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

Robert Erlich\textsuperscript{1} and Francis Inniss\textsuperscript{1}

Search and Discovery Article #30353 (2014)**
Posted August 18, 2014

*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

**AAPG©2014 Serial rights given by author. For all other rights contact author directly.

\textsuperscript{1}PanAtlantic Exploration Company, Houston, TX, USA (rerlich@paexploration.com)

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


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

Robert Erlich and Francis Inniss
Part 1
• The nature of “The Cretaceous Play” and its variants

• Where the “fan/channel play” is working and why
  o 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”

• 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
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

Ghana Discoveries

**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

*Line Length = 40 km*

From Kosmos Investor Presentation (2014)
“The Cretaceous Fan/Channel Play,” Ghana

Ghana: Expanding Opportunities

Jubilee to Teak Cross Section

SC Channel to Teak Cross Section

West Cape Three Points
APC WI 31%

- PROSPECT
- DISCOVERY
- SUCCESSFUL WELL
- 2011 PLANNED DRILLING

Cenomanian Oil Low Poroperm
Ghana: Transitioning Tweneboa / Enyenra

**Planned 2011 Activity**
- Drill 4+ Appraisal Wells
- Conduct 2 DSTs
- Move Toward Sanction
Regional Drilling Activity and Results, 2005-2014

Map and Data from IHS, various public sources

- **2011 TD 5639m**: 14 m Turonian pay, 270 m of wet Turonian sand.
- **2011 TD 5142m**: 14 m Turonian pay, 270 m of wet Turonian sand.
- **2010 TD 4862m**: 6 m Campanian pay, 35 m Turonian pay (34-42 API).
- **2012 TD 5400m**: 8 m Turonian pay.
- **2011 TD 5142m**: 8 m Turonian pay.
- **2011 TD 6465m**: 30 m Turonian pay.
- **2012 TD 4742m**: Turonian oil.
- **2012 TD 4850m**: 21 m Turonian pay (37 API), 11 m Albion pay (44 API).
- **2012 TD 3665m**: Cretaceous shows.
- **2012 TD 5142m**: 270 m of wet Turonian sand.
- **2011 TD 5400m**: wet Campanian, 8 m Turonian pay.
- **2012 TD 6465m**: 30 m Turonian pay.
- **2013 TD 4100m**: 48 m Turonian pay, 9 m Cenomanian pay, 14 m Albian pay (tight).
- **2014 TD 3100m**: 40 m net oil pay 34 API, Turonian/Older fans?
- **2014 New Well**: Goshtern.
- **2005 TD 3100m**: wet Cenomanian sand.
- **2013 TD 4100m**: 48 m Turonian pay, 9 m Cenomanian pay, 14 m Albian pay (tight).
- **2014 TD 6465m**: 30 m Turonian pay.
- **2013 TD 5639m**: 14 m Turonian pay, 270 m of wet Turonian sand.
- **2013 TD 4742m**: Turonian oil.
Cretaceous Fan Distribution, Sierra Leone, Liberia

Sierra Leone and Liberia: Current View

- **Venus B #1 Discovery**
- **Mercury-1 Discovery**
- **Jupiter-1**
- **SL-07B-10**
- **Montserrado/Montserrado Deep**
- **LB-17**
- **LB-15**
- **~1,400 mi² 3D**
- **~2,300 mi² 3D**
- **~900 mi² 3D in Progress**
- **ANADARKO WI BLOCK**
- **SUCCESSFUL WELL**
- **DISCOVERY**
- **PLANNED DRILLING**
- **CAMPAIGN**
- **LOWER CAMPAIGN-TURONIAN**
- **Relinquished**
- **~5 MM Gross Acres**
- **Line Length = 40 km**

- **Chevron ExxonMobil**
- **African Petroleum**

From Anadarko Investor Presentation (2011)
Sierra Leone and Liberia: A Familiar Look

Sierra Leone, Liberia Fan System: Ghana Analogue

Source Rock

ENYENRA TO JUBILEE IN SCALE TO SIERRA LEONE/LIBERIA

110 Miles

27 Miles

ANADARKO PETROLEUM CORPORATION

From Anadarko Investor Presentation (2011)
“Bee Eater” Fan System, LB-08 and 09

Bee Eater (low perm?)
Apalis
Narina (1st Well)

Line Length = 40 km

From African Petroleum Investor Presentations (2012-13), Africa Oil and Gas (March 10, 2014)
Liberia Block LB-09: Regional Seismic, Narina-1

Multiples source rock intervals from Cenomanian - Albian

Multiple, stacked Reservoirs in the Upper Cretaceous

Cenomanian and Turonian Basin Floor Fans

Campanian channel-fan sequences

Multiple trap types
“Discoveries” vs Distance From Paleo-shelf Margin

Data From IHS, Various Company Sources
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?

Concerns

• Complicated reservoir architecture/geometry
  o Influence of salt tectonics

• Reservoir deliverability
  o Less mature sands (carbonates)

• Trap and seal integrity
  o Influence of salt tectonics

• Charge access/focus
  o Younger reservoirs are vertically and laterally disconnected from older source horizons

• Overall play and prospect risk
  o Going up, not down
Exporting “The Cretaceous Play” to Northwest Africa

Offshore Agadir Basin Petroleum System

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)
Foum Assaka Block – FA-1 Well

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

Ireland – Porcupine Basin

**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 km² 3D seismic program completed 2013
  - First well targeted in 2016

From Kosmos Investor Presentation (2014)
"The Cretaceous Play": Caribbean and SOAM

Late Cenomanian – Turonian GDE

Fluctuating Eutrophic/Warm Atlantic-Tethyan Ocean

After Erlich et al. (2003)

Area of Fan Development
Play Opener: Zaedyus-1, French Guiana

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

**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
Block 47 Cretaceous Submarine Canyon and Fans

Critical Trapping Point (ultimate updip seal)

Paleogene Slope Fans/Channels

MTC

Slope Fans

L. Albian

L. Albian-Neocomian

Cen-Turonian U/L Albian

LK Mega-slump

U. Albian?

Lower Neocomian

Jurassic?

Seismic Data Courtesy of Staatsolie

Adapted From Erlich and Keens-Dumas (2007)
Focus on Suriname operated exploration for Jubilee play

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)
Upper Cretaceous Submarine Fan/Channel System

Flattened near the Base of the Oligocene Detachment

Seismic Data Courtesy of Petrotrin (interpretation and comments, 1999)
MD-34 Slope Channel System

Interpretation: Slope Channel Lag Deposits

Adapted From Erlich et al. (2003)
Restored View, Possible Maximum Extent of Cenomanian-Turonian Source/Reservoir System

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.

Adapted From Erlich and Keens-Dumas (2007)
Fan/Channel Play: Summary and Conclusions

- 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).
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, April 2014

- **Sonangol (2014)**
  - 3D Seismic
  - Lease:
    - North 25
    - North 33
    - North 34
    - North 35

- **Petronas (2012)**
  - 4650m
  - Lease:
    - North 44
    - North 45
    - North 50
    - North 51
    - North 52
    - North 53
    - North 54

- **PDVSA (2012)**
  - 4250m
  - Lease:
    - Cabo de San Antonio 1
    - Cabo de San Antonio 2
    - Cabo de San Antonio 3

- **Repsol (2004)**
  - 3166m
  - Lease:
    - Repsol
    - Repsol (2012)
    - Repsol (2012) 4455m

Map and Data from IHS
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
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
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