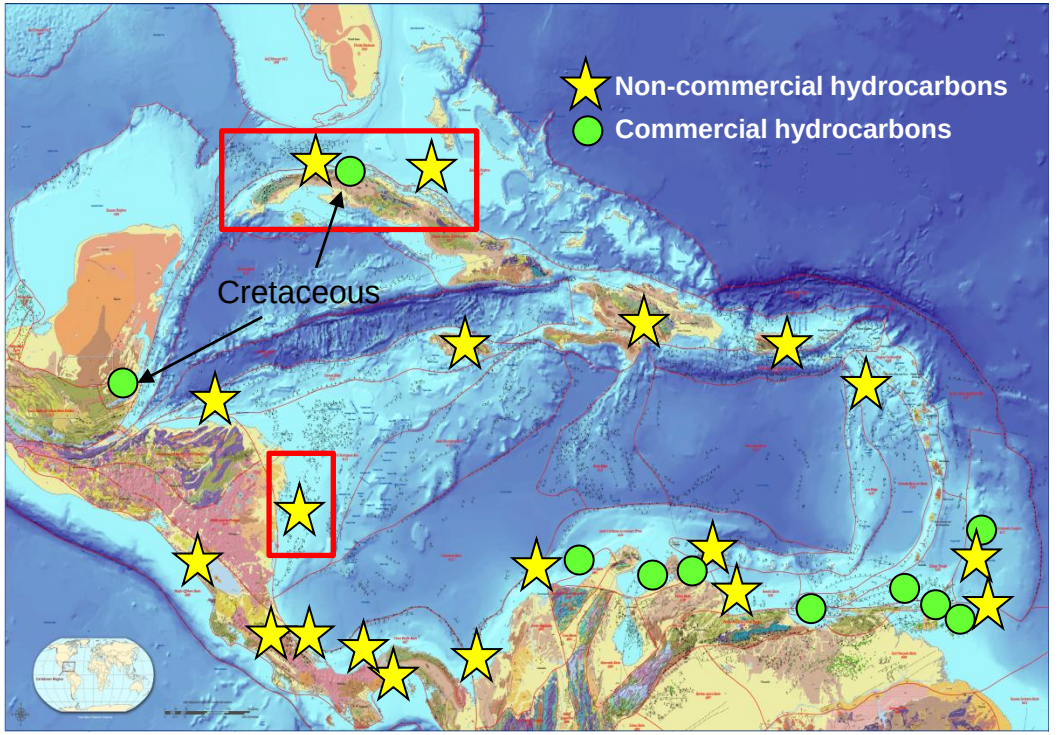
NBL

From Noble Investor Presentation (December 2013)

Exploration in the ROC*, 1970-Present: Summary

PanAtlantic

*Rest of the Caribbean



Since 1970, where has exploration worked?

- Trinidad – Onshore (Carapal Ridge); Offshore: north (West Tobago) and east coast offshore
- Colombia – Chuchupa, Ballena Fields
- Venezuela – Paria (Gulf and offshore northern peninsula), Plataforma Deltana, Gulf of Venezuela (Perla)
- Cuba – northern coastal zone
- Barbados – Woodbourne extensions
- Belize – Spanish Lookout

Since 1970, where has it failed?

- Most of the Caribbean region

Why? What Prevents Success?

- Wrong geologic concept (play risk)
- Old/poor technology or application of technology, lack of key data
- Economics/price environment
- Politics
- Exploration philosophy

Summary Thoughts

- **The Neogene section in Trinidad has worked well**
- **The older rocks (Paleogene and Cretaceous) have not worked well**
- **Incomplete play risk assessments have been the basis for some poor exploration decisions**

Thanks for Attending

Bob Erlich and Francis Inniss