Realising the Deep Water Hydrocarbon Potential of Senegal*

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Abstract

The AAPG Search and Discovery forum is designed to highlight new discoveries that have surprised the industry and provided important learnings for geoscientists for future exploration. The SNE discovery, in particular, is one such example which was not seen by the industry despite many years of study in the basin and was (wrongly) considered a high-risk exploration well when identified.

Two new deepwater wells were completed by Capricorn Senegal, a subsidiary of Cairn Energy, in 2014 offshore Senegal. These were the first deepwater wells in the country (excluding Kora-1 in the joint administered AGC). Both these wells are significant new oil discoveries and open new plays in the region. Both these plays were in an area of the world (NW Africa) that was receiving close attention from the Industry especially since the Jubilee discovery by Kosmos in Ghana. What is significant is that neither play was identified by the operators who had operated the blocks from 2004-12 and done extensive geological work. Furthermore, the plays were not initially discovered by booming amplitudes as many of the most recent large play openers have been (in Ghana, Uganda, Mozambique, Guyana, and Tortue in Mauritania) although amplitudes did help to de-risk the play to some extent after the play was identified. Although Conoco and Cairn both identified the Fan play, no company apart from Cairn identified the SNE play, and almost all companies saw the subsequent wells as extremely high risk. Why was this, and what are the lessons learned for successful exploration?

Subsequently Cairn and partners have drilled eight appraisals on the SNE discovery (two with further exploration targets) which have increased STOIIP estimates and progressed the discovery towards commerciality. Cairn has a 40% Working Interest (WI) in three blocks offshore Senegal (Sangomar Deep, Sangomar Offshore, and Rufisque) ConocoPhillips had 35% WI which it sold recently to Woodside, FAR Ltd 15% WI, and Petrosen, the national oil company of Senegal 10%.

To be the first company to open a new play is one of the most significant ways to create value in Exploration. Although one in four new plays may be serendipitously found, it is known that the primary key to success is completing full geoscientific analyses of basins on a regional scale with the integration of as much data as possible. Play based evaluations are complimented by rigorous competitor intelligence and regular
government engagement. All companies must have an independent quality assurance process with the appropriate disciplines and correct experience levels in the QA/QC team and the ability to harness the widest range of experience and knowledge from within their companies. Ideally a management that has geoscience experience, or trusts its geoscientists and the process, is essential. Too often geoscientists miss opportunities through cognitive bias or not fully and properly integrating the data. In many cases in-experienced staff are sent to data rooms and have time only to listen to the operators (sellers) point of view. The danger (and hence higher risk) of farm-ins is always the limited time for evaluation and so a good regional understanding is important. With integrated geoscience, strong accessible technical capabilities, and advanced insight Cairn has opened up the West African margin between Senegal and Sierra Leone and these discoveries should act to significantly enhance the economy and benefit the people of Senegal in the long term.

Reference Cited

Realising the Deep Water Hydrocarbon Potential of Senegal

A technically-driven success story challenging existing geoscience paradigms: lessons for successful exploration

Dr. J.A.P. Clayburn, Cairn Energy PLC, October 2017
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These forward-looking statements are, by their nature, subject to significant risks and uncertainties and actual results, performance and achievements may be materially different from those expressed in such statements. Factors that may cause actual results, performance or achievements to differ from expectations include, but are not limited to, regulatory changes, future levels of industry product supply, demand and pricing, weather and weather related impacts, wars and acts of terrorism, development and use of technology, acts of competitors and other changes to business conditions.

Cairn undertakes no obligation to revise any such forward-looking statements to reflect any changes in Cairn's expectations with regard thereto or any change in circumstances or events after the date hereof.
Agenda

- Introduction
- Cairn entry into Senegal: How the plays were opened
- Why Discoveries were made when others thought it was too high risk?
- SNE-1 and FAN-1 discoveries
- Appraisal and Development
- Future work: Adding Value: Further Exploration Potential
- Conclusion: What are the key factors in good exploration?
Two New Plays Opened in an Active World

Internal Exploration Study

- Critical success factors for new play identification
- Most Important is taking care of the Fundamentals - Understand the Geology
- Second is Serendipity - you must be Active to Succeed
- Technology is an Enabler - Important but does not Drive Exploration Success
Cairn Energy PLC

Introduction
Introduction

About Cairn Energy PLC

- One of Europe’s leading oil and gas exploration and development companies, listed on the London Stock Exchange
- Discovered and developed oil and gas reserves in locations around the world
- Headquarters in Edinburgh with offices in Stavanger, London, Mexico City and Dakar, Senegal
- Focused on growing resource base in Senegal, Norway and the UK
- Additional interests elsewhere in Africa, Central America and the Atlantic Margin
Introduction

Track Record

- Experienced and successful exploration, appraisal and development operator
- Operations conducted onshore and offshore, shallow and deepwater, benign and harsh weather environments
- Focus on highest HSE standards and sustainable development practices
- Model corporate citizen with demonstrable, successful record of community investment

- Successful track record of adding value to Joint Venture partnerships
- Delivered a series of flagship developments from exploration successes in South Asia
- Focus on monetisation of success

- In excess of US$4.5 billion (bn) returned to shareholders over last decade
- Commitment to continued delivery of value from discovery and development
Regional Setting: Why was Cairn looking in this area?

- Exploration strategy focused on multiple play types formed from break-up of supercontinent Pangaea.
- Provides underexplored mature hydrocarbon basins of Mesozoic and Tertiary age with common geologic themes.
- Experience in passive margin and rift basin exploration with operational capability in frontier areas.
- Deepwater areas adjacent to shelf acreage where a number of wells were drilled in 1960s and 1970s.
- Wells encountered petroleum, demonstrating potential for working hydrocarbon system, but without confirming any commercially viable discoveries.
- Utilising modern 3D seismic data and drilling capability, Cairn’s recent programme and success in Senegal has opened up a new and emerging hydrocarbon basin.
Why Senegal?

- Previous offshore wells demonstrated oil on the shelf (Esso 1968-1972, Rufisque dome)
- Seismic indication of hydrocarbons
- Deep Sea Drilling Project wells further offshore (1970s) indicated Cretaceous source rocks – seen extensively on West African margin
- No wells previously in deep water, except the Kora-1 well in AGC profund.
- Cairn basin modelling suggested good chance of a mature source kitchen

Why RSSD? (Rufisque, Sangomar and Sangomar Deep Blocks)

- Cairn’s basin modelling suggests mature HC source kitchen within the western part of the RSSD block
- Several prospects and leads identified by Hunt and FAR on 3D seismic
Exploration

RSSD Exploration History

With Jubilee, Kora-1 and MSGB Gas Discoveries for Reference

<table>
<thead>
<tr>
<th>Operator</th>
<th>Hunt</th>
<th>FAR</th>
<th>Cairn</th>
</tr>
</thead>
</table>

- **Jubilee Discovery**
- **FAR Farm-in**
- **COP Farm-in**
- **Kosmos Entry**
- **Jubilee, Kora-1 and MSGB Gas Discoveries**

**OIL PRICE ($/BARREL) (inflation adjusted price)**

**CUMULATIVE SEISMIC (KM/KM²)**

**CUMULATIVE NO. OF WELLS DRILLED**

- **Rufisque Gambia 3D & SOSP 3D**
- **TGS NWA m/c 2D**
- **ROP & Sangomar Deep 3D**
- **FAN-1 & SNE-1 Discoveries**
- **Guembeul-1 & Teranga Discoveries**

**Shell 2D**

**Rufisque Dome 2D**

**Vanco 2D**

**Wolof & Diola-1**

**Jammah-1**

**Casamance Basin & Rufisque Dome**

**Jubilee Discovery**

**FAR Farm-in**

**COP Farm-in**

**Kosmos Entry**

**Jubilee Discovery**

**FAR Farm-in**

**COP Farm-in**

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**COP Farm-in**

**Kosmos Entry**
Exploration

Geological Model: Hunt / Petrosen 2006, Adopted by FAR

- The Jurassic to Cenomanian is marked with a long lived carbonate platform. Following the Cenomanian, during a period of quiescence, the Turonian source rock was laid down in anoxic deep water.

- Following deposition of the source, the platform was exposed and the carbonates karstified. The period is represented by the Senonian unconformity.

- Post the Senonian unconformity, incised erosional shelf channels transported paralic sands to the upper slope. Stacked seismic amplitude anomalies represent these deposits.
Exploration

Senegal - Plays and Leads: Hunt / FAR / Petrosen Post 3D

L Cretaceous Carbonate shelf Margin play

Slope fan play

Top Aptian

173 sq km closure in highlighted area

Original source Hunt 2006 published in Martin et al 2010
Exploration

Cairn Views on the Existing Plays

Upper Cretaceous Fans: Identified. Hard thin loop: poor thin sands (carbonate cements?)

High trap risk. Low volumes envisaged
Cairn View Initially on the ‘Albian Buried Hill’

- Not a ‘Buried Hill but a subaqueous unconformity trap’; huge significance for SNE later
- Regional and local knowledge lead Cairn to have a different age for the target
- Did not see evidence of carbonates or Karst at this level
- Noted the unusual semi conformable ‘soft’ amplitude and were intrigued
- The volumes were too small to go for the block on its own
- Later work significantly downgraded this prospect prior to drilling (the well driven by the appraisal location)
Exploration

Cairn View of Aptian Karst Prospect

- Top Aptian Karst: Strong seismic evidence to support the Hunt – FAR karst interpretation
  Hugely significant as it fed into the development of the new SNE Play

- Became the secondary target of SNE-1
Exploration

Depth Section – Karst and the New Plays

- Concern over top seal in collapsed Karst area
Pre-Drill Interpretation (Hunt / FAR)

Exploration

Senegal: A Success Story, Cairn Energy PLC
Exploration

Two New Play Concepts – Pre-Drill Interpretation

- Sub-Aqueous Unconformity
- Sands in the Albian
- Prograding

Possible Charge from the East (Albian SR)

Cretaceous

<table>
<thead>
<tr>
<th>Upper</th>
<th>Maastrichtian</th>
<th>Campanian</th>
<th>Santonian</th>
<th>Coniacian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>Aptian</td>
<td>Barremian</td>
<td>Hauterivian</td>
<td>Valanginian</td>
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</tbody>
</table>

- Clastic Reservoir
- Carbonate Reservoir
- Source

Senegal: A Success Story, Cairn Energy PLC
The Concept SNE Albian Platform Edge Clastic Play

Dec 2012: Flattened TWT Section
Early Albian Depositional Environment
Lower Albian Shelf Edge (Dec 2012, Farm-in Stage)

Attributes, Seismic Facies and Velocity Analysis Helped to Reduce Reservoir Risk
**Results of Drilling Campaign**

**Exploration**

- *Clastic Reservoir*
- *Carbonate Reservoir*
- *Source*

**Projected FAN-1**

- **Campanian-Maastrichtian**
- **Santonian**
- **Turonian**
- **Cenomanian**

**Projected SNE-1**

- **Sands in the Albian**
- **Sub-Aqueous Unconformity**
- **Prograding**

**Projected BEL-1**

- **Sands in the Albian**

**Cretaceous**

- **Upper**
  - Maastrichtian
  - Campanian
  - Santonian
  - Coniacian
  - Turonian
  - Cenomanian
- **Aptian**
- **Albian**
- **Berriasian**
- **Hauterivian**
- **Valanginian**
- **Barremian**

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*Senegal: A Success Story, Cairn Energy PLC*
Many Companies saw the SNE-1 Well as Very HIGH Risk

- Four key reasons why many companies saw the SNE-1 well as very HIGH Risk

- In addition to the fact that none had identified the SNE Albian sand play, so all companies were evaluating the Aptian Carbonates and so called Buried Hill

1. Source: the Turonian is immature in this basin
2. Charge, it is difficult to get hydrocarbons to charge the shelf
3. Trap: if you charge into and up the carbonate platform and unconformity how will you stop it leaking in a fully carbonate system AND if you charge up the unconformity you will get sands deposited along the transgressive surface and leak the structure
4. Biodegradation: low temperatures on the Platform margin
Regional Seismic Tie to DSDP367 Where is the SR?

**World class source rock**
- TOC = 6-34%
- HI = 450-650

**Top Black Shale (Turonian)**

**Early Tertiary (Palaeocene)**

**Senonian Unc**

Early correlation: Wedge matches input of Albian clastics

TOC = 6-34%
HI = 450-650
Exploration: Transformation Ratio (Type II B Kerogen)

Turonian/Albian Source Rock Maturity – GG 32°C/km

Sensitivity: Modelling uncertainty: Shallow vs Deep Pick Interpretation

Shallow Pick

- Low Turonian maturity

Pre-Drill modelling

Deep Pick (Turonian or Albian SR)

- Peak Oil Window within the FAN-1 fetch area
- Enough expelled volumes capable of charging platform prospects
Exploration: Transformation Ratio (Type II B Kerogen)

Turonian/Albian Source Rock Maturity – Tertiary H Pulse

Sensitivity: Shallow vs Deep Pick Interpretation

Shallow Pick

Deep Pick (Turonian or Albian SR)
Exploration: Transformation Ratio (Type II B Kerogen)

Albian/Older Source Rock Rock Maturity

Sensitivity: GG 32°C/km vs Tertiary HP

GG 32°C/km

Tertiary HP
The Rufisque dome is an igneous upwelling creating a localised high within the License area. The crest of the structure has been tested by RF-1 (not shown) and DKM-2 and two flank wells have also been drilled (RF-2 and RF-3). All three wells have encountered hydrocarbon shows.

- RF-3 tested for oil in Senonian sands (16ft net pay) and RF-2 tested oil in Cretaceous carbonates.
- Fair to good oil shows were encountered in DKM-2 within the Tertiary and Cretaceous aged sections.
- Producing Fields: Gadiaga and Dam Niado in Upper Cretaceous sourced from Turonian.

Original source: Hunt published in Martin et al 2010
Encouraging Seismic Anomaly on the Platform

- Flat spot approximately 10km south of SNE-1
Pre-Drill Interpretation (Hunt/ FAR)

Trap: Transgressive lag following the coastal onlap of a sub-aerial unconformity will leak the trap
Exploration

Jammah-1 Synthetic Well Tie

Platform Edge and so called “Buried Hill” reservoirs are expected to be within the Cenomanian to Albian Cenomanian shelf sands underlain by Albian slope clastic sediments Turoanian seal and deepwater shales in the Campanian overlie the unconformity. Cenomanian shelf sands underlain by Albian slope clastic sediments
Two New Play Concepts – Pre-Drill Interpretation

The Major Senonian unconformity is Sub Aqueous

Albian sands must have reached the basin
Exploration

Risk of Biodegradation – Buried Hill (Tertiary HP)

- Source: Turonian
- Fetch area: 387.17 km²
- Oil charge: 5848.40 mmbbls
- Present res. Temp: 65
- Oil API after degradation: 34
Risk of Biodegradation – Buried Hill (Tertiary HP)

Casamance Wells SF4 and CM9 tested 34 and 32 API Oil from 700 m and 220 m, respectively.

CM9 temp. of 42 C (uncorr.) @ 500 m
Exploration

North Fan location: N Fan Thin Hard Sands, Limited Column Height
Exploration

H180 Level: Class IV AvO

- COP viewed this level as a Californian style Turbidite
- FAR linked it to a Fan as New Age’s Al Hamdallilah prospect
- Cairn had non reservoir interpretations
Exploration

Basin: Albian Sediments

H300 Amplitudes: Coast parallel, thermohaline influence and depth of burial issues

Conoco happy with pinchout geometry
Discovery and Appraisal
The Opportunity – Two Discoveries

- Active petroleum system with world class source rock proven at FAN-1
- FAN-1 and SNE-1: discoveries in Albian sandstones
- Cairn’s preliminary evaluation: 7-8 play types
- Largest prospects drilled: two wells to test the highest number of play types (4)
- SNE-1 results are in the upper range of initial estimates – mean values more than double pre-drill estimate
- Source rock at FAN-1 better than expected, reservoir quality under evaluation
- A number of prospects and leads under evaluation to be matured as drillable targets
Discovery and Appraisal

**FAN-1 Discovery**

- Turonian-Albian reservoir – mediocre quality
- Hydrocarbon column >500m (net oil 29m)
- Oil gravity 28-41° API
- Presence and maturity of good quality source rock proven on multiple levels
- HC presence confirmed from Turonian to Albian

<table>
<thead>
<tr>
<th>Gross Oil (STOIP) in place</th>
<th>P90</th>
<th>P50</th>
<th>P10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>250 mmboles</td>
<td>950 mmboles</td>
<td>2,500 mmboles</td>
</tr>
</tbody>
</table>

3D view of top reservoir level with superimposed seismic amplitude
Discovery and Appraisal

FAN-1 Forward Programme

- FAN Appraisal scheduled 2017/2018
  - Seismic reprocessing and reservoir characterisation
  - Ongoing analysis of rock and fluid samples, well log data
  - Remapping of the field boundaries and surfaces
- Evaluation Programme submitted
  - Potentially multiple wells
  - Contingent testing and coring of the reservoir
  - Aimed at confirming reservoir model, commercial volumes and deliverability
Discovery and Appraisal

**SNE-1: Review, Initial Resources and Updates**

- Dual target well – Albian clastics and Aptian carbonates
- Oil and gas discovered – 2C resource 330mmbbls
- Reservoirs – Upper and Lower units
- 32° API Oil Quality – Log, rock and fluid samples
- Clear Gas-Oil and Oil-Water Contacts
- Depth conversion indicates larger structure
- Drilling time and costs ahead of target
Value Creation in Senegal

Eleven wells in three years; two basin opening discoveries and seven successful appraisal wells

“Two basin opening discoveries in first twelve months of operations”

“Four wells completed ahead of schedule and under budget”

Operational success provides options for commercialisation

- Cairn farm-in as Operator to 3 blocks Senegal, 65% WI
- Farm down 25%
- Oil discovery FAN-1
- Second Oil discovery SNE-1
- Multi-well three year evaluation plan presented to Government of Senegal
- Phase two drilling operations commence
- Contingent resource upgrade
- Gross oil in place on SNE >2.7 b barrels
- Development planning underway
- Stena DrillMAX rig contracted in lower cost environment
- Two appraisal wells plus seven optional wells including exploration prospects
- Phase two drilling operations commence
- Concept select
  - FEED
  - FID
  - First Oil
Development and Production – Senegal

SNE Development

Aligned approach to develop Senegal’s oil resources

Development Philosophy

- JV principles for SNE development:
  - Economically robust project with low breakeven
  - Standardised, field proven equipment and suppliers
  - Guided by international standards
  - Attracts international project finance

- These principles result in the JV pursuing:
  - A phased development concept
  - Consideration of re-deployment of suitable FPSO vessels versus conversion / new-build
  - Scalable subsea infrastructure
  - …which should drive lower capex to first oil and lower overall project breakeven

- Expressions of interest (EOI) have been sought and received from contractors and Operators for subsea and FPSO
## SNE Development

### SNE Field Characterisation

- Water depth (WD) 650 - 1,400 metres
- Following discovery well, seven further penetrations have been completed on SNE
- Eight DSTs* completed in four separate wells (SNE-2, SNE-3, SNE-5 and SNE-6)
- Two distinct reservoir horizons
  - S400 Upper reservoirs
  - S500 Lower reservoirs
- Comprehensive data (including re-processed 3D seismic) allows accurate reservoir and fluid description
- Environmental baseline survey complete
- Ongoing geotechnical survey to gather metocean and seabed data

* Including interference test

### SNE Reservoir Schematic

- **S400 Upper Reservoirs**
- **S500 Lower Reservoirs**

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Development and Production – Senegal

SNE Development

Reservoir and Oil Quality

- Good correlation of gross reservoir packages
- Connectivity in S400 upper reservoirs demonstrated by interference test in a clearly preferred orientation
- DST in S500 lower reservoir confirms expected good inter-well connectivity
- Water flood planned for both sets of reservoir
- Crude quality suitable for major refinery markets in Africa, Europe and US, and expected to attract strong pricing

Updated Gross Contingent Resources*

| May 2016 | 1C 274 | 2C 473 | 3C 906 |
| August 2017 | 1C 346 | 2C 563 | 3C 998 |

* Resource estimates by ERC-Equipoise

Schematic Cross Section

- Upper Zone DST 1A (11m) maximum flowrate ~4,600 bopd
- Upper Zone DST 1B (15m + 12m) combined maximum flowrate ~5,400 bopd
- Lower Zone DST Stabilised but constrained flowrate ~8,000 bopd
- Upper Zone DST 1B (18m + 8m) maximum flowrate ~4,200 bopd
- Upper Zone DST 1A (18m) maximum flowrate ~4,500 bopd
- Upper Zone DST 1B (15m + 5.5m) combined maximum flowrate ~5,200 bopd

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46
**SNE Development**

**Timeline**
- Targeting Final Investment Decision (FID) by end 2018:
  - Complete Front End Engineering and Design (FEED)
  - Evaluation Report and Exploitation Plan to be submitted and approved by Government of Senegal
- Transfer of Operatorship for development phase

**Production**

*First Oil 2021 - 2023*

**Discovery**

- 2014
- 2 – 4 Years
- 3 – 5 Years

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Exploration

Atlantic Margin - Senegal

Third Phase of Exploration Drilling Commenced 2017

- VR-1 exploration target on SNE appraisal well to test deeper carbonate play
  - Oil shows in tight formation
- FAN SOUTH-1 follow on to FAN-1 basin discovery
  - Recovered 31° oil from lower Cretaceous, upper Cretaceous wet
  - Net reservoir below pre-drill estimate, assessing potential
- SNE NORTH-1 Northern test of SNE field play
  - Discovery separate accumulation to SNE
    - Gas and Condensate in S400 reservoir
    - Oil in S500 reservoir below oil-water contact at SNE
    - Demonstrates potential for additional finds in basin
Remaining Exploration Potential Around SNE

**Sangomar Deep Offshore Block**
- SNE NORTH-1 40 – 80 mmboe (mean – P10) Gross Mean Contingent Resource
- Additional potential 65 – 130 mmboe (mean – P10) Gross Mean Prospective Resource
- Requires stratigraphic trap element to north
- Target for future appraisal

**Rufisque Offshore Block**
- Maturing leads on newly processed 3D seismic
- Capitaine prospect most attractive to-date
- Regional focus for hydrocarbons
- Impact resource potential in shallow water
- Would require standalone development

**Sangomar Offshore Block**
- Multiple leads being matured
- Within 30 km tie back distance of SNE
- Lower commercial threshold
Conclusion
Conclusion

Key Lessons for Exploration

The opening of new plays requires the combination of:

- Detailed regional knowledge,
- Always having experienced staff in key datarooms with capability modelling and access
- Correct interpretation and integration of all available data, without cognitive bias to a preferred model at odds with key pieces of data
- Modelling a range of uncertainties and unbiasedly risking of multiple scenarios
- Critically assessing the operators interpretations and plays
- An appropriate high quality QA/QC team, and process, is essential, tapping all available knowledge in the company and being totally supported by upper management (which should contain technically advanced members)
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