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

Martin, L., I. Effimoff, J. Medou, and M. Laughland, 2010, Hydrocarbon Prospectivity of Offshore Senegal - Unlocking the Door to a New Deepwater Petroleum Province: AAPG Convention, New Orleans, Louisiana, April 11-14, 2010, Search and Discovery Article #10278 (2010). Website accessed June 2018.





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

Disclaimer

These materials contain forward-looking statements regarding Cairn, our corporate plans, future financial condition, future results of operations, future business plans and strategies. All such forward-looking statements are based on our management's assumptions and beliefs in the light of information available to them at this time.

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

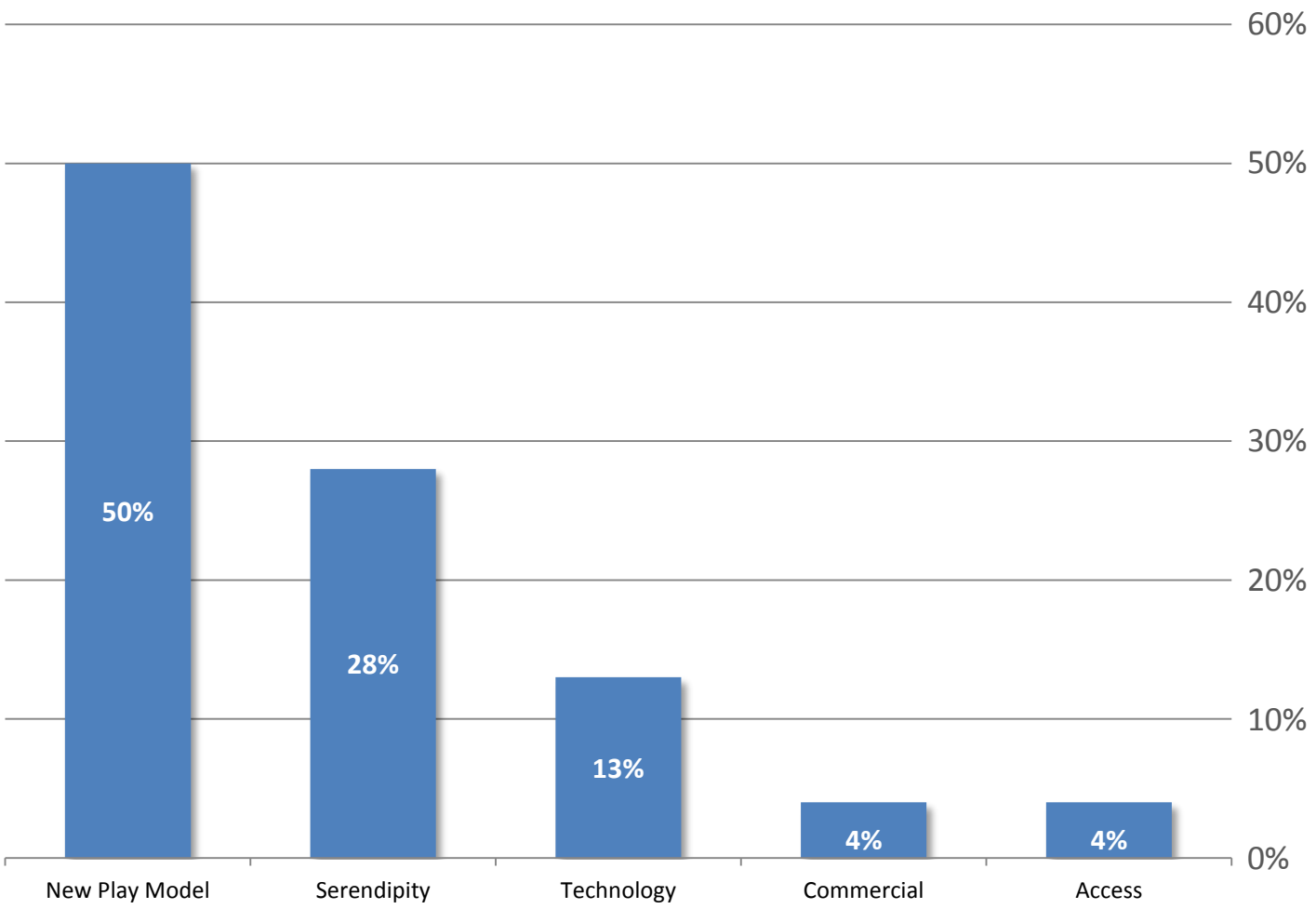
- Introduction
- Cairn entry into Senegal: How the plays were opened
- Why Discoveries were made when others thought it was too high risk?
- SNE-1 and FAN-1 discoveries
- Appraisal and Development
- Future work Adding Value: Further Exploration Potential

- 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

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

Track Record

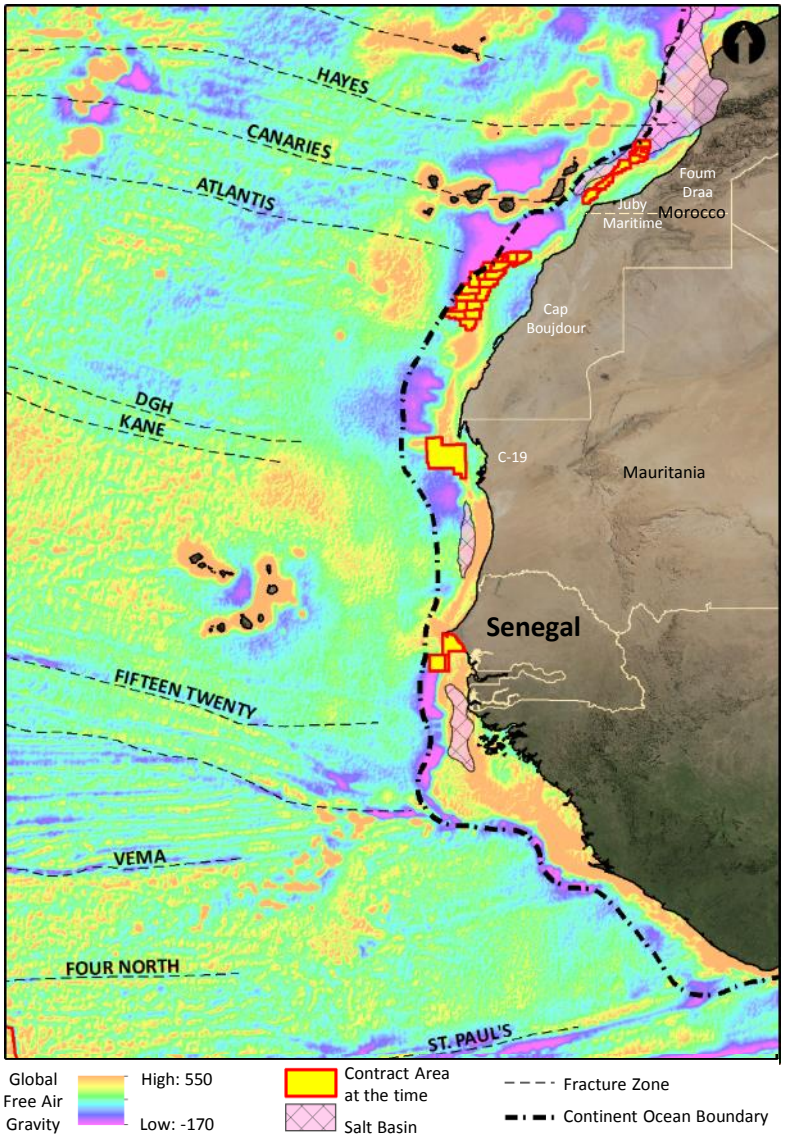
- Experienced and successful exploration, appraisal and development operator
- Operations conducted onshore and offshore, shallow and deepwater, benign and harsh weather environments
- Focus on highest HSE standards and sustainable development practices
- Model corporate citizen with demonstrable, successful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

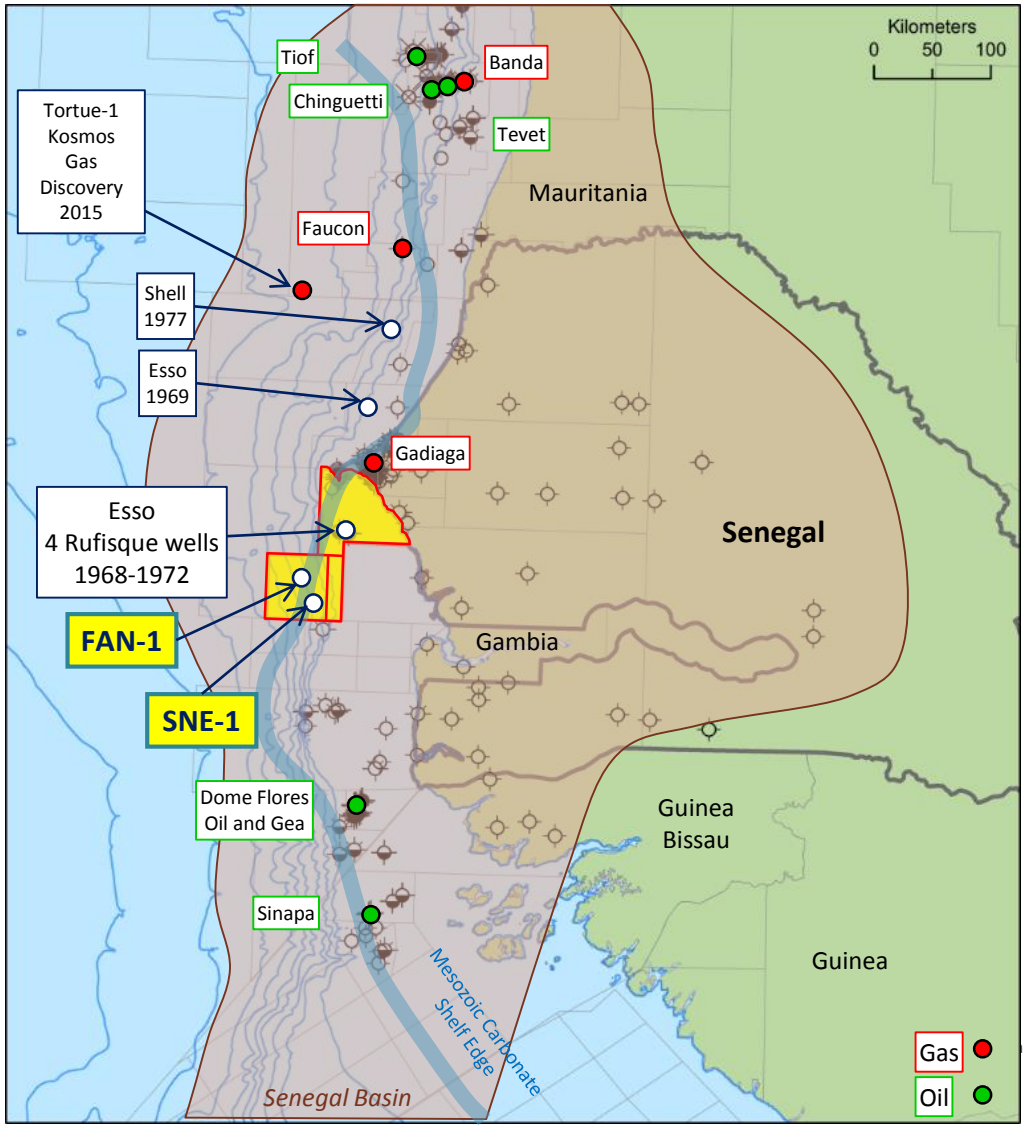


Why Senegal?

- 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

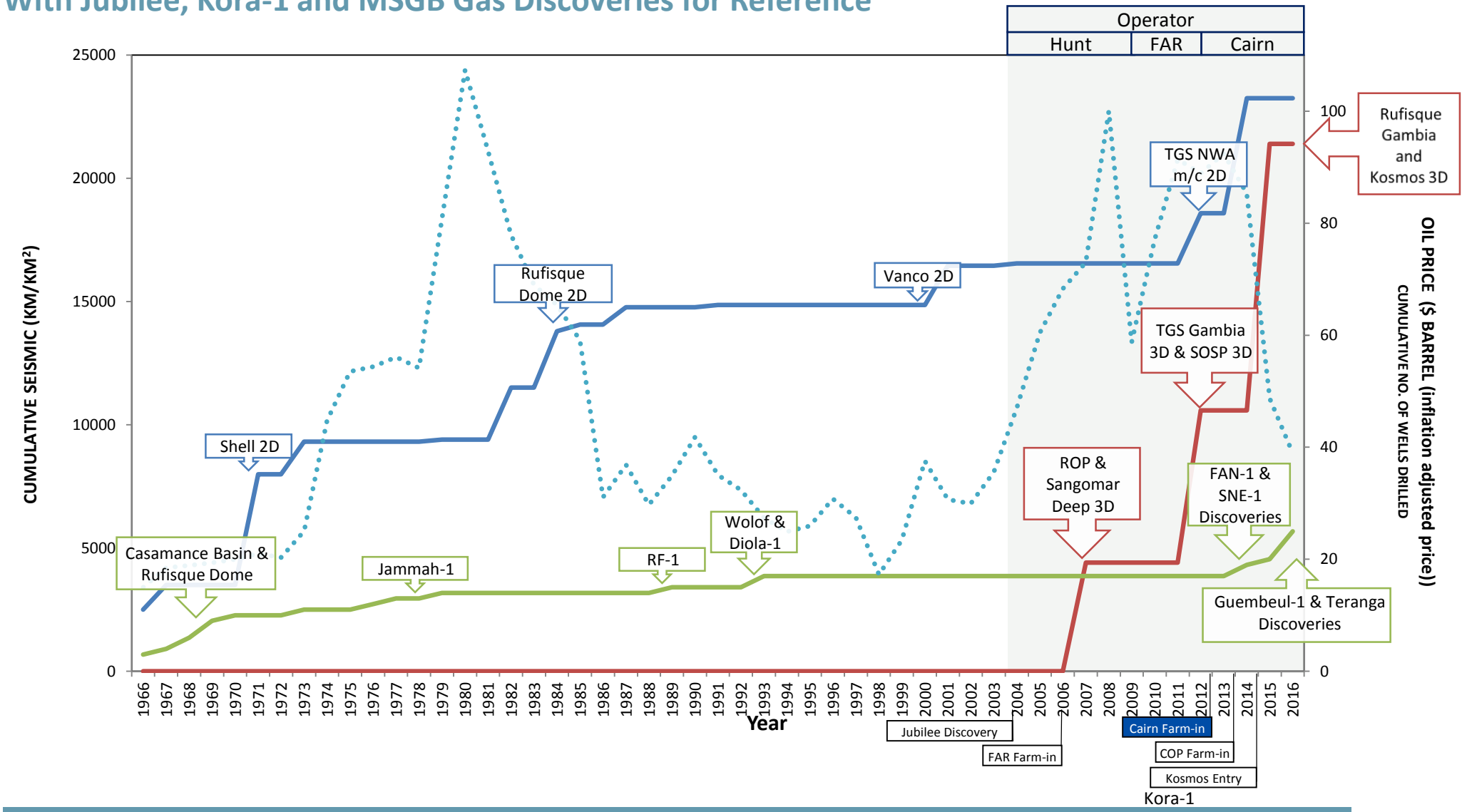
Why RSSD ?
(Rufisque, Sangomar and Sangomar Deep Blocks)

- 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

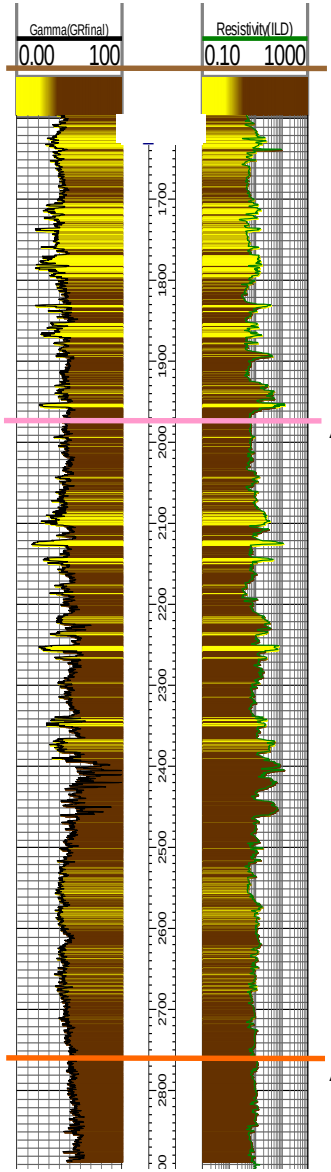


RSSD Exploration History

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



Geological Model: Hunt / Petrosen 2006, Adopted by FAR

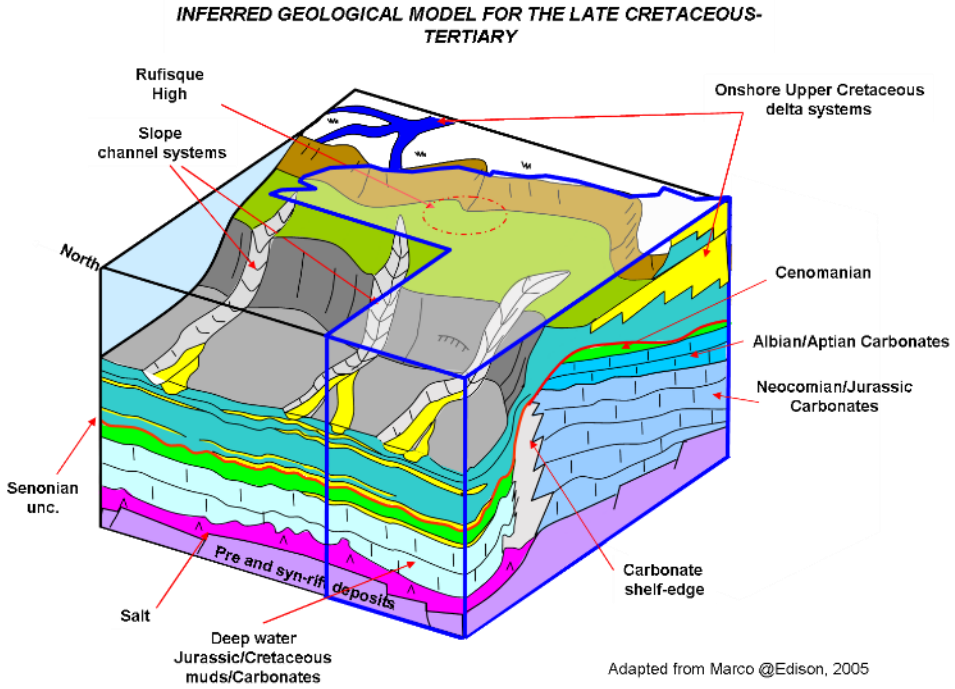


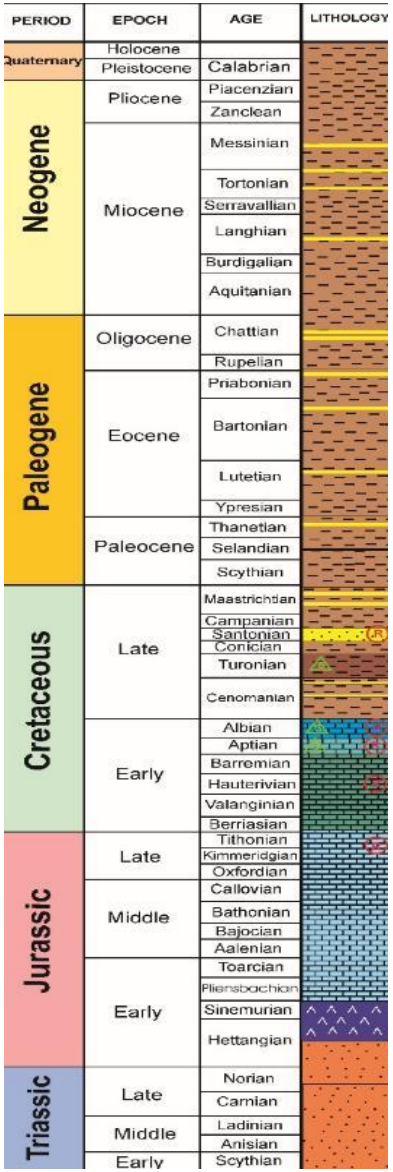
Top Cenomanian

Top Albian

Top Aptian

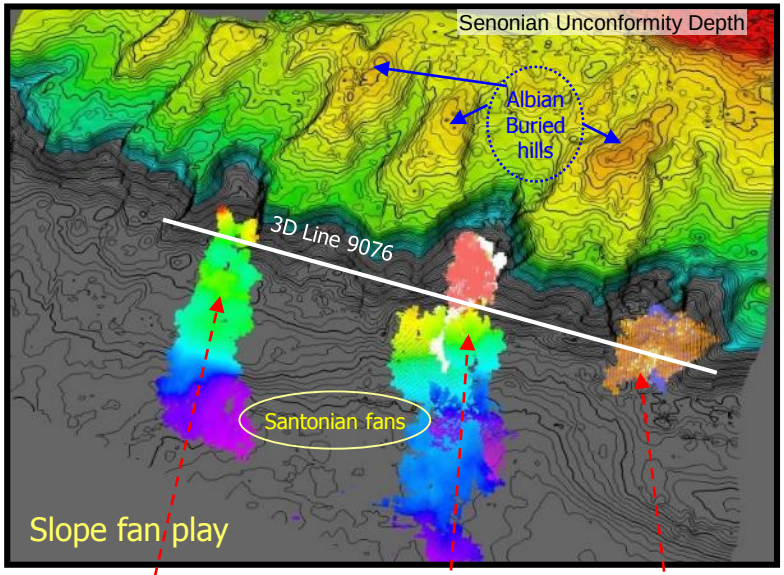
- **The Jurassic to Cenomanian is marked with a long lived carbonate platform.** Following the Cenomanian, during a period of quiescence, the Turonian source rock was laid down in anoxic deep water
- **Following deposition of the source, the platform was exposed and the carbonates karstified. The period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

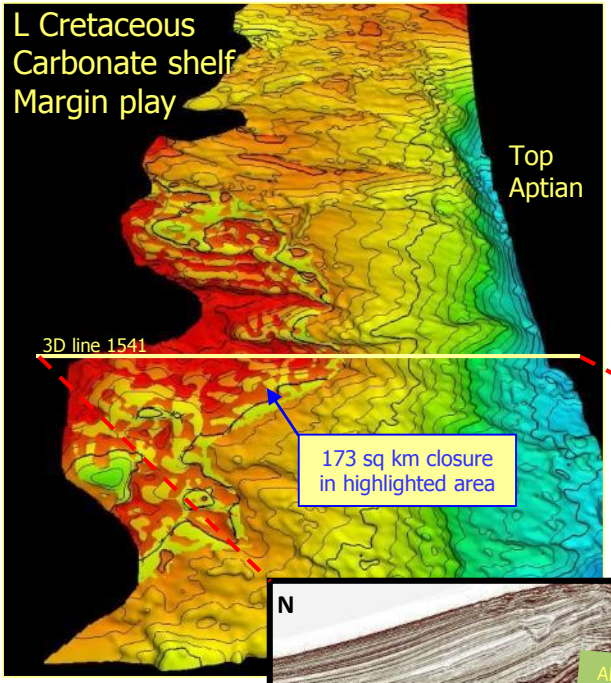


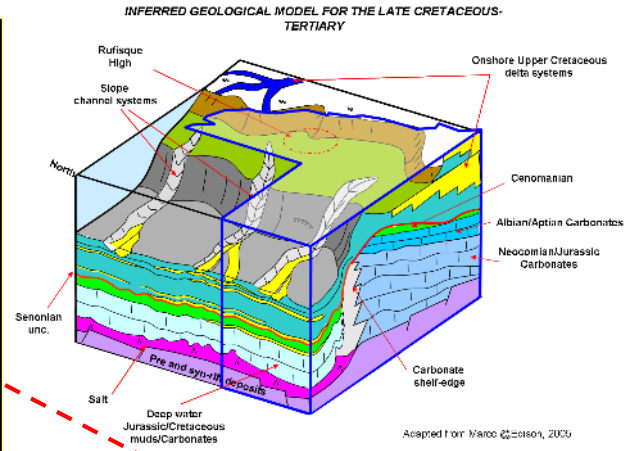


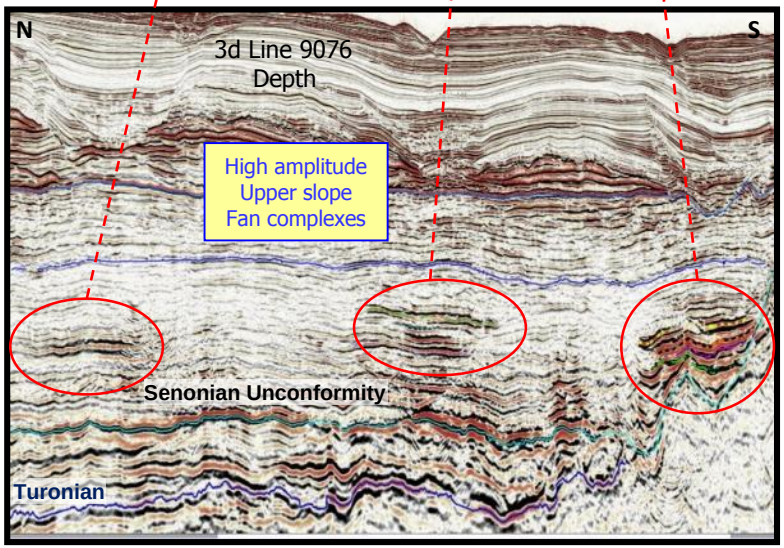
Original source Hunt published in Martin et al 2010

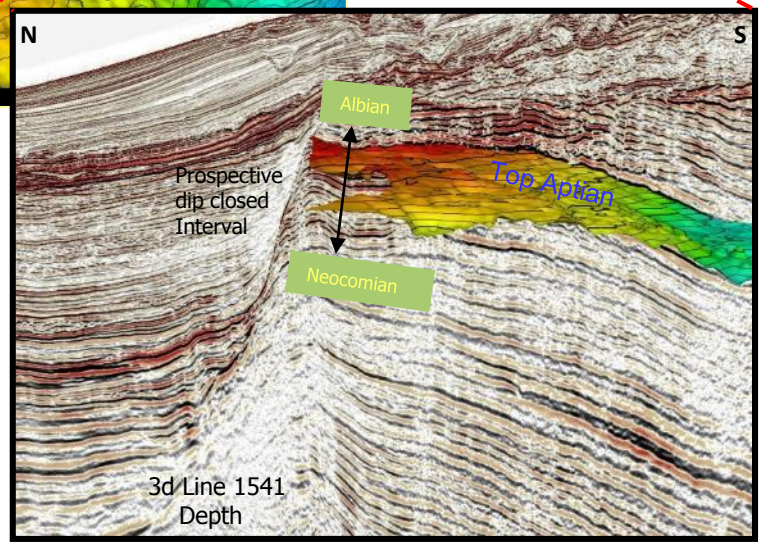
Senegal - Plays and Leads: Hunt / FAR / Petrosen Post 3D







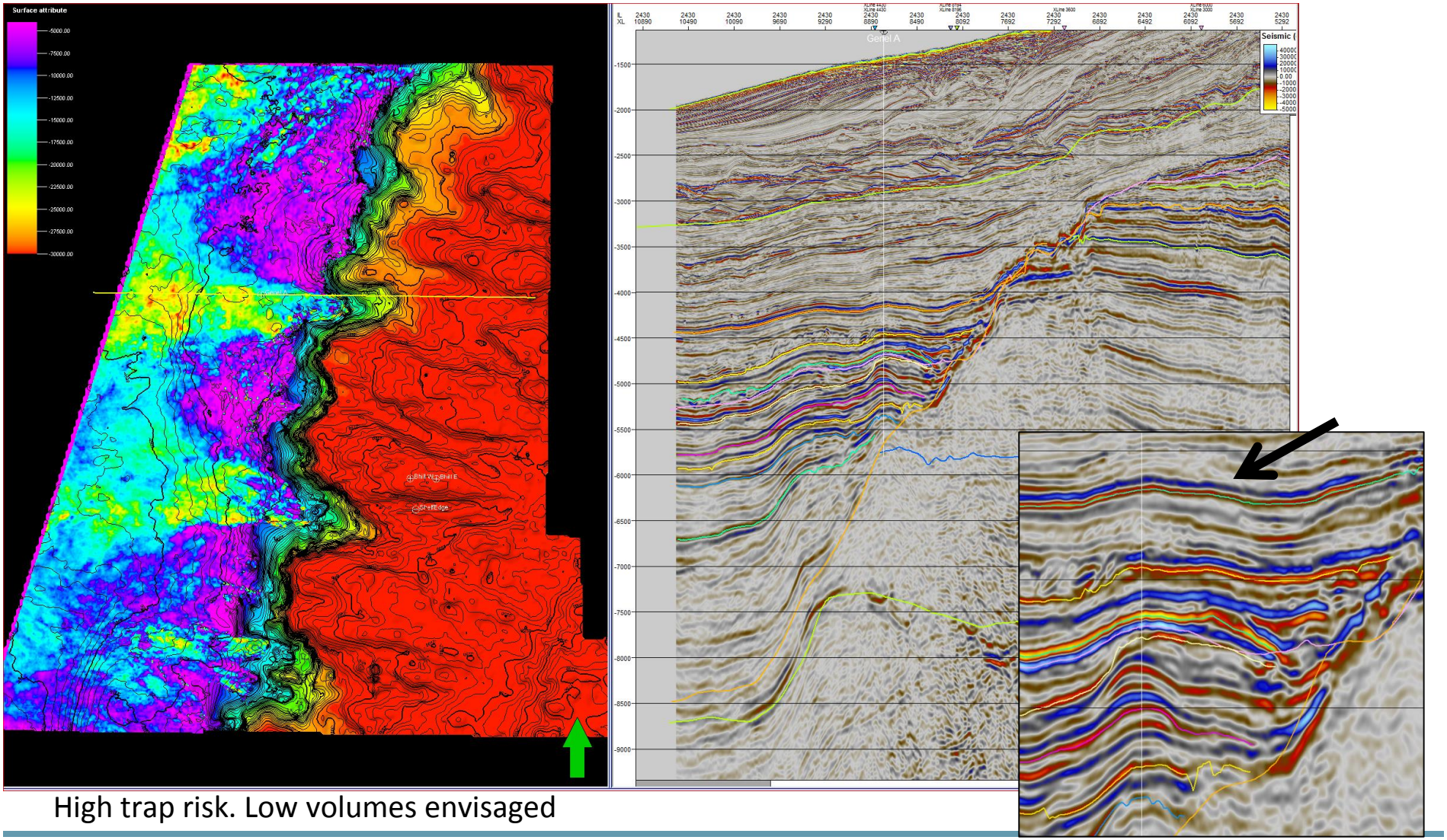




Original source Hunt 2006 published in Martin et al 2010

Cairn Views on the Existing Plays

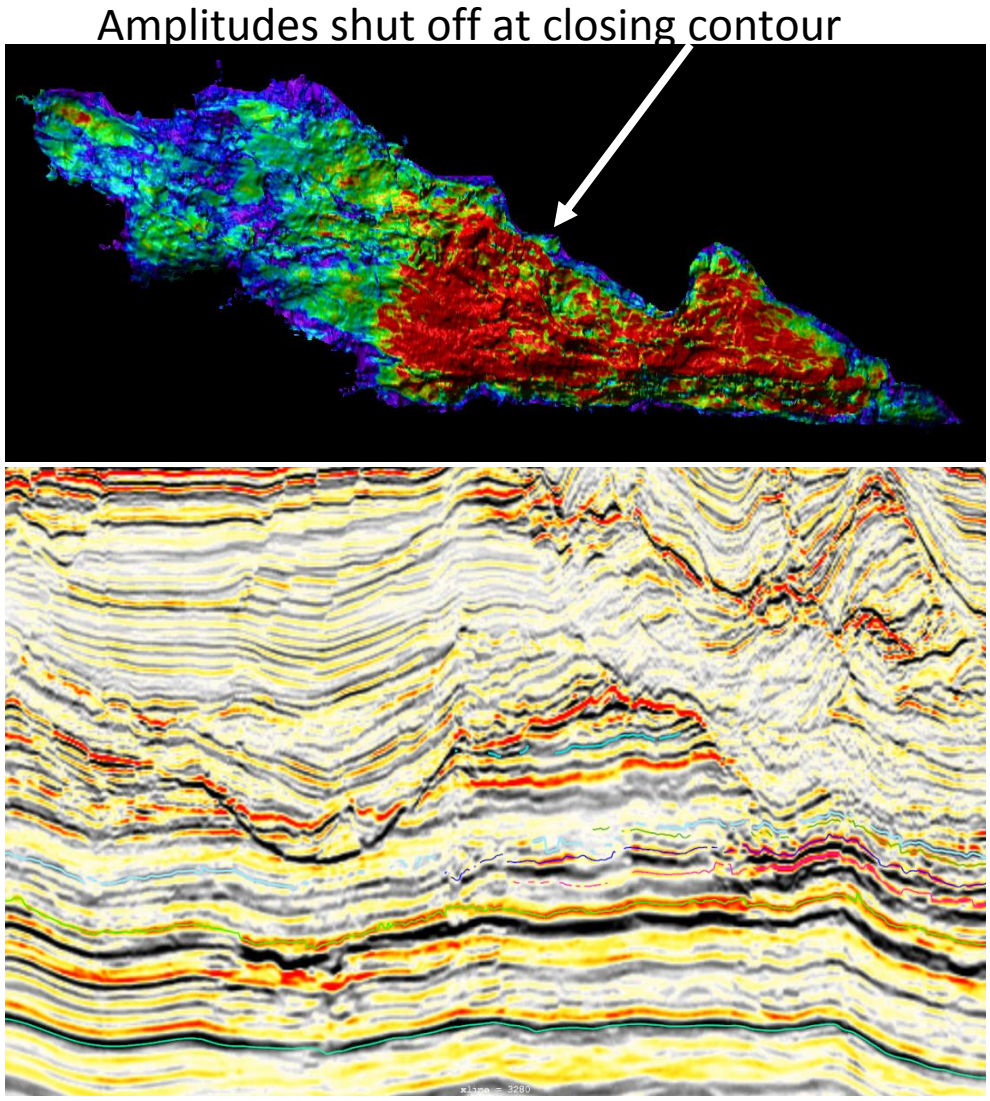
Upper Cretaceous Fans: Identified. Hard thin loop: poor thin sands (carbonate cements?)



High trap risk. Low volumes envisaged

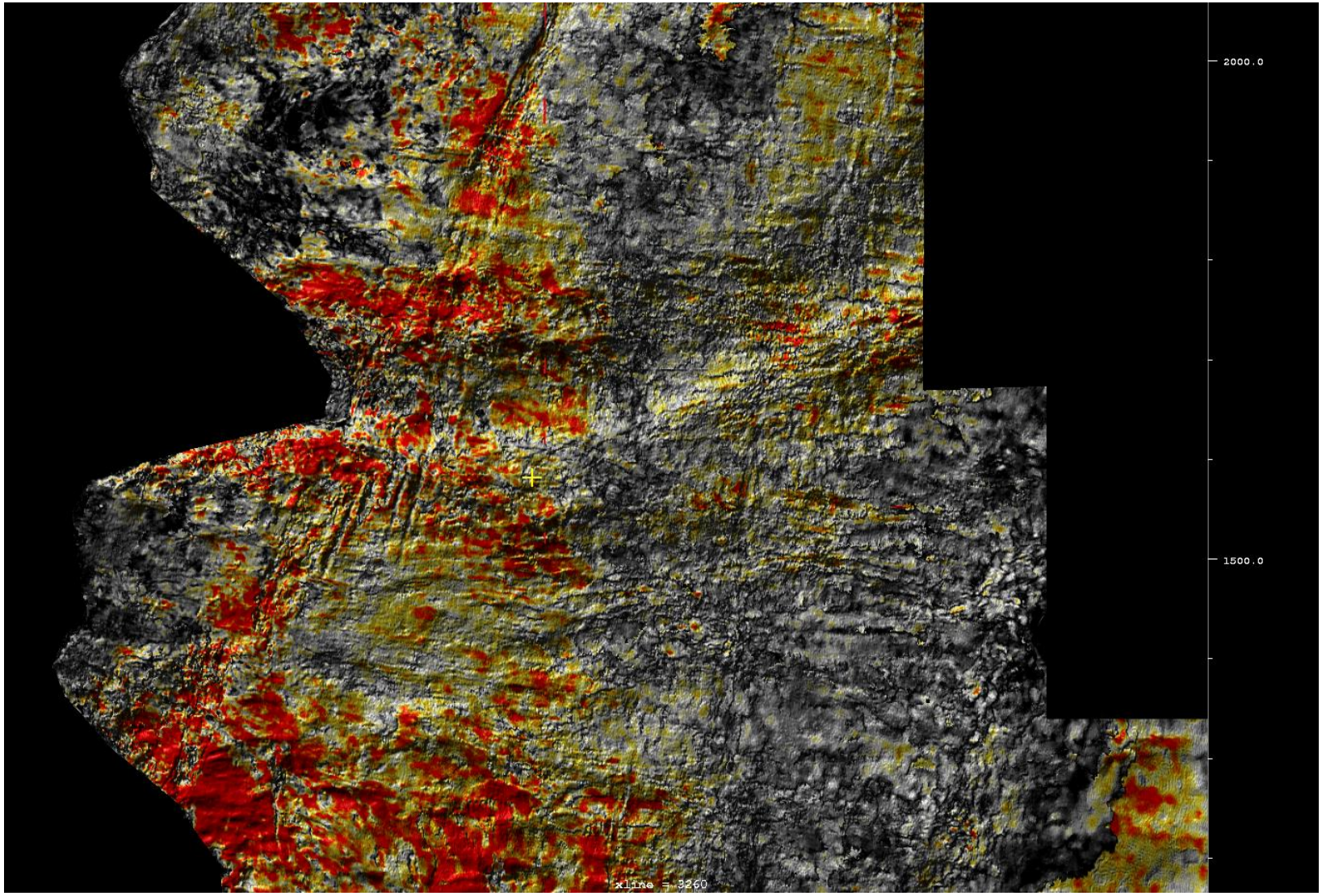
Cairn View Initially on the 'Albian Buried Hill'

- 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)



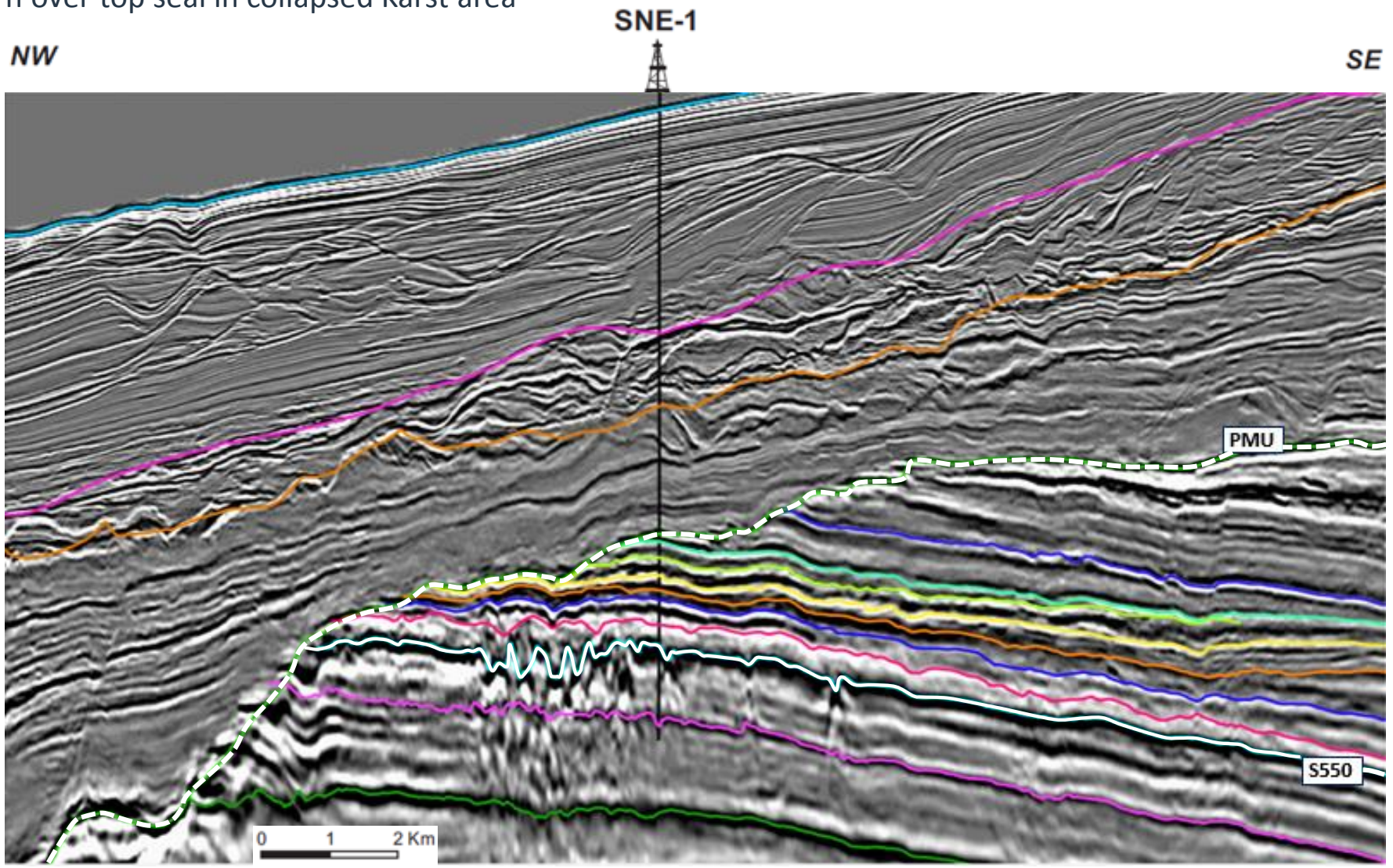
Cairn View of Aptian Karst Prospect

- 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

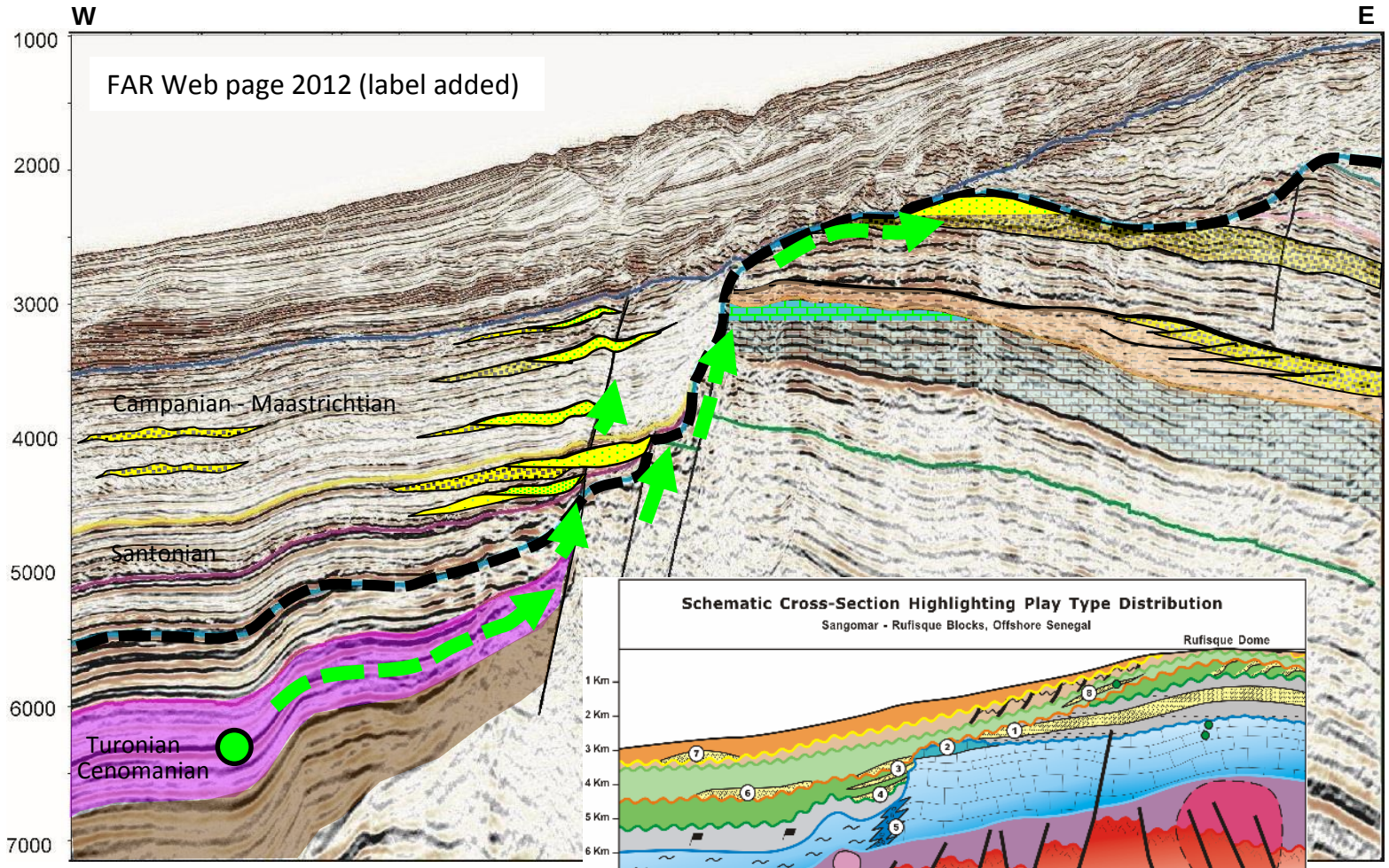


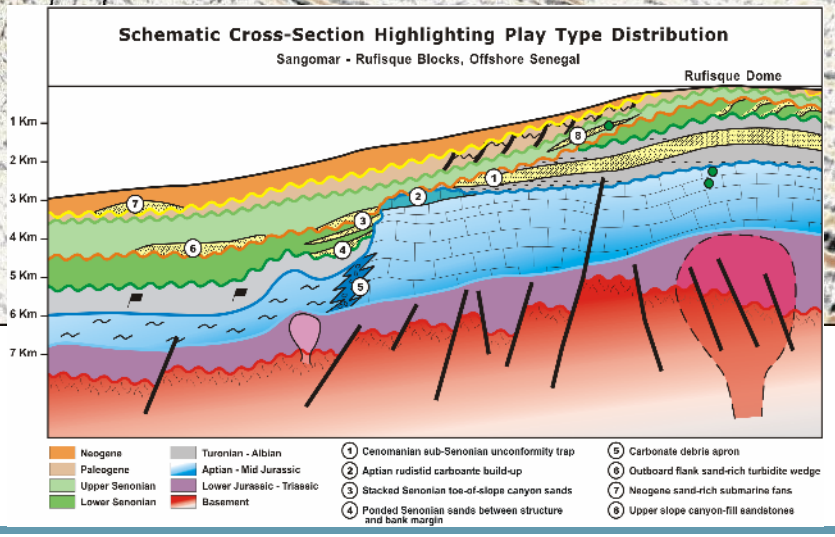
Depth Section – Karst and the New Plays

- Concern over top seal in collapsed Karst area



Pre-Drill Interpretation (Hunt / FAR)



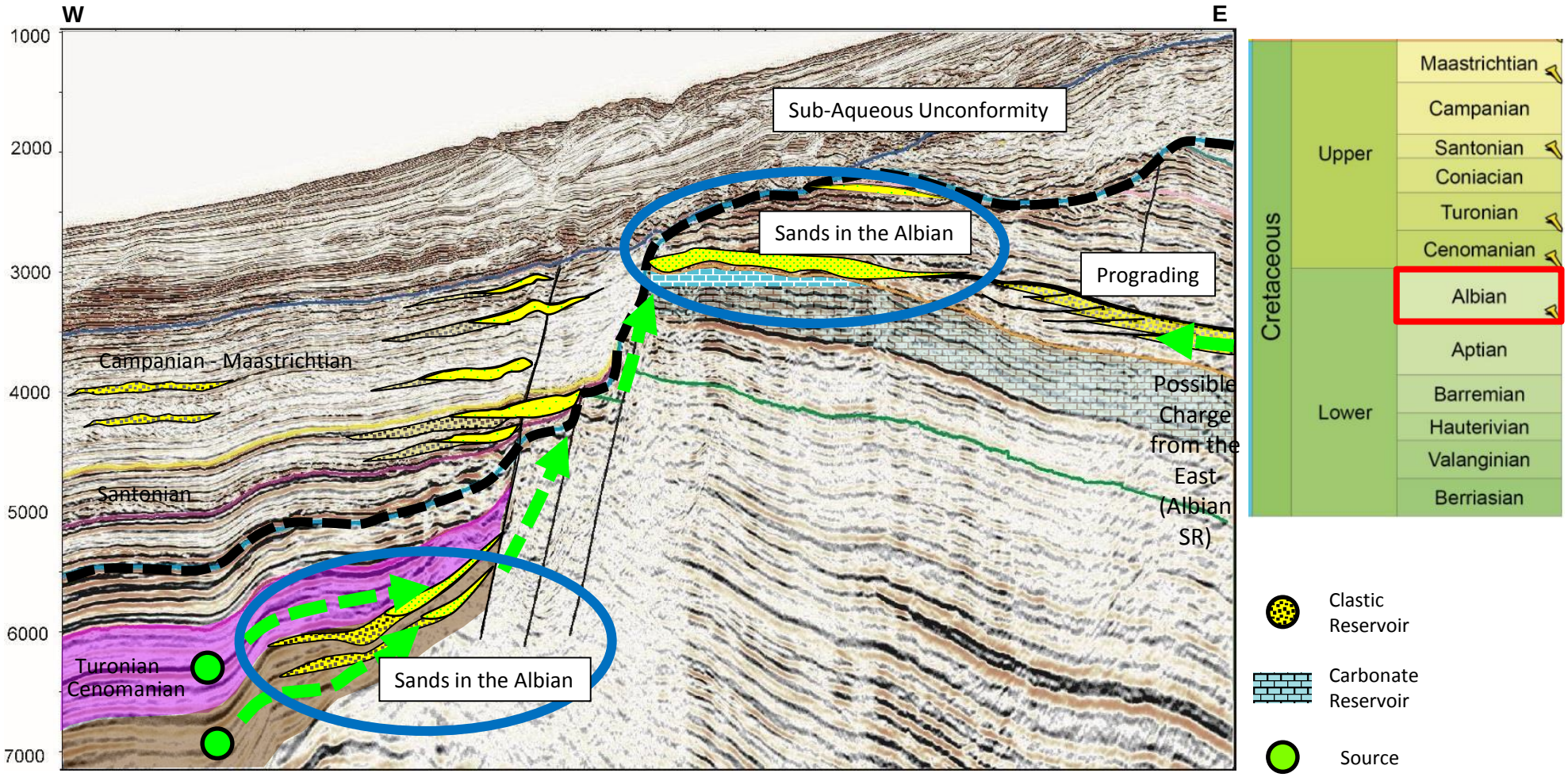


Clastic Reservoir

Carbonate Reservoir

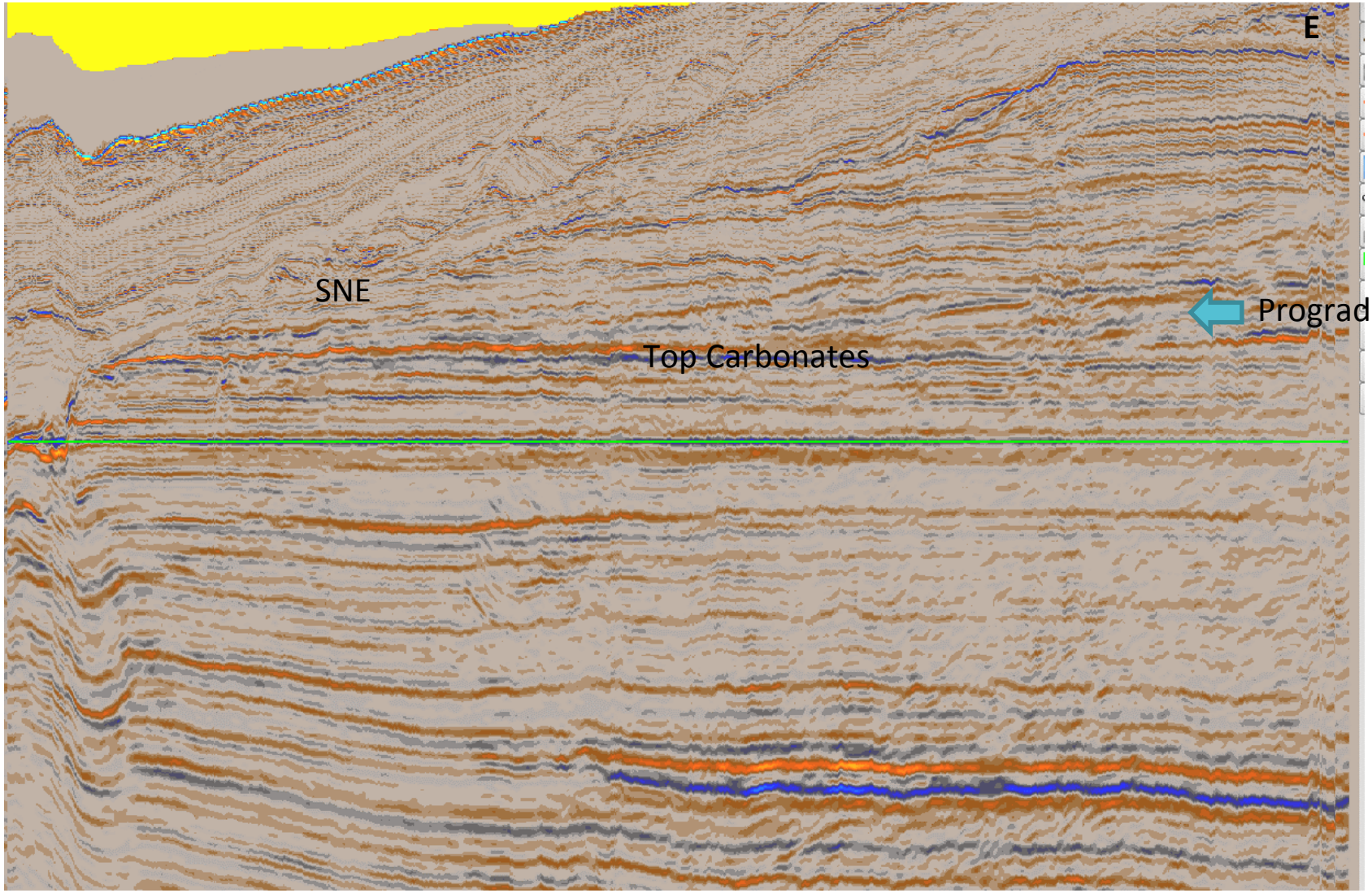
Source

Two New Play Concepts – Pre-Drill Interpretation

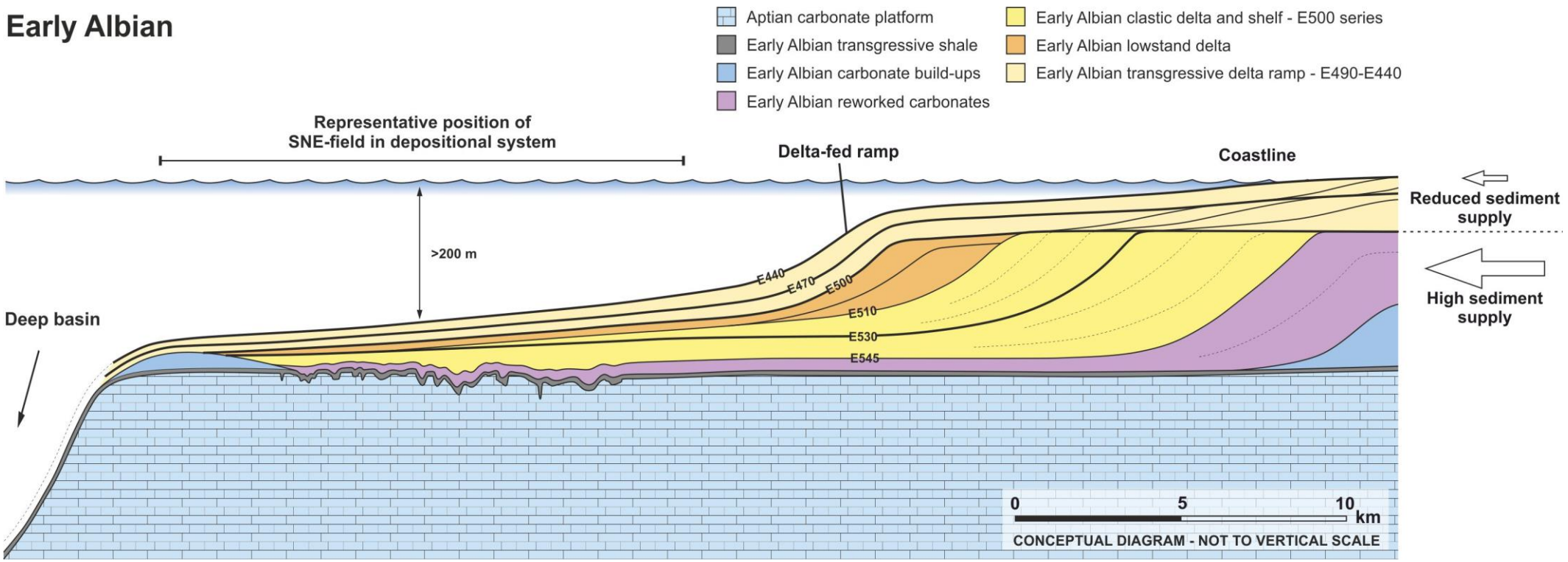


The Concept SNE Albian Platform Edge Clastic Play

Dec 2012:
Flattened
TWT Section



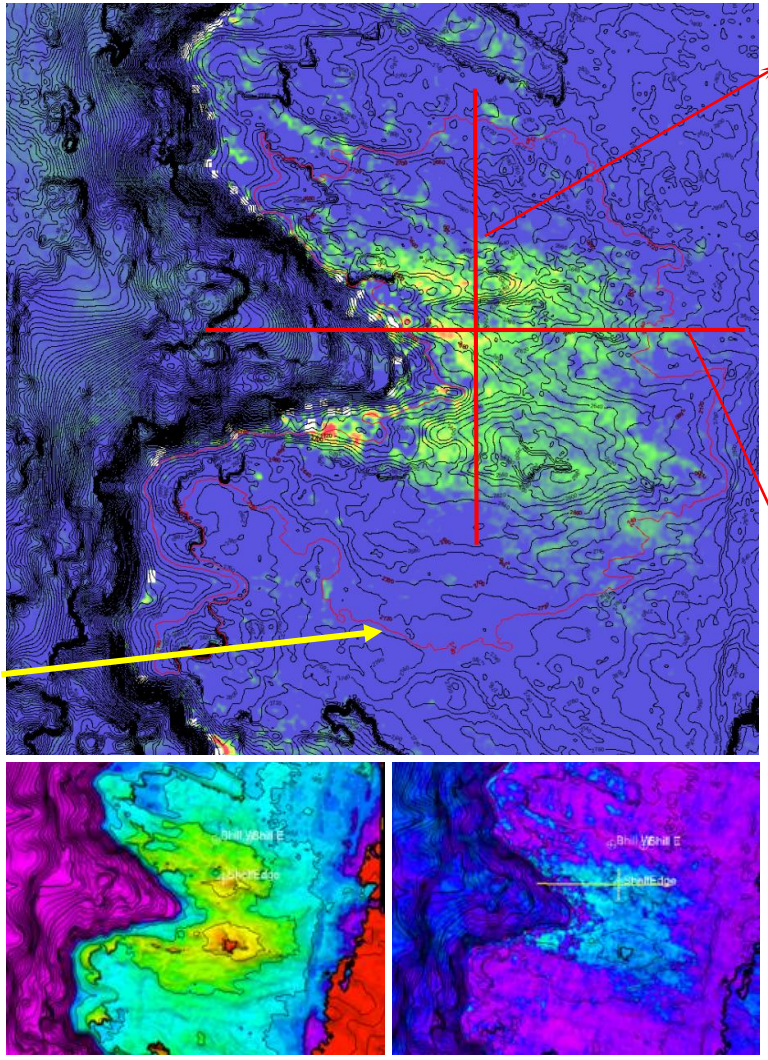
Early Albian Depositional Environment

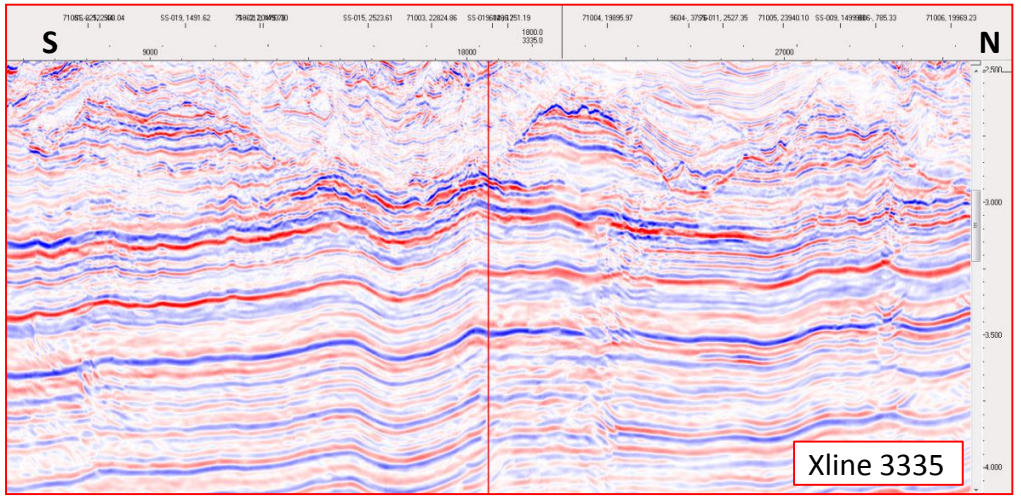


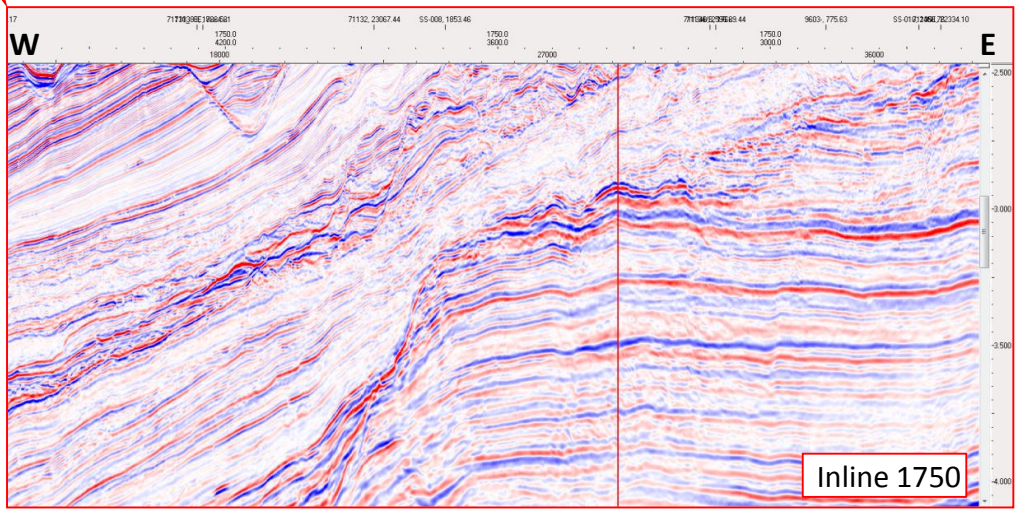
Lower Albian Shelf Edge (Dec 2012, Farm-in Stage)

Attributes, Seismic Facies and Velocity Analysis Helped to Reduce Reservoir Risk

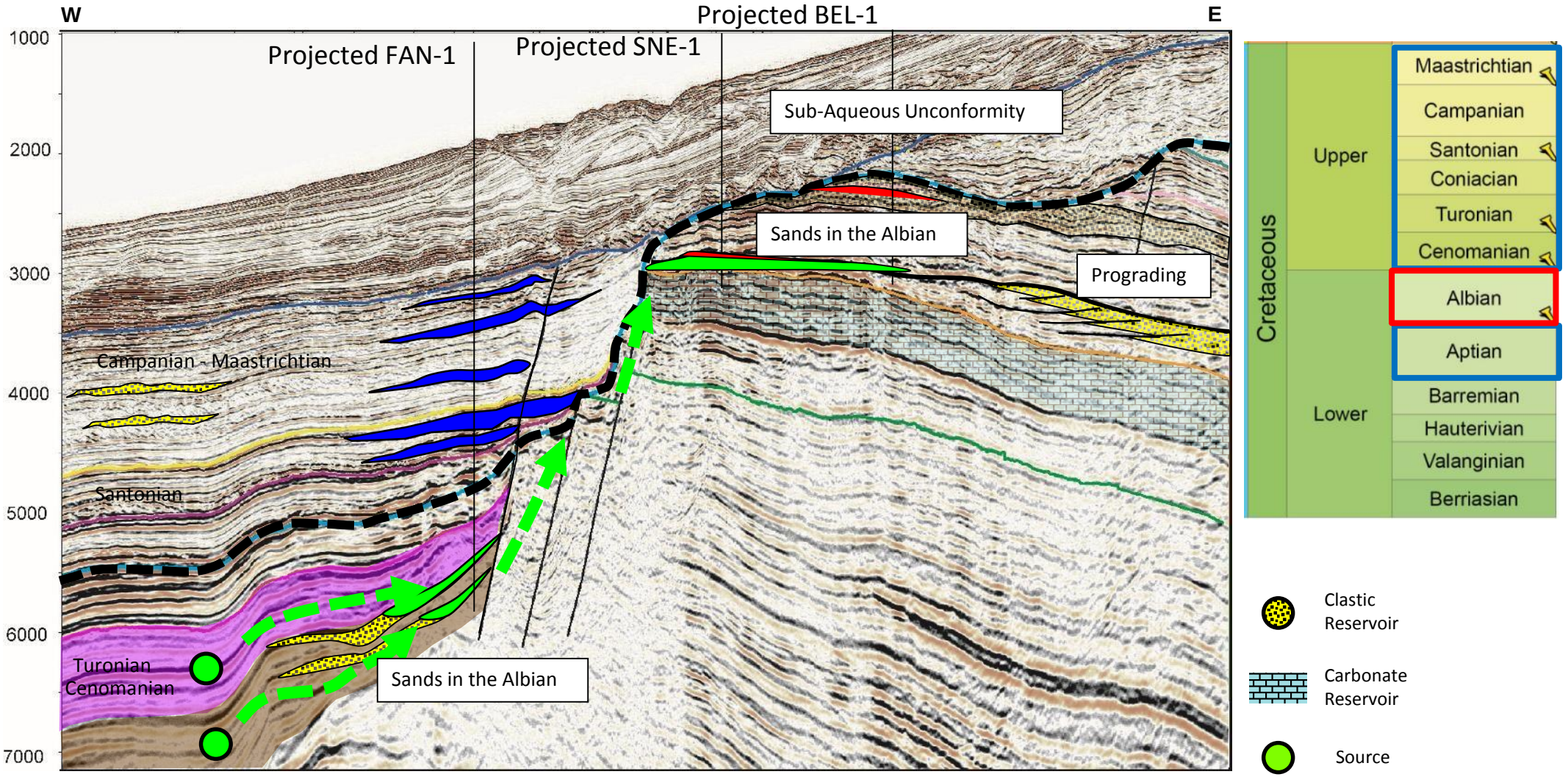
Structural contour







Results of Drilling Campaign



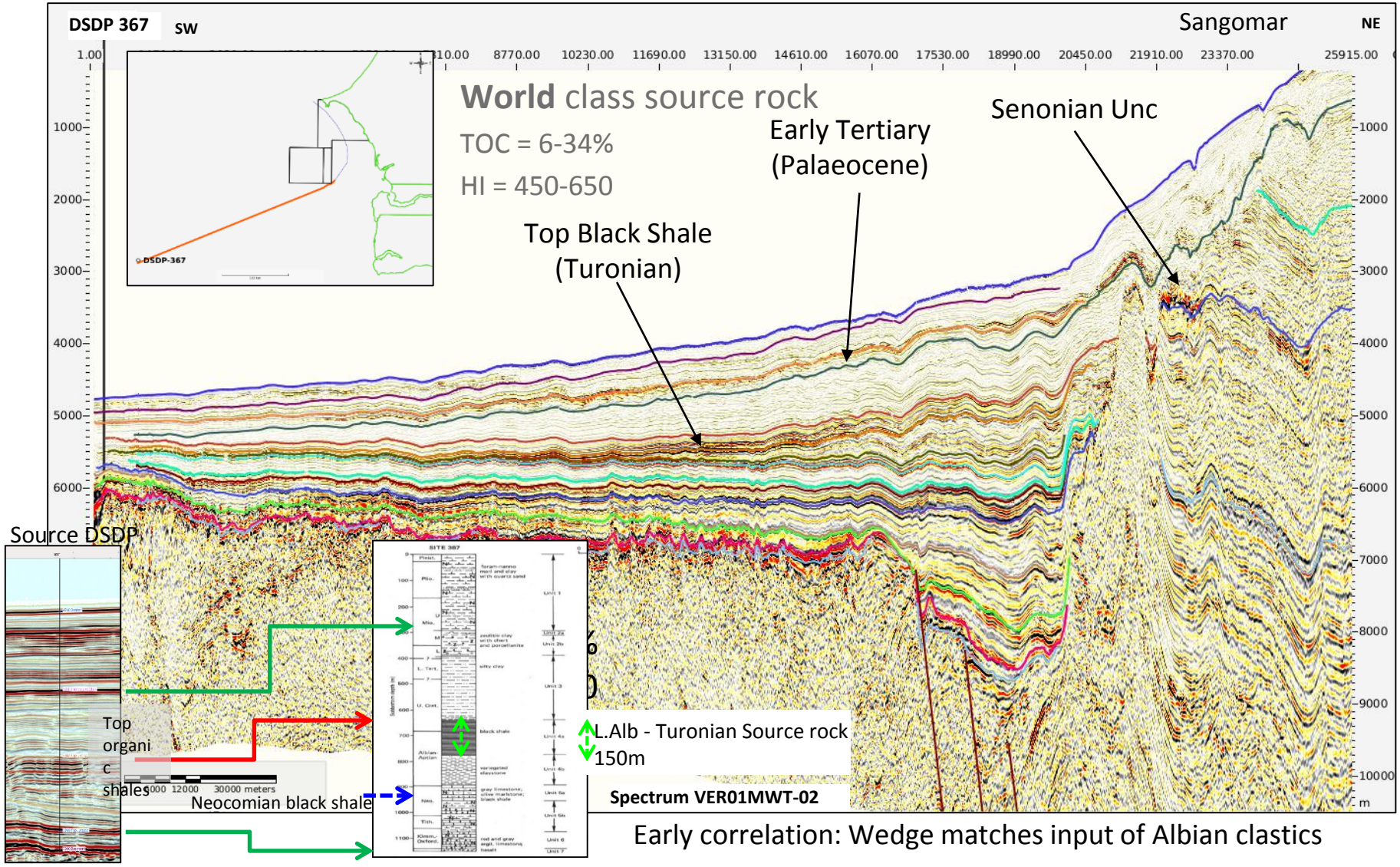
Many Companies saw the SNE-1 Well as Very HIGH Risk

- 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?



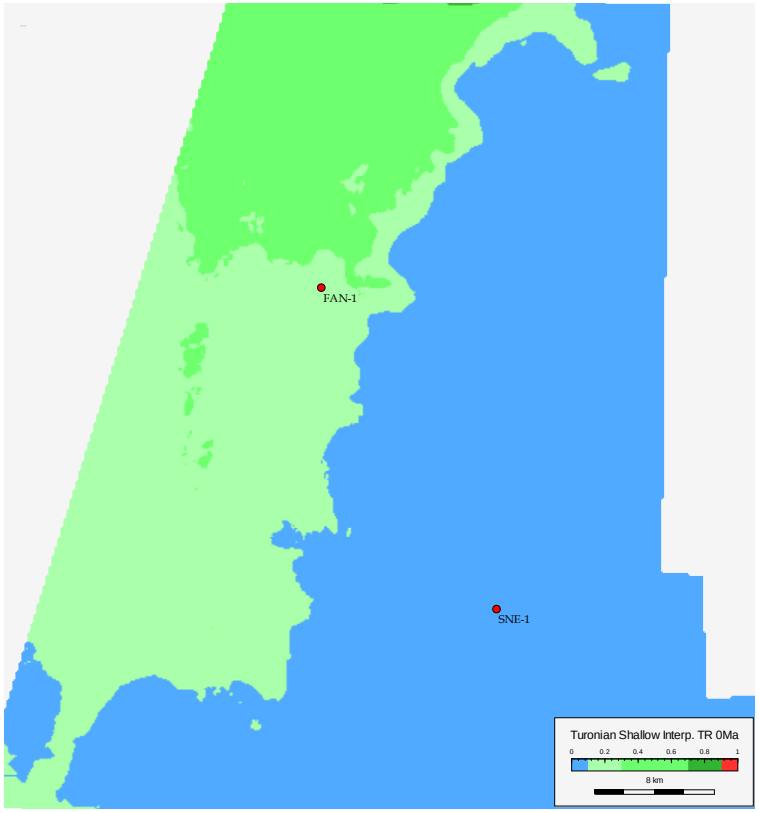
Early correlation: Wedge matches input of Albian clastics

Exploration: Transformation Ratio (Type II B Kerogen)

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

Sensitivity : Modelling uncertainty: Shallow vs Deep Pick Interpretation

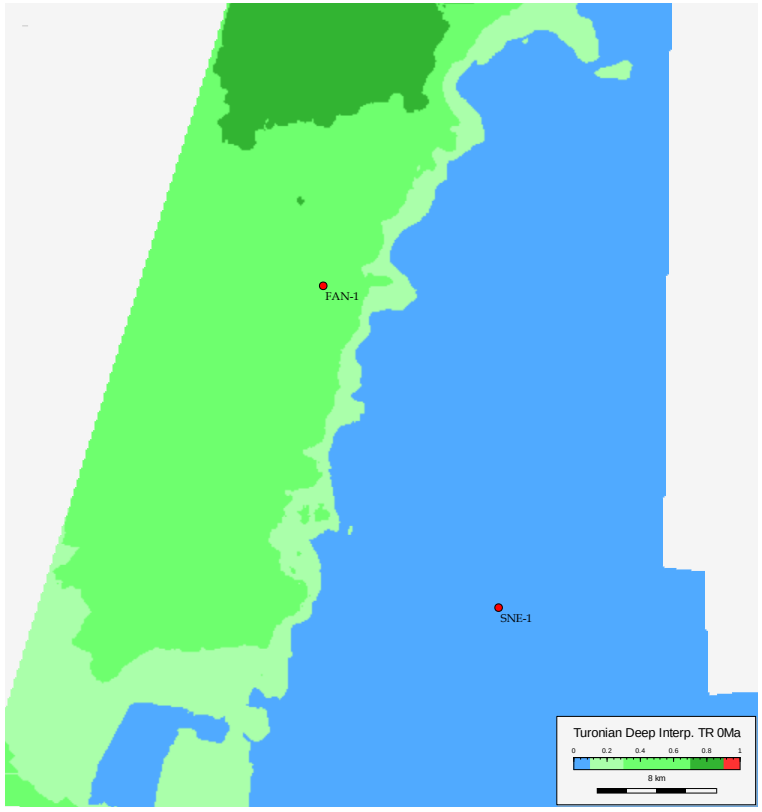
Shallow Pick



- Low Turonian maturity

Pre-Drill modelling

Deep Pick (Turonian or Albian SR)



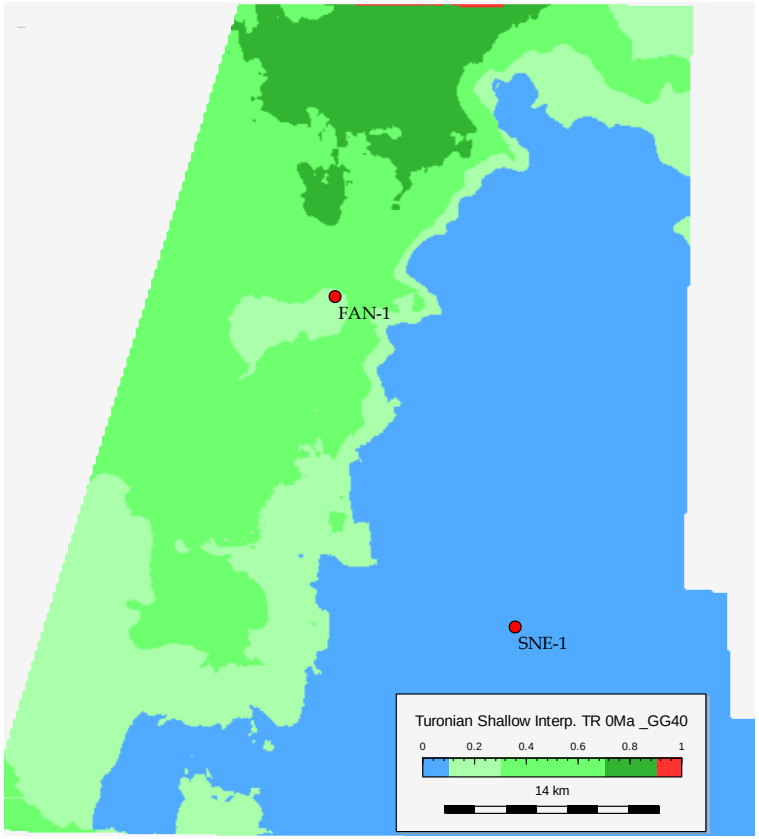
- Peak Oil Window within the FAN-1 fetch area
- Enough expelled volumes capable of charging platform prospects

Exploration: Transformation Ratio (Type II B Kerogen)

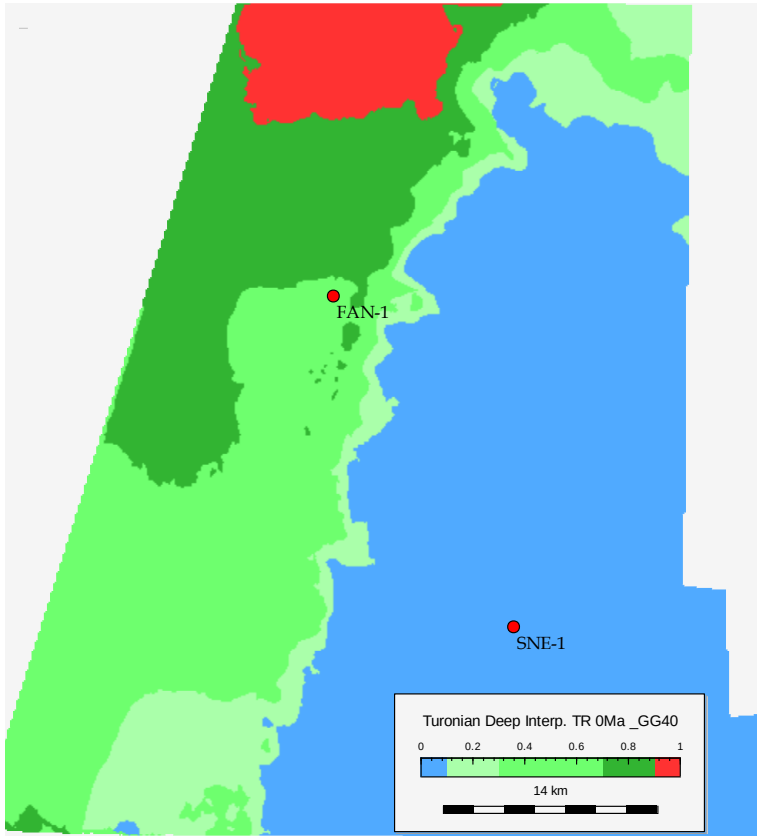
Turonian/Albian Source Rock Maturity – Tertiary H Pulse

Sensitivity : Shallow vs Deep Pick Interpretation

Shallow Pick



Deep Pick (Turonian or Albian SR)

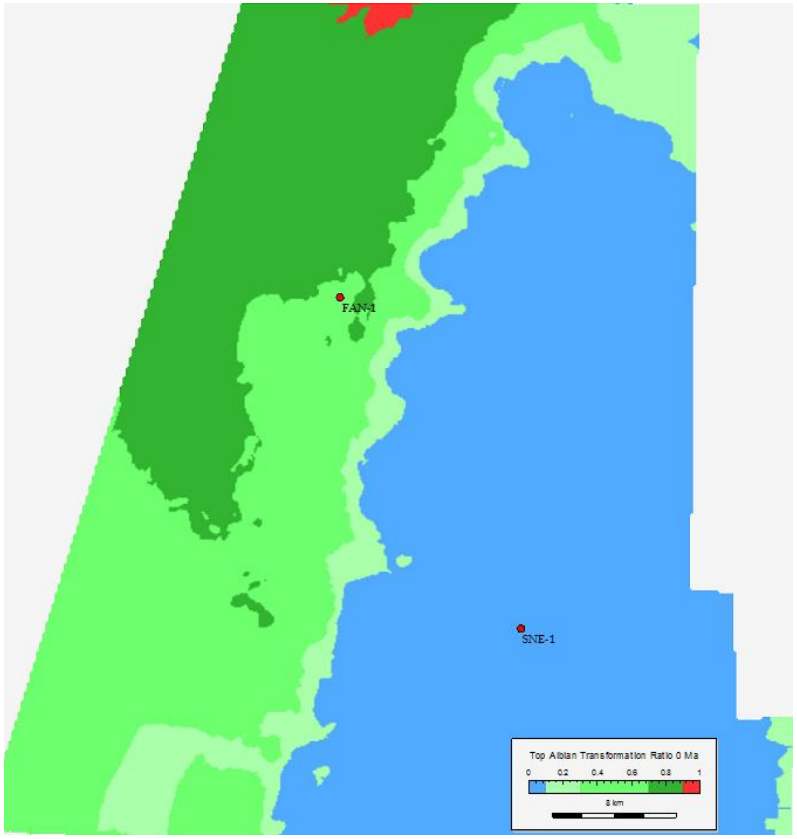


Exploration: Transformation Ratio (Type II B Kerogen)

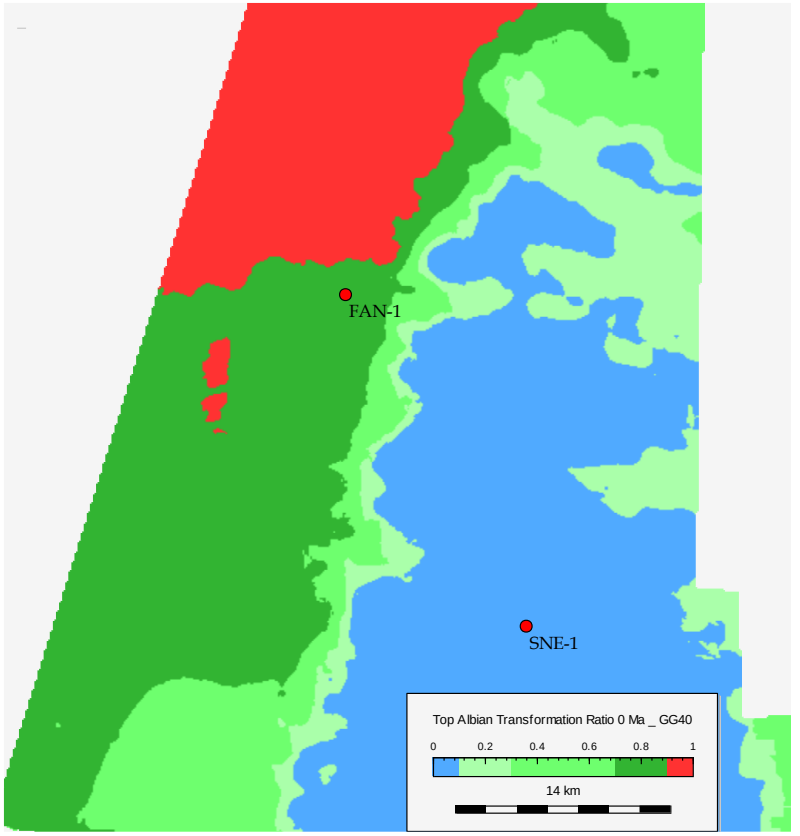
Albian/Older Source Rock Maturity

Sensitivity : GG 32°C/km vs Tertiary HP

GG 32°C/km



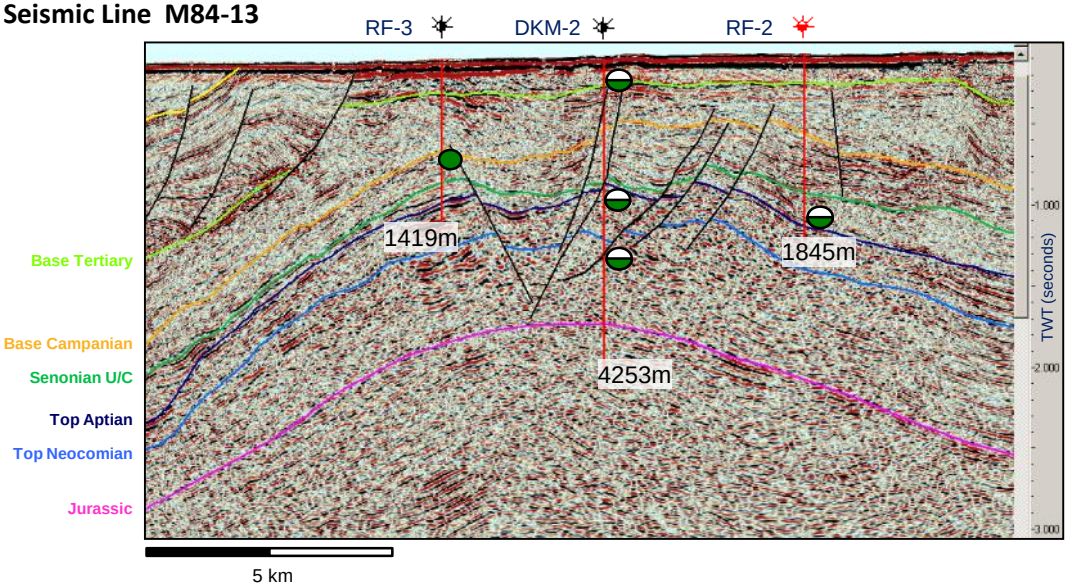
Tertiary HP

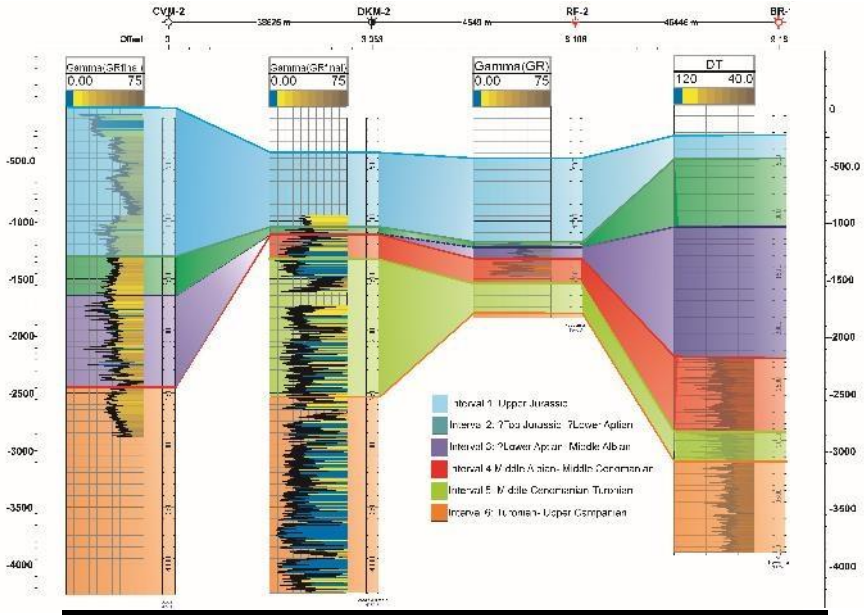


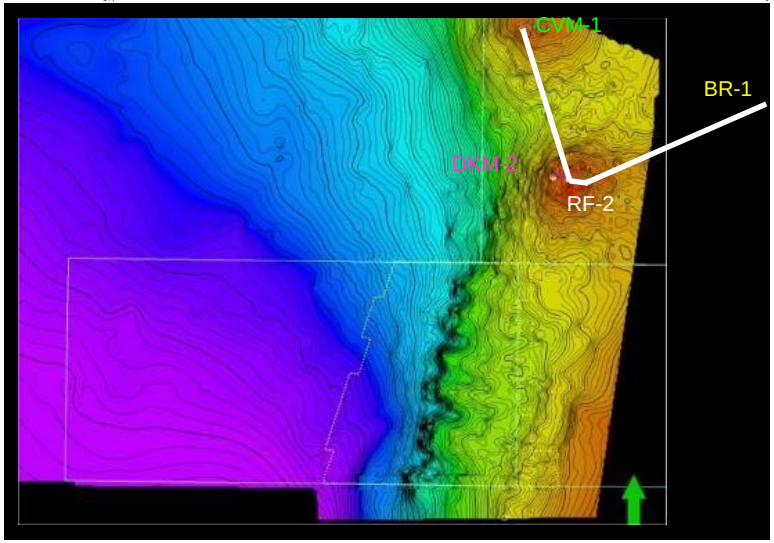
Charge/ Migration from the Basin to the Platform

Rufisque Dome and Gadiaga / Dam Niado: Oil in Senonian Sands

Seismic Line M84-13





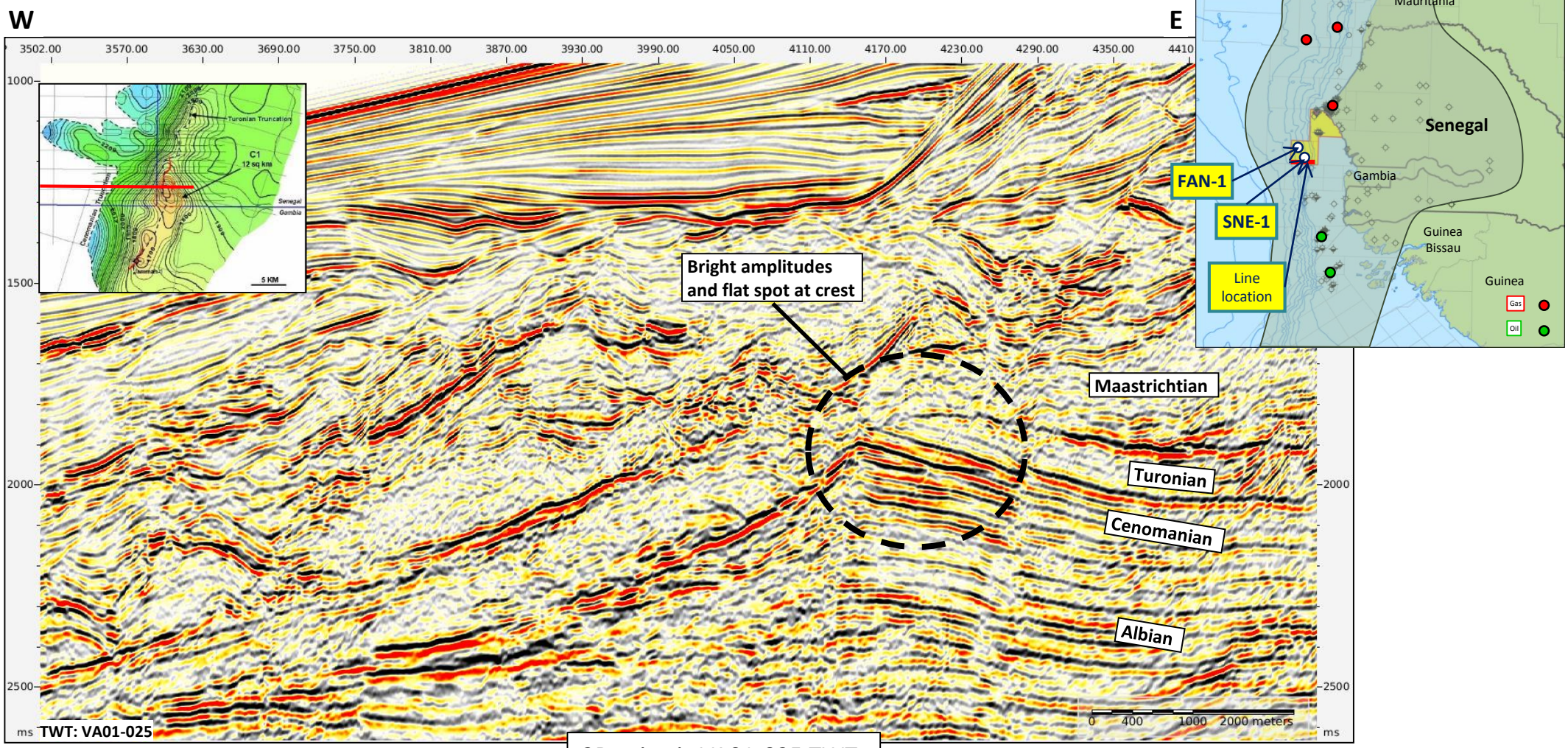


- The Rufisque dome is a igneous upwelling creating a localised high within the License area. The crest of the structure has been tested by RF-1 (not shown) and DKM-2 and two flank wells have also been drilled (RF-2 and RF-3). All three wells have encountered hydrocarbon shows
- RF-3 tested for oil in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

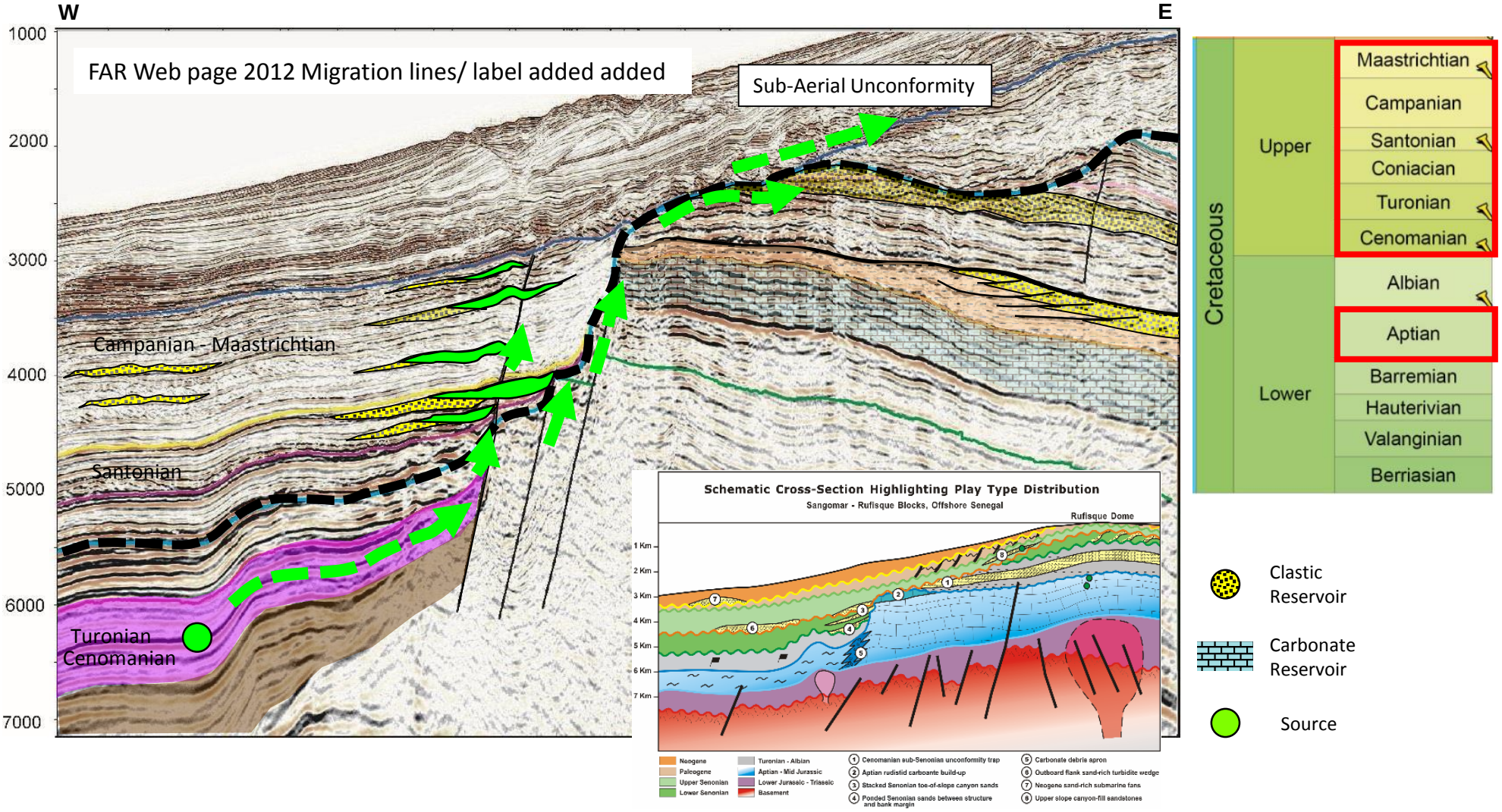
- Flat spot approximately 10km south of SNE-1



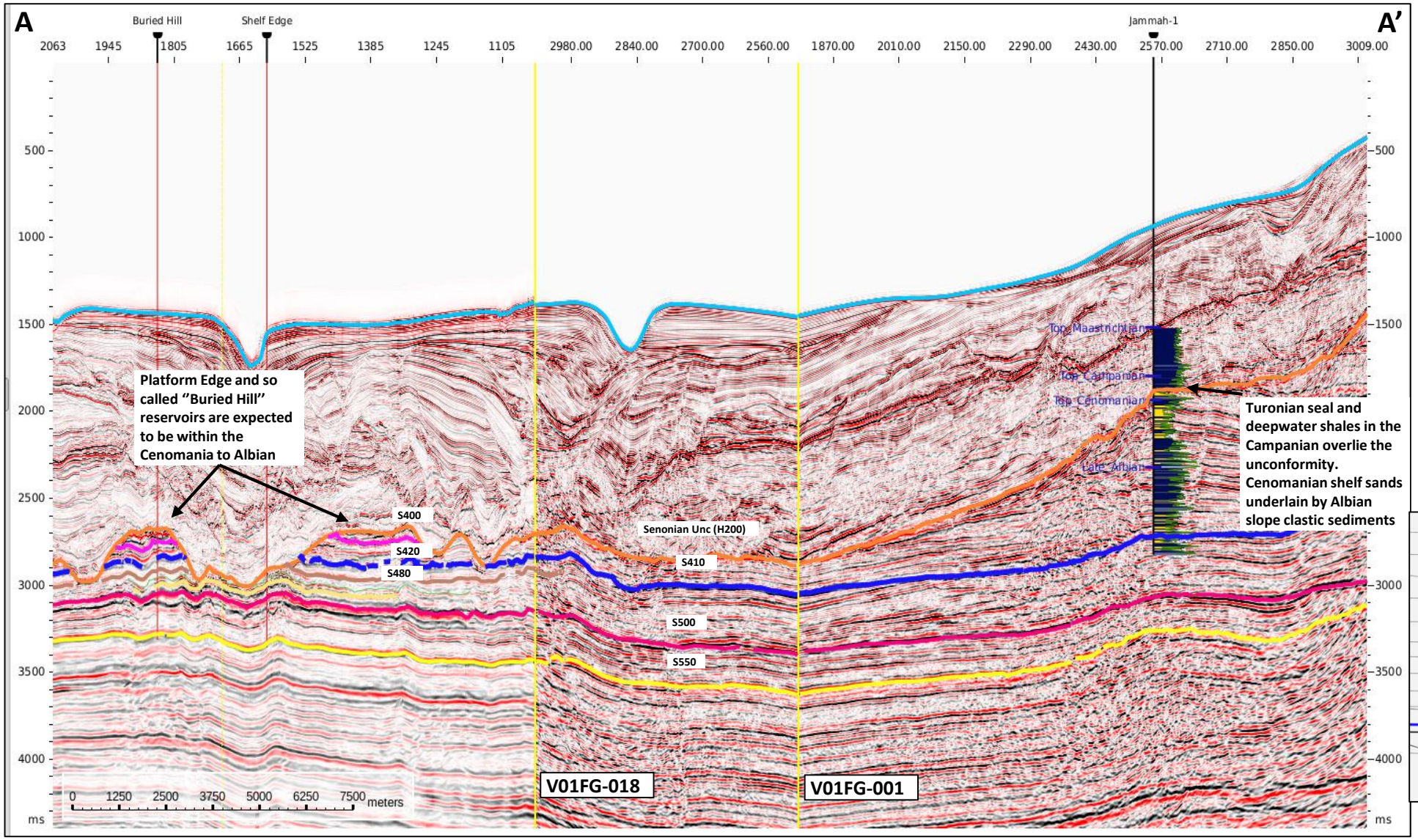
2D seismic VA01-025 TWT

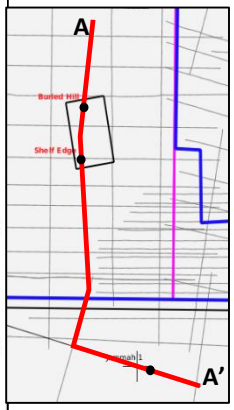
Pre-Drill Interpretation (Hunt/ FAR)

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

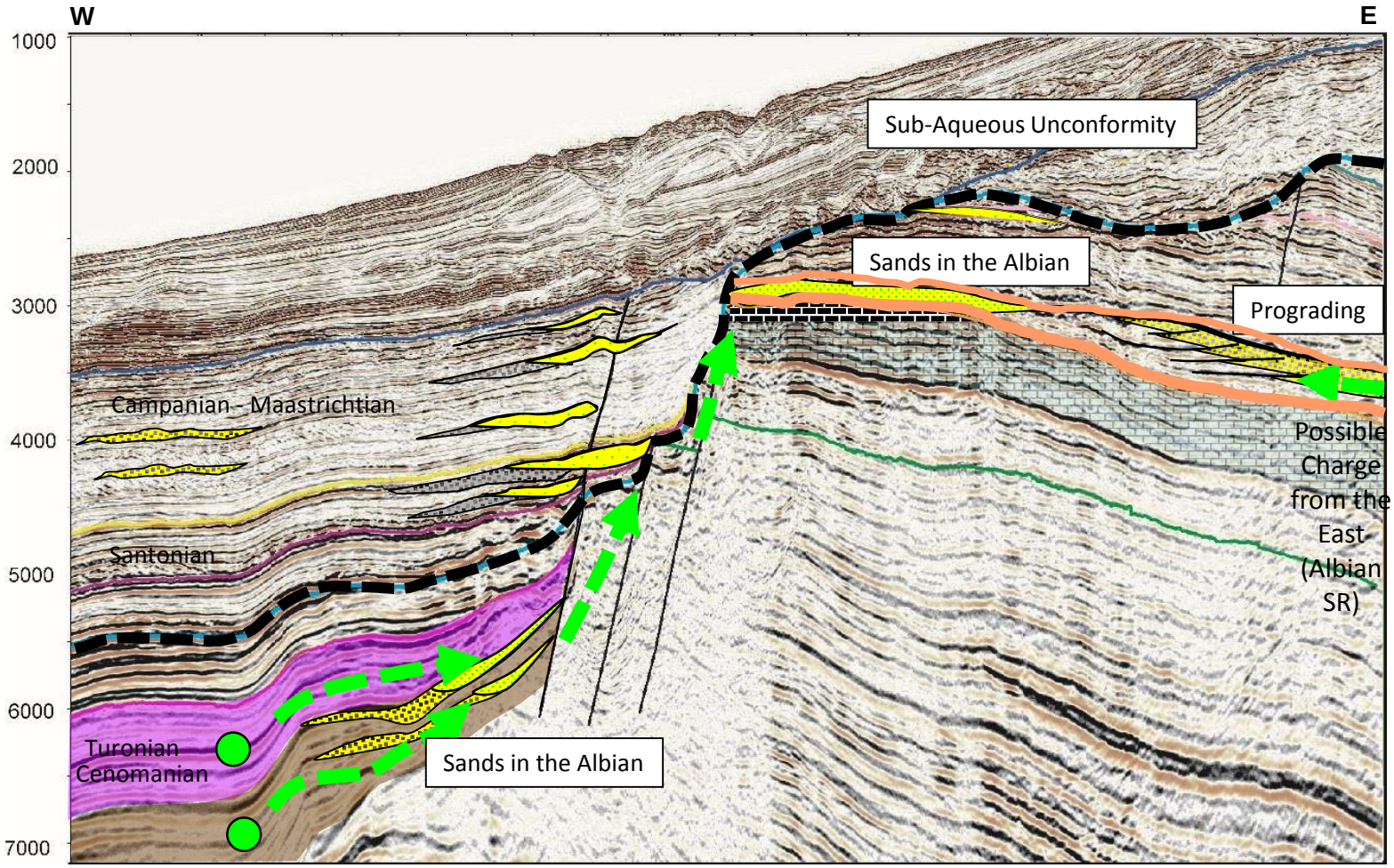


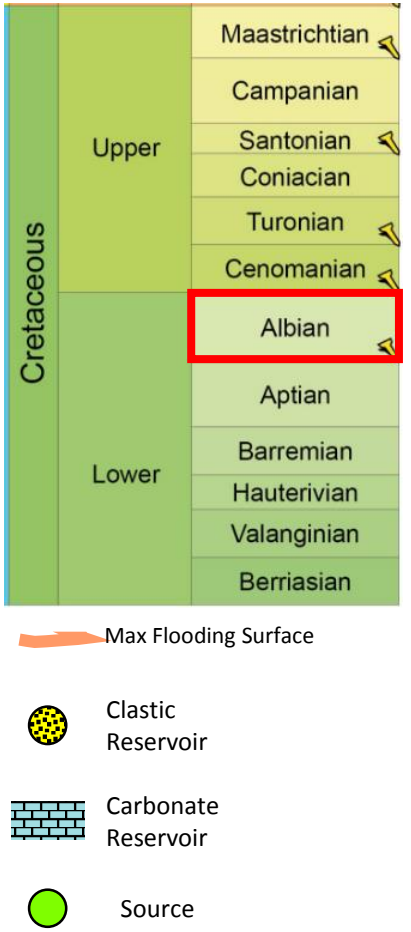
Jammah-1 Synthetic Well Tie





Two New Play Concepts – Pre-Drill Interpretation

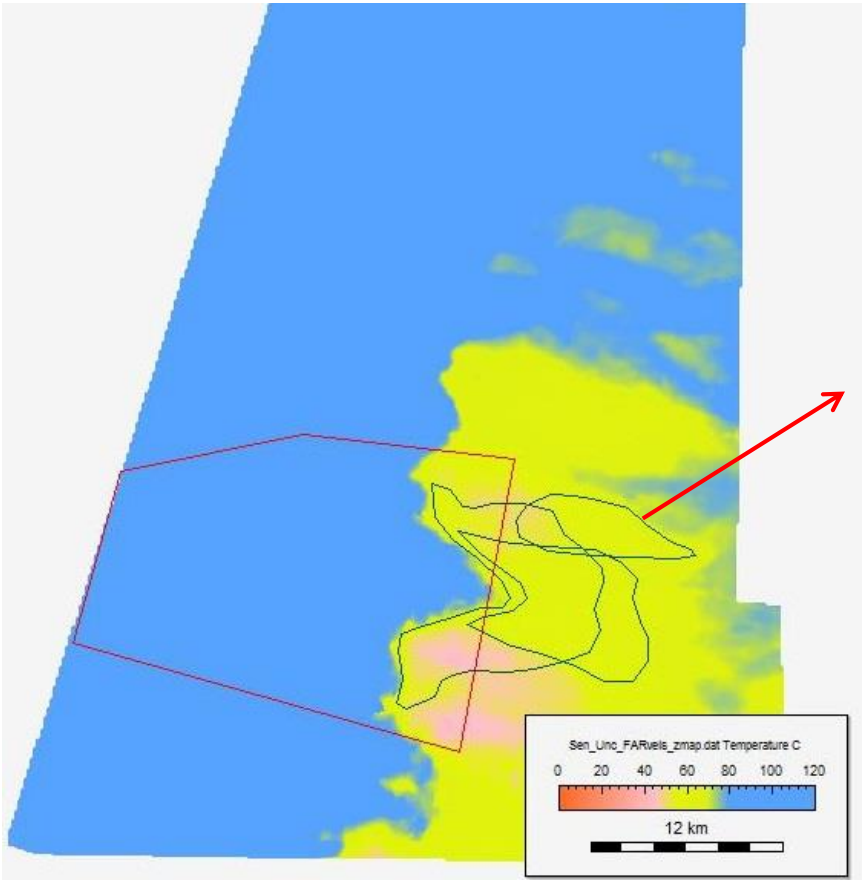


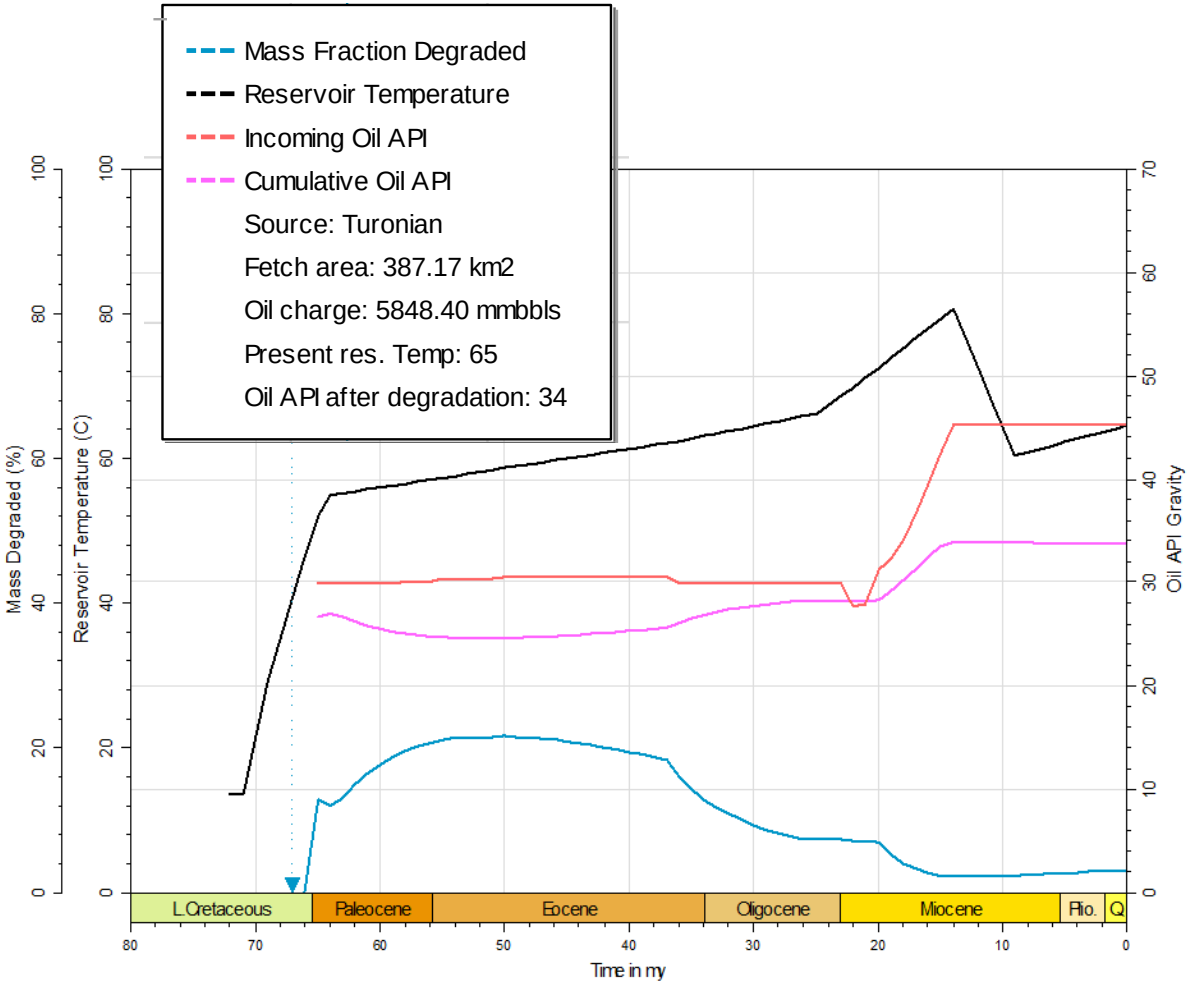


The Major Senonian unconformity is Sub Aqueous

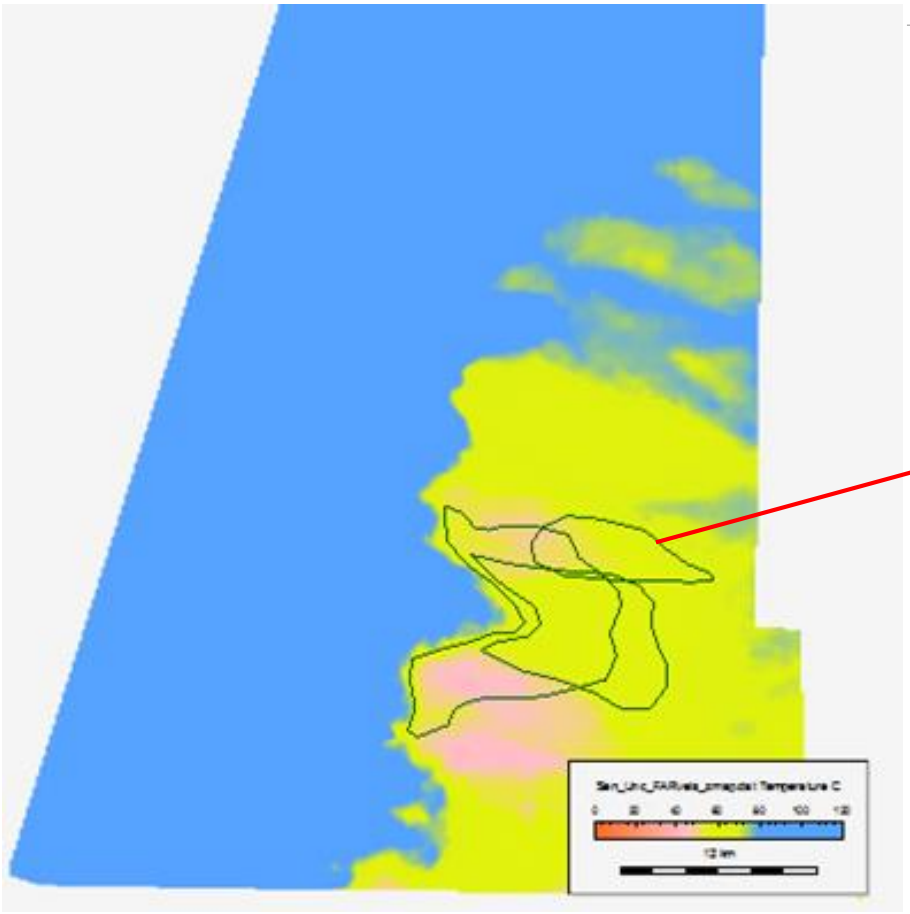
Albian sands must have reached the basin

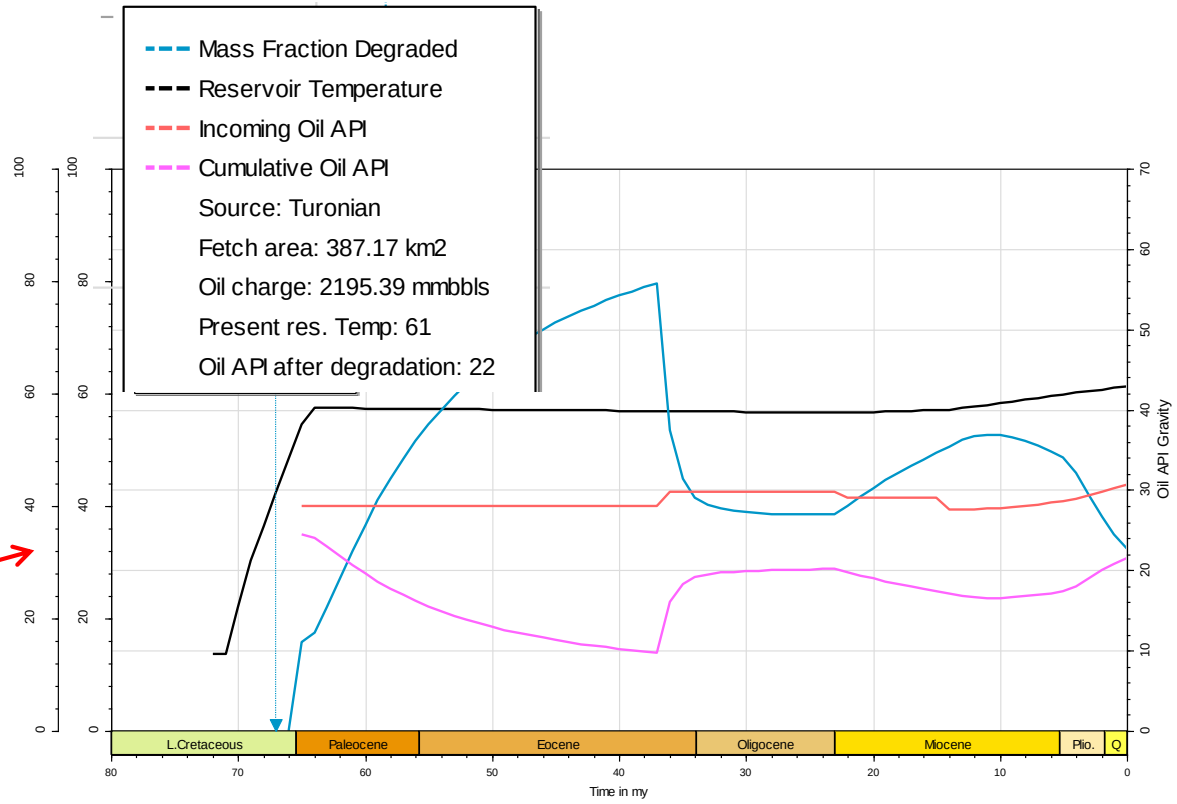
Risk of Biodegradation – Buried Hill (Tertiary HP)





Risk of Biodegradation – Buried Hill (Tertiary HP)

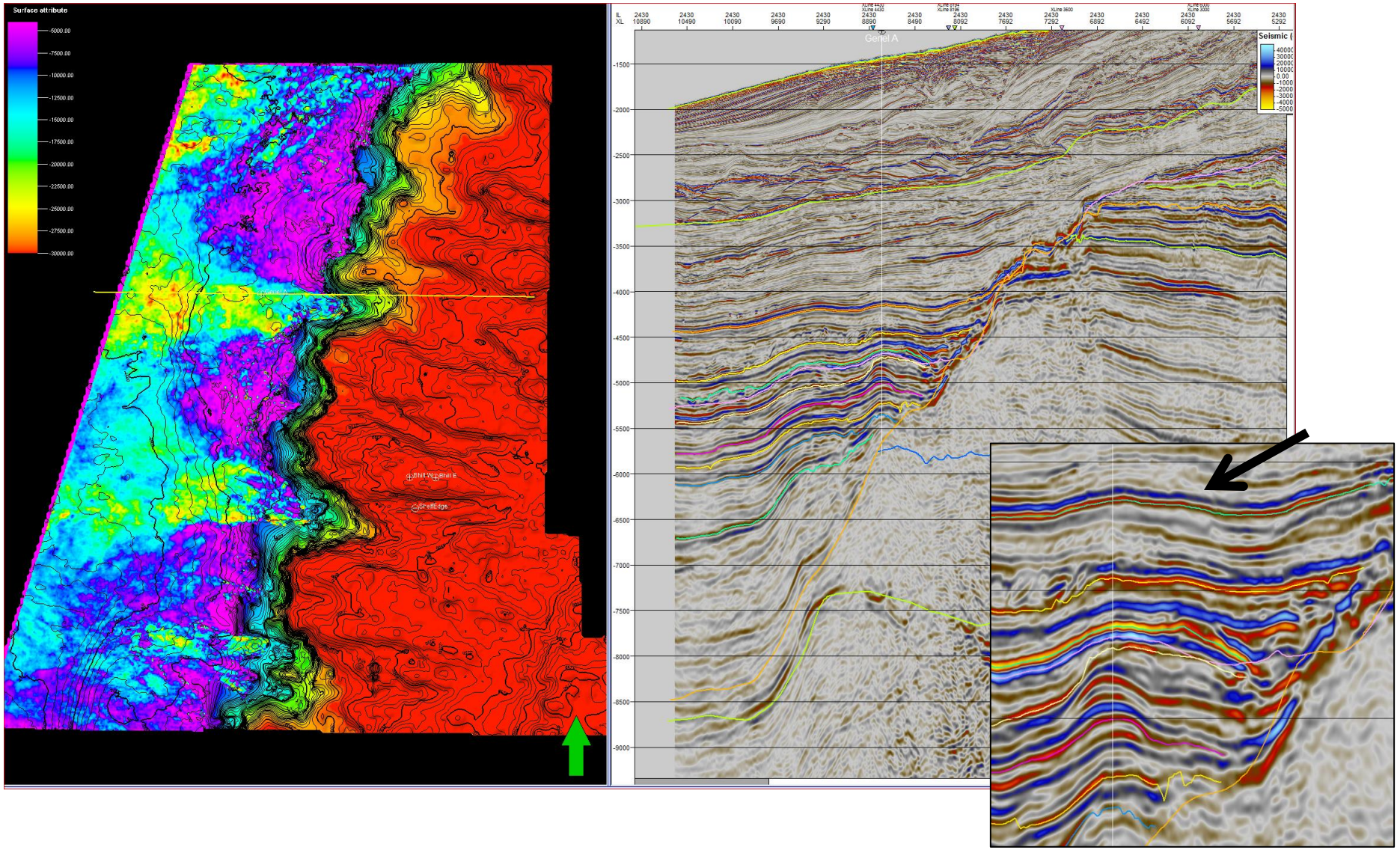




Casamance Wells SF4 and CM9 tested 34 and 32 API Oil from 700 m and 220 m, respectively.

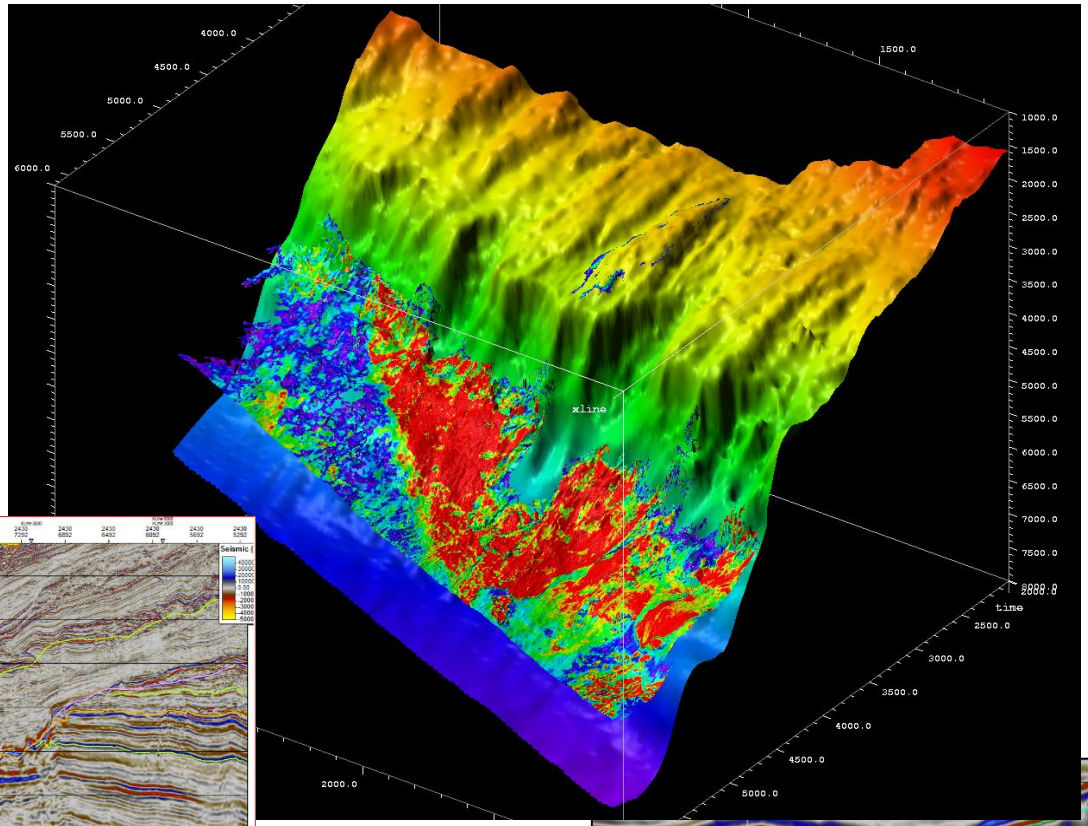
CM9 temp. of 42 C (uncorr.) @ 500 m

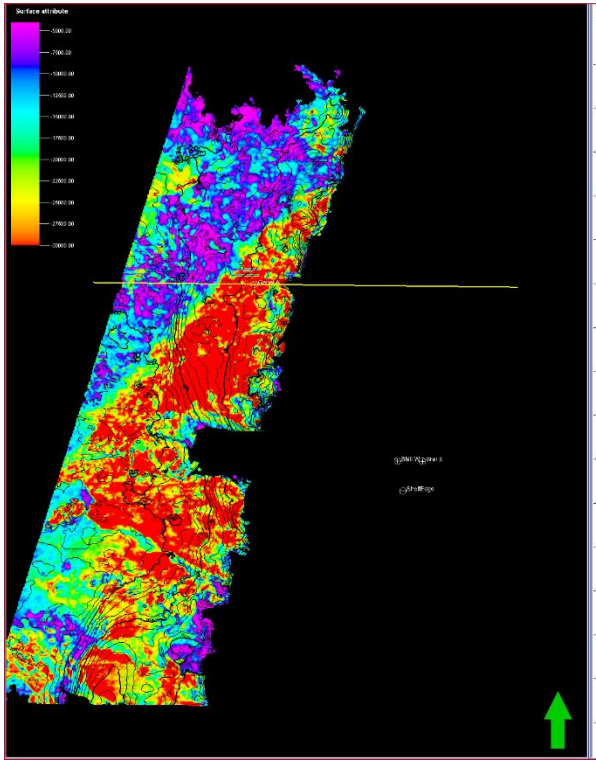
North Fan location: N Fan Thin Hard Sands, Limited Column Height

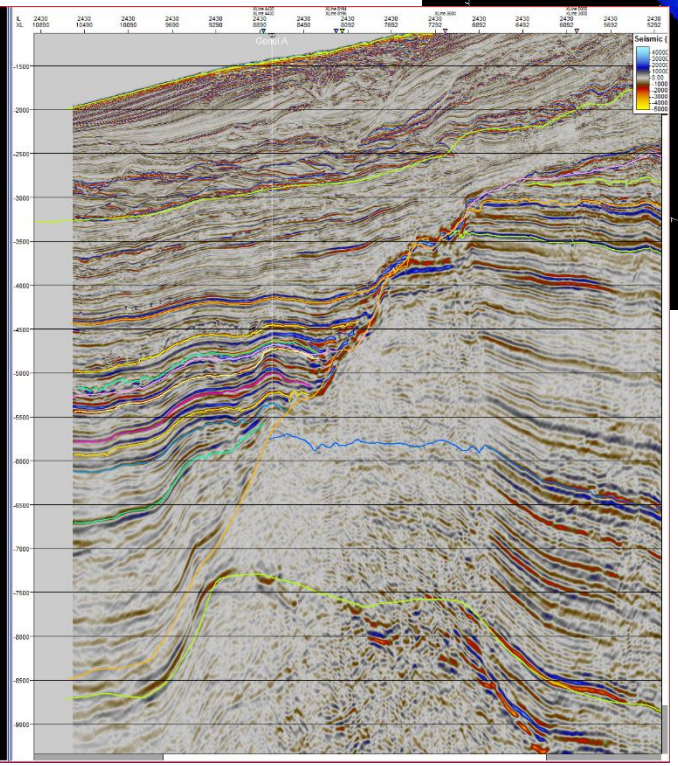


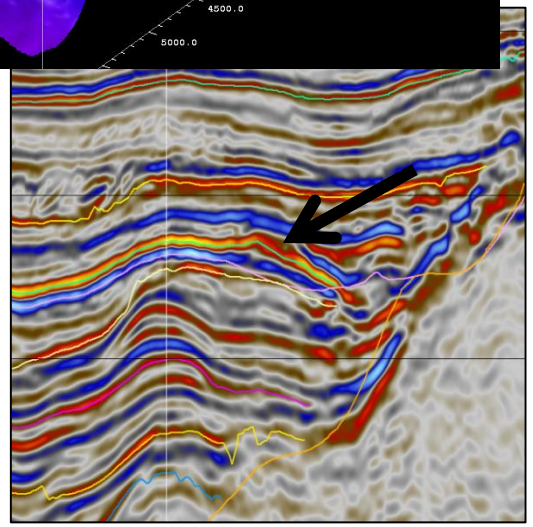
H180 Level: Class IV AvO

- 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



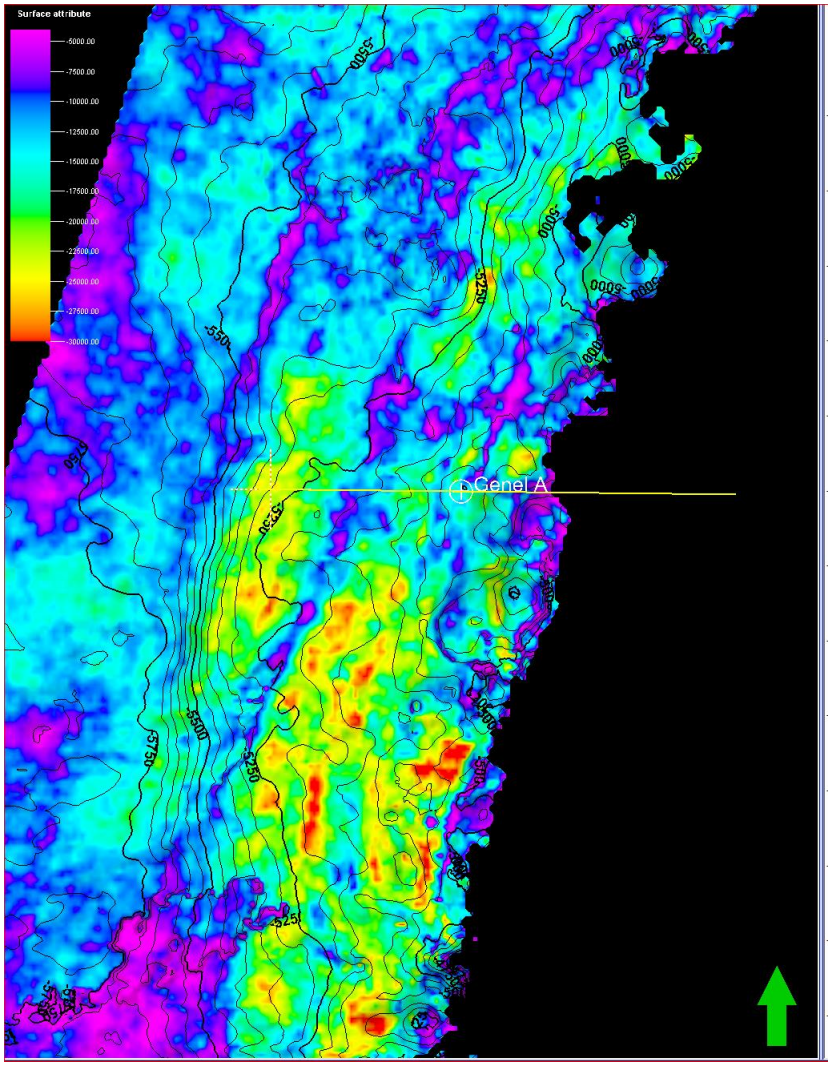


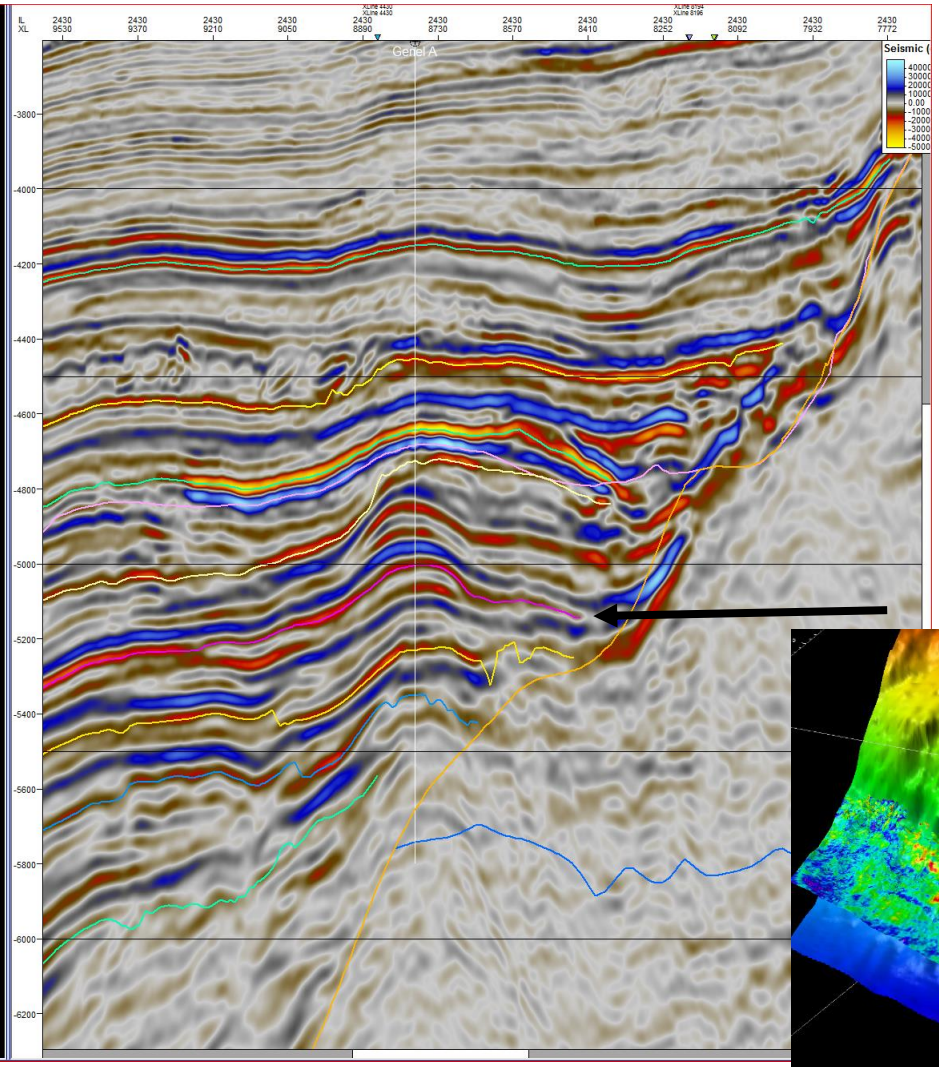




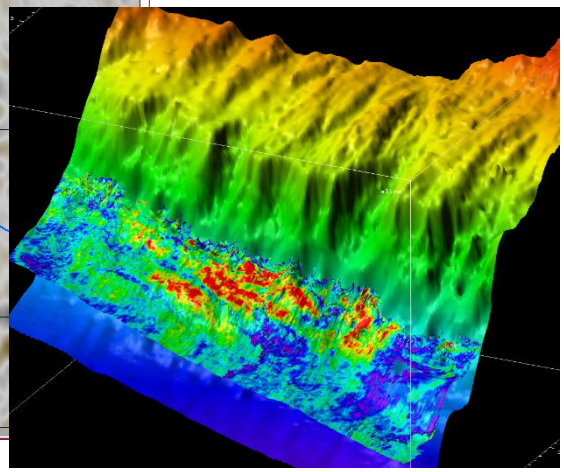
Basin: Albian Sediments

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





Conoco happy with pinchout geometry

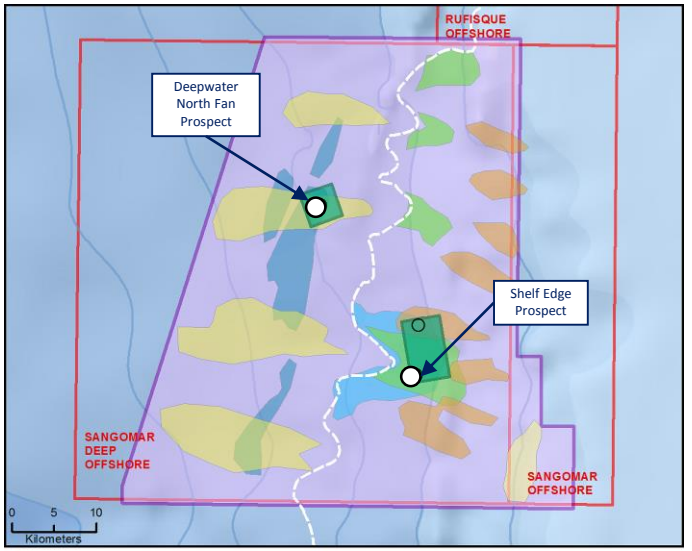


Discovery and Appraisal

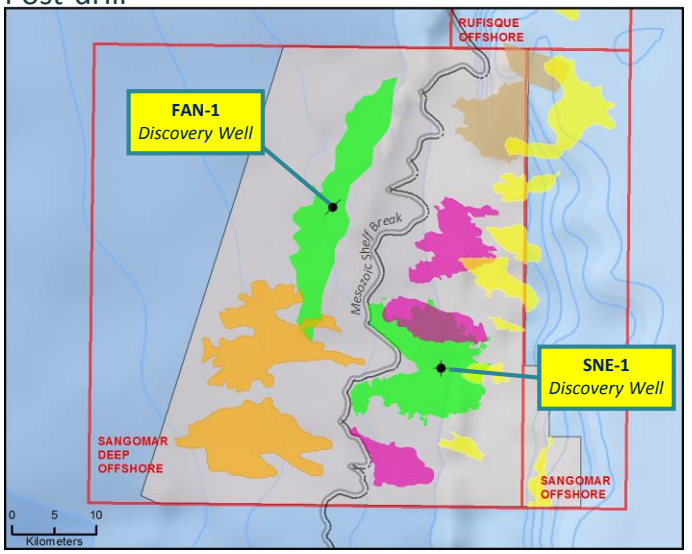
The Opportunity – Two Discoveries

- 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

Pre-drill



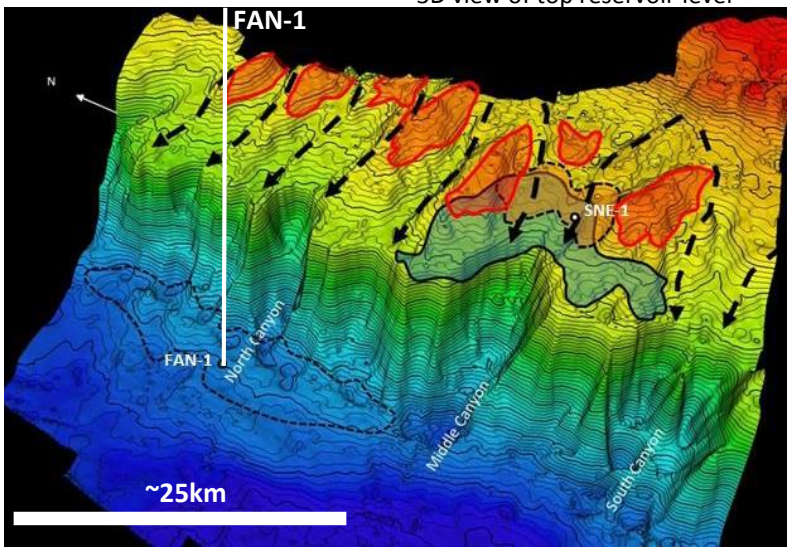
Post-drill



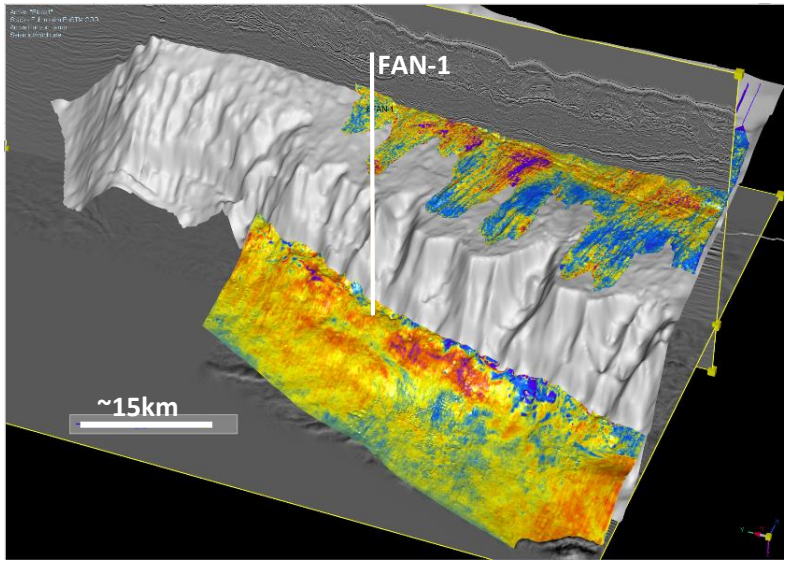
FAN-1 Discovery

- 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

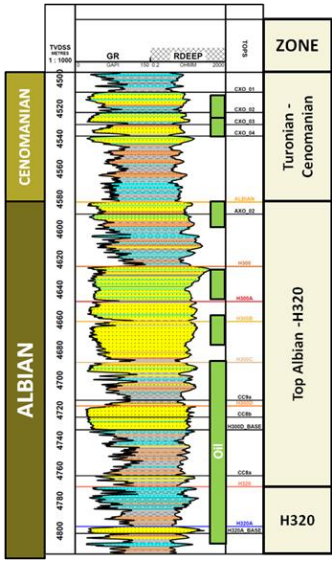
3D view of top reservoir level



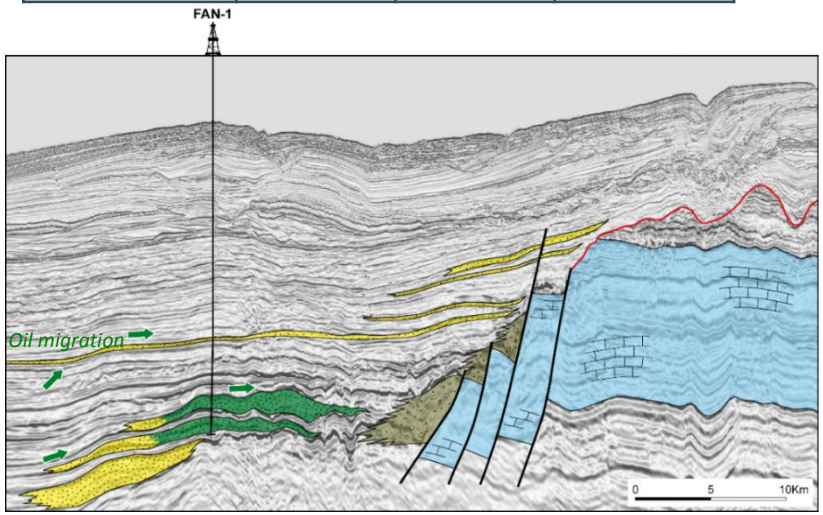
3D view of top reservoir level with superimposed seismic amplitude



FAN-1 reservoir level

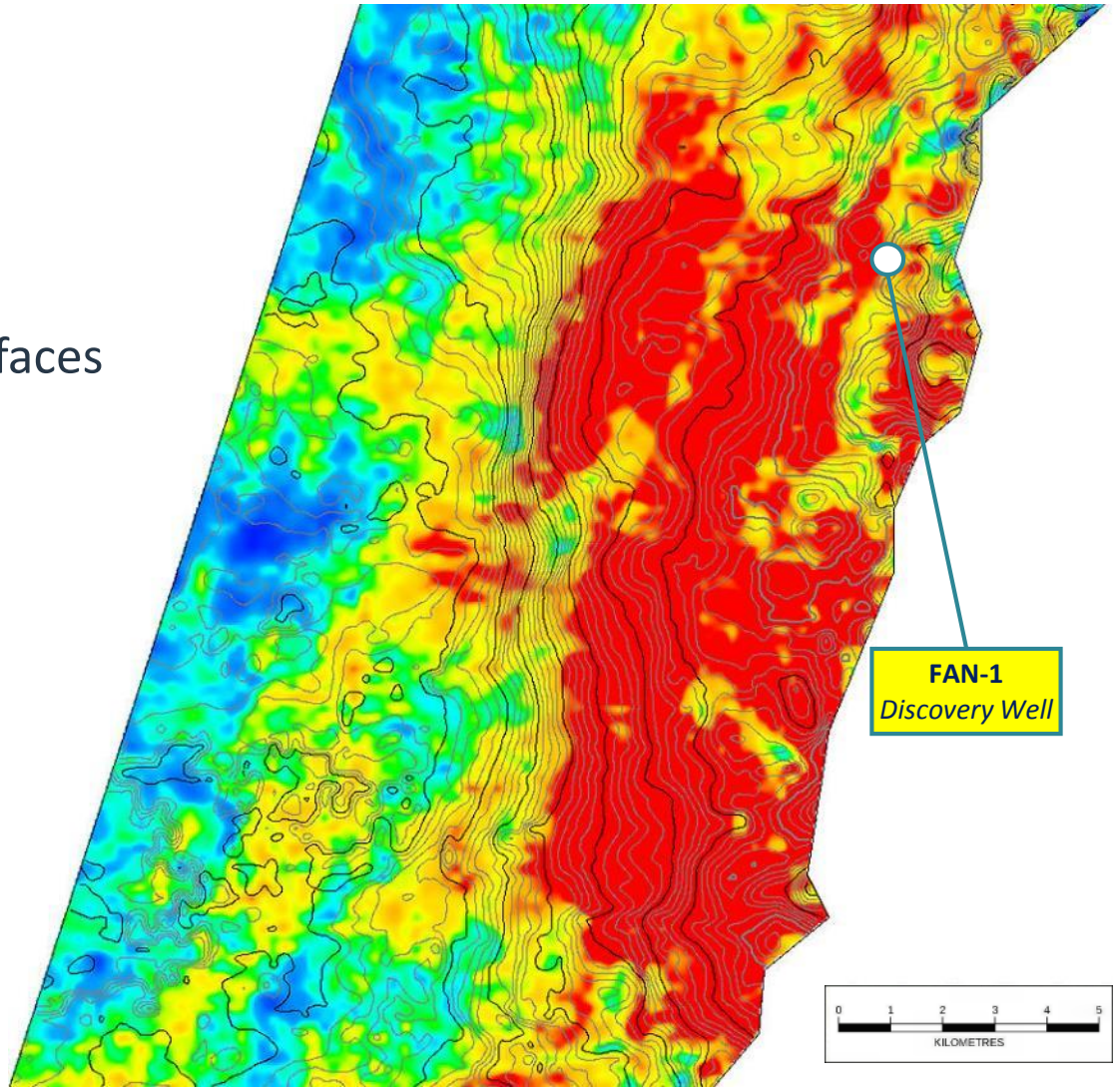


Gross Oil (STOIIP) in place	P90	P50	P10
	250 mmbbls	950 mmbbls	2,500 mmbbls



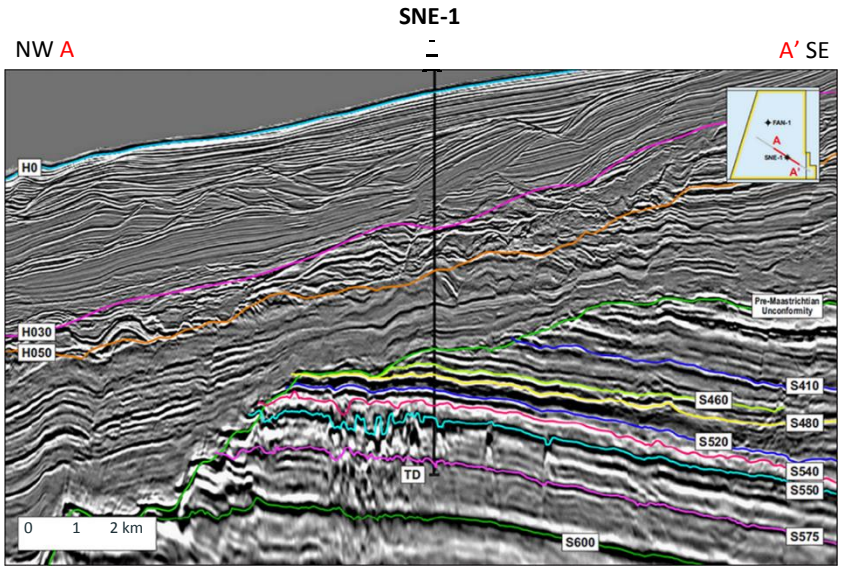
FAN-1 Forward Programme

- 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

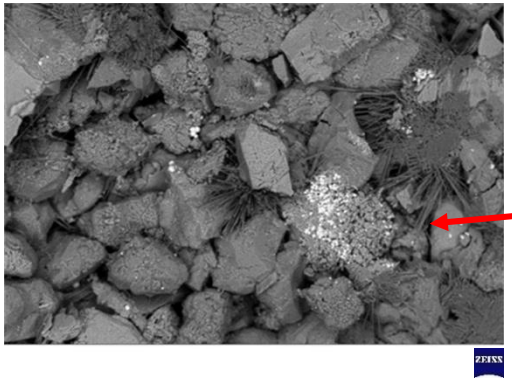


SNE-1: Review, Initial Resources and Updates

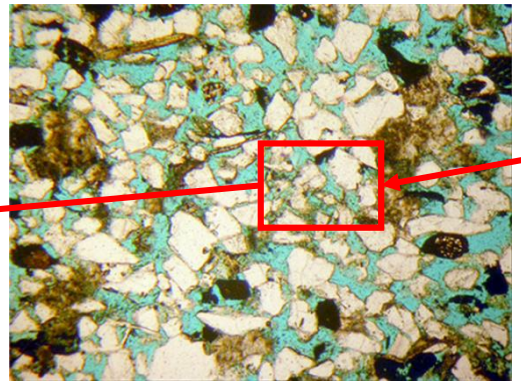
- Dual target well – Albian clastics and Aptian carbonates
- Oil and gas discovered – 2C resource 330mmbbls
- Reservoirs – Upper and Lower units
- 32° API Oil Quality – Log, rock and fluid samples
- Clear Gas-Oil and Oil-Water Contacts
- Depth conversion indicates larger structure
- Drilling time and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



Scanning Electron Microscope Image

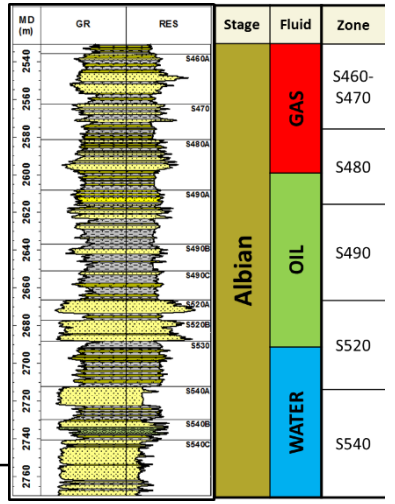


Microscope Thin Section



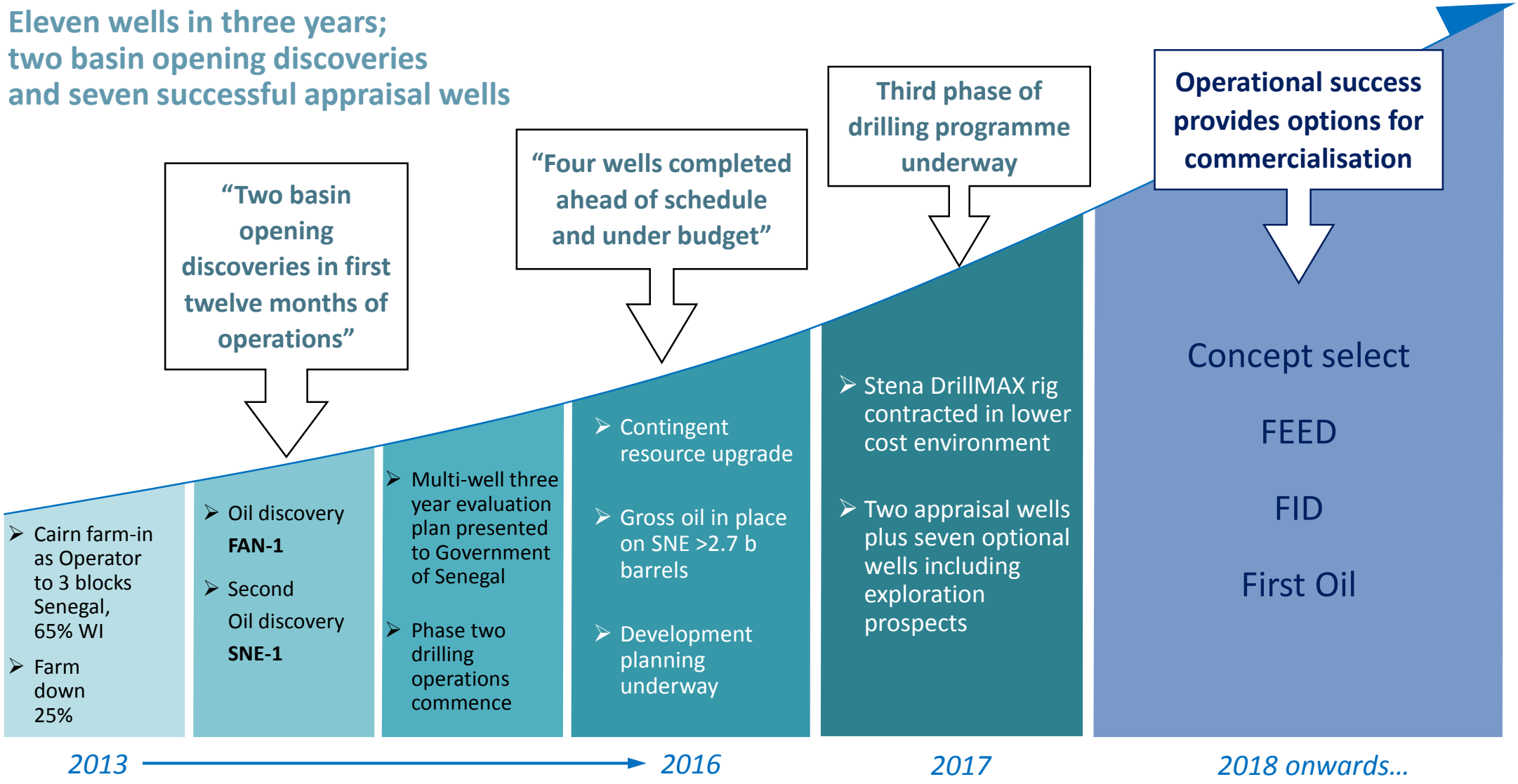
Sidewall Core Sample

SNE-1 reservoir level



Value Creation in Senegal

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



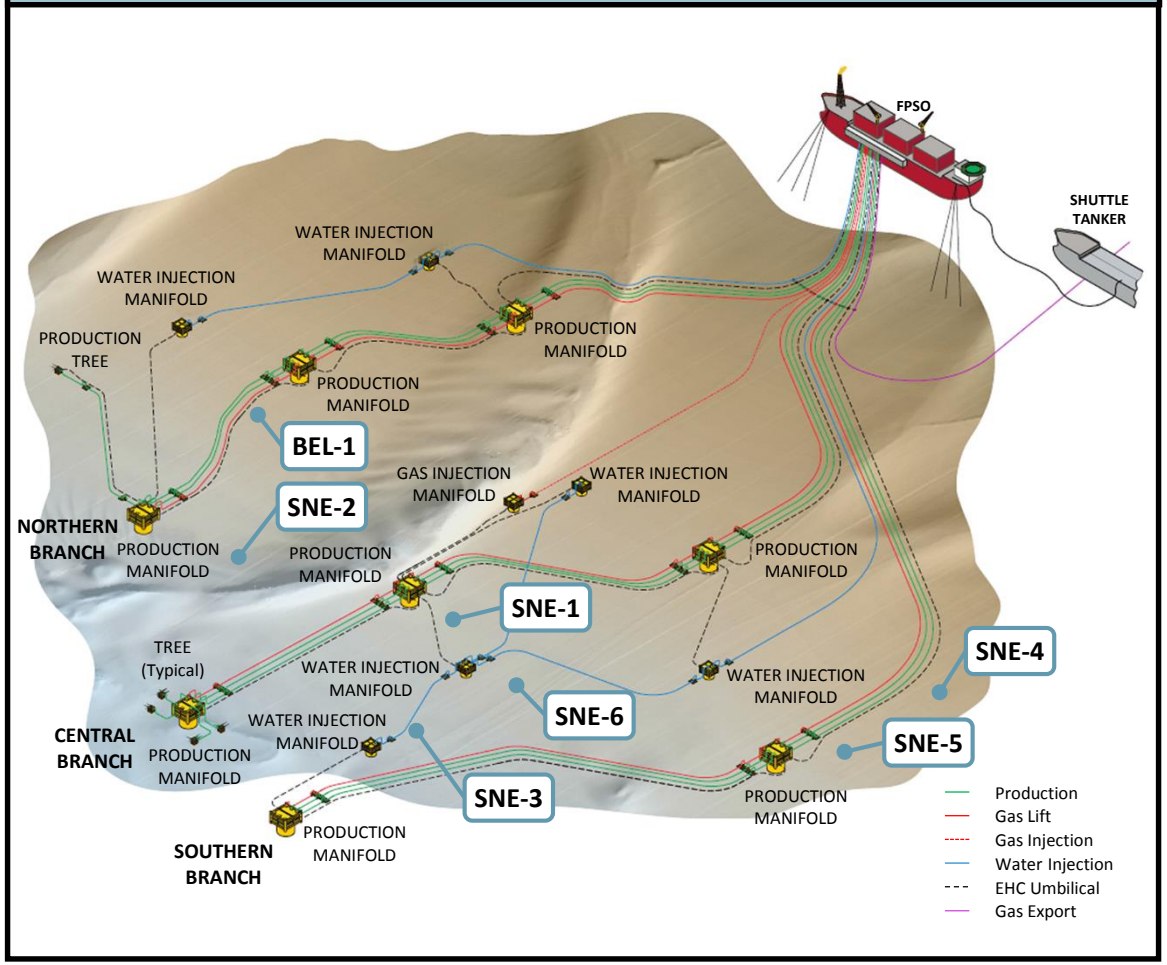
SNE Development

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 Full Field Development Schematic



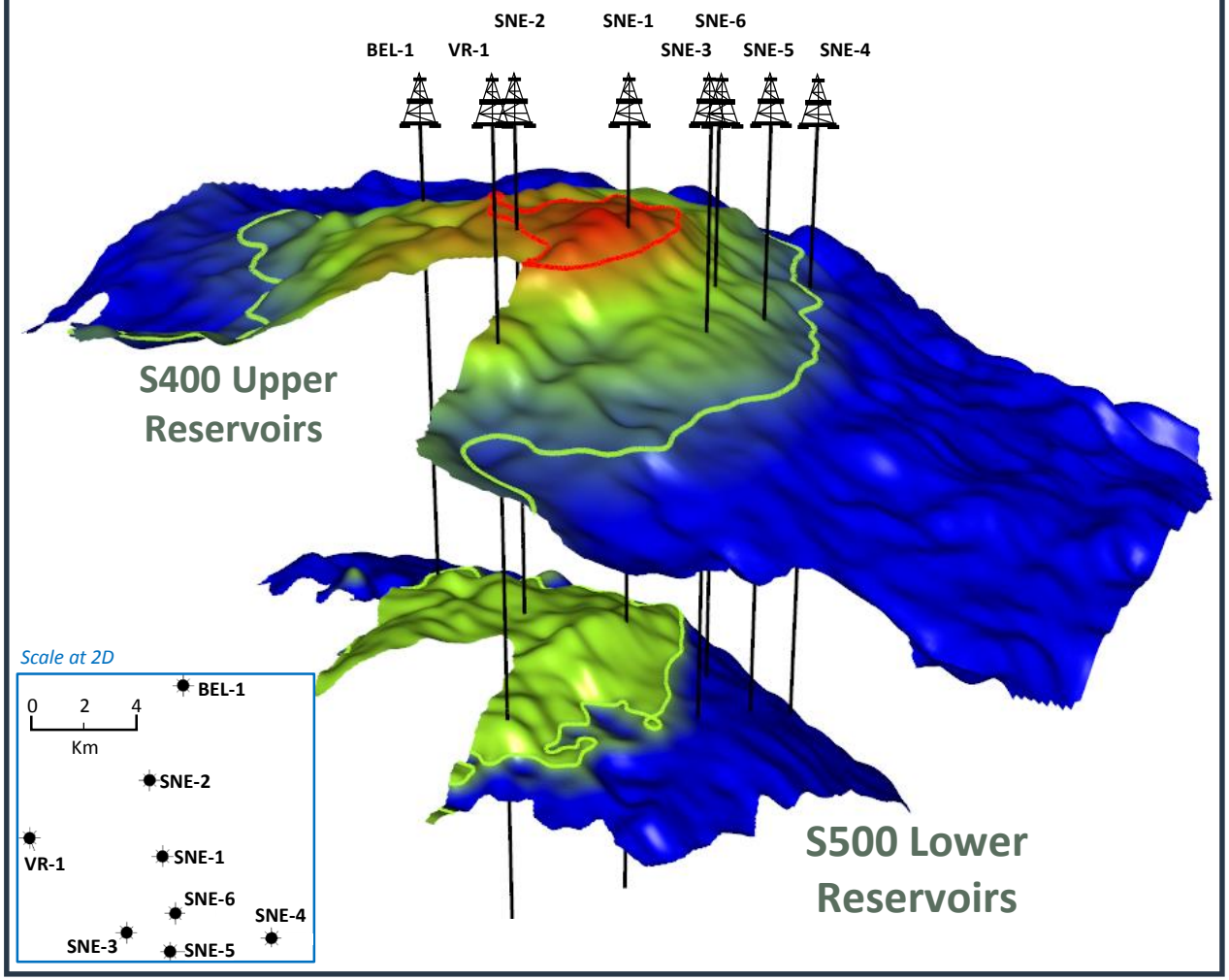
SNE Development

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



SNE Development

Reservoir and Oil Quality

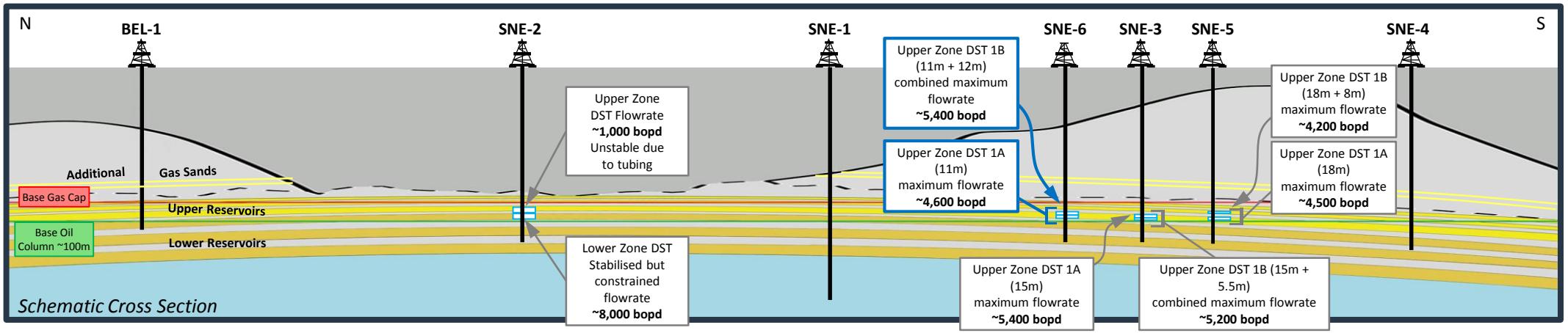
- Good correlation of gross reservoir packages
- Connectivity in S400 upper reservoirs demonstrated by interference test in a clearly preferred orientation
- DST in S500 lower reservoir confirms expected good inter-well connectivity
- Water flood planned for both sets of reservoir
- Crude quality suitable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

Updated Gross Contingent Resources*

Contingent Resource (mmbbls)			
May 2016	1C **274**	2C **473**	3C **906**

Contingent Resource (mmbbls)			
August 2017	1C **346**	2C **563**	3C **998**

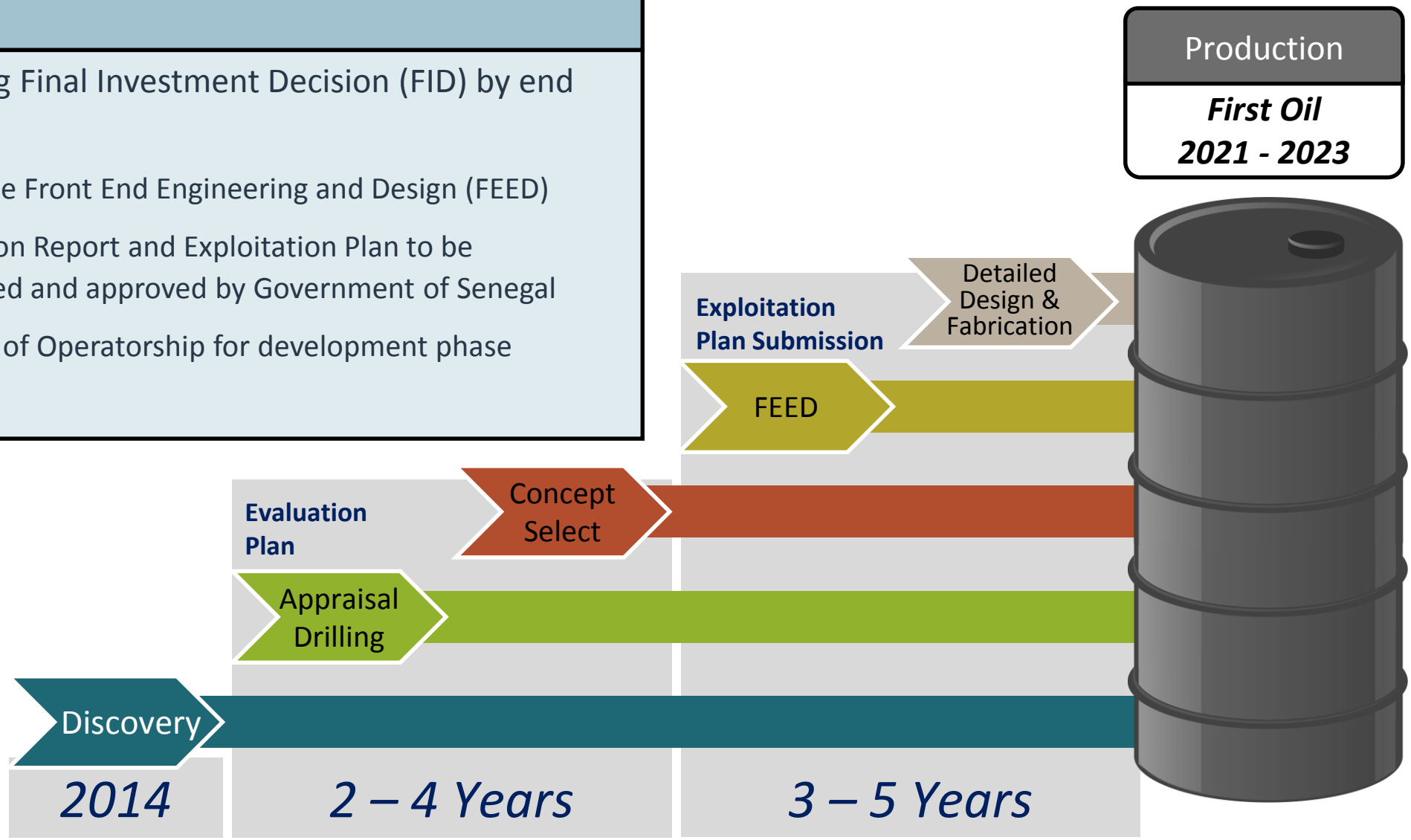
* Resource estimates by ERC-Equipoise



SNE Development

Timeline

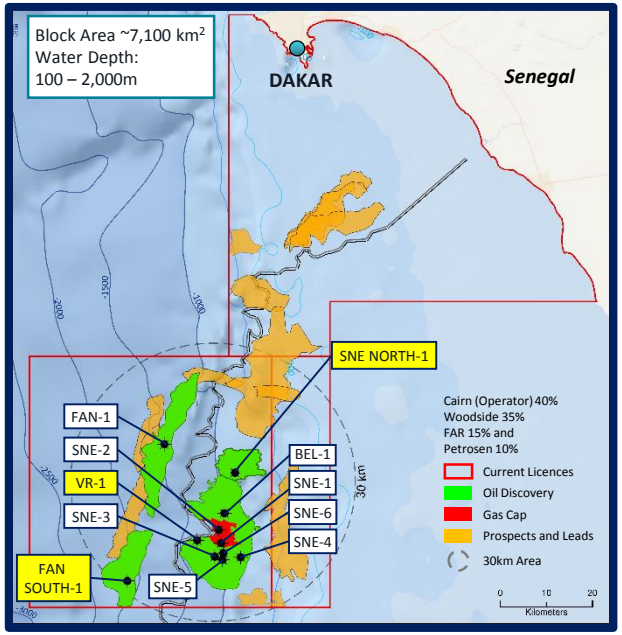
- Targeting Final Investment Decision (FID) by end 2018:
  - Complete Front End Engineering and Design (FEED)
  - Evaluation Report and Exploitation Plan to be submitted and approved by Government of Senegal
  - Transfer of Operatorship for development phase



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



Stena DrillMAX

Remaining Exploration Potential Around SNE

Sangomar Deep Offshore Block

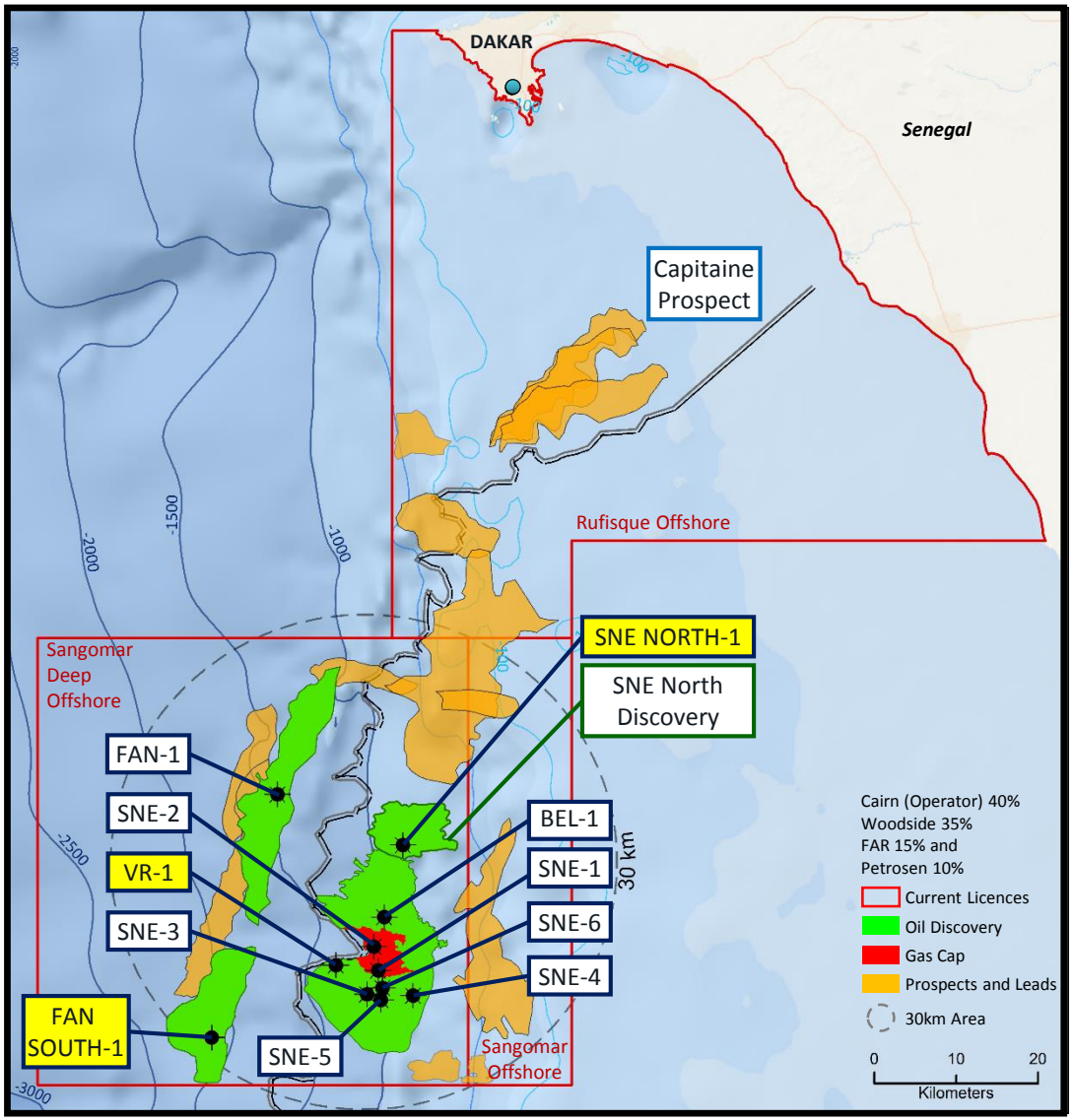
- SNE NORTH-1 40 – 80 mmboe (mean – P10) Gross Mean Contingent Resource
- Additional potential 65 – 130 mmboe (mean – P10) Gross Mean Prospective Resource
  - Requires stratigraphic trap element to north
  - Target for future appraisal

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

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)

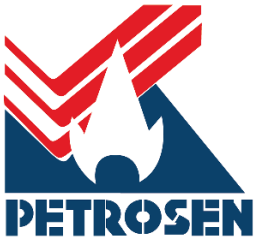
Acknowledgements

The RSSD JV partners

Petrosen, Woodside Energy, FAR Ltd and Cairn Energy

are gratefully acknowledged for permission

to present this paper



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