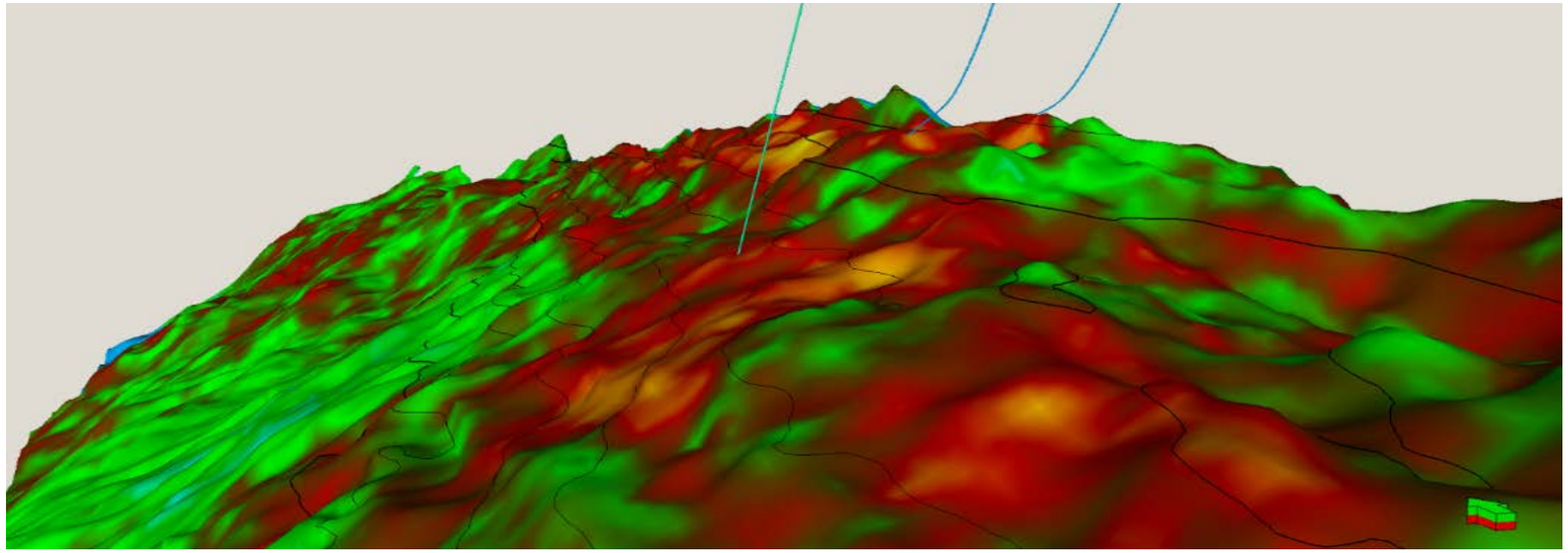
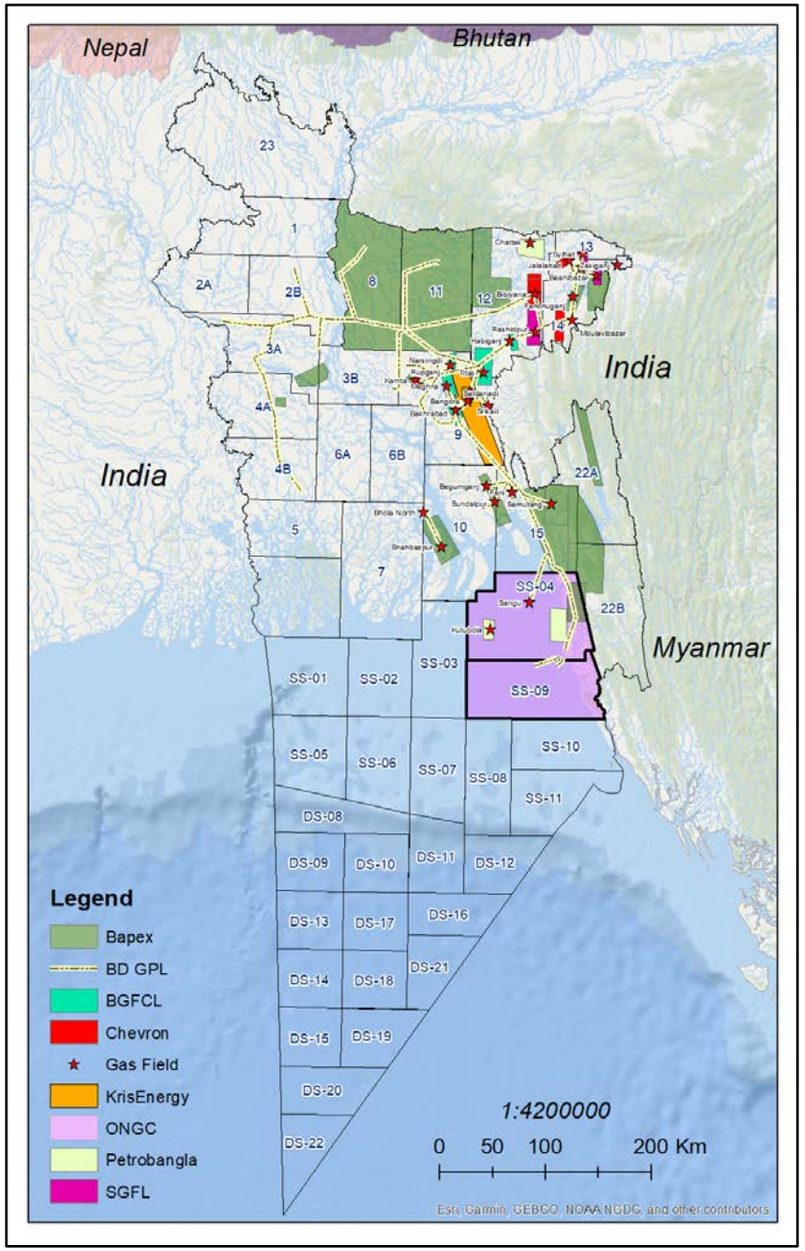


Hydrocarbon Potential of a Basin Floor Fan Complex – A Comparative Study of the Bengal and Rakhine Basins

March 9th, 2023

Contents

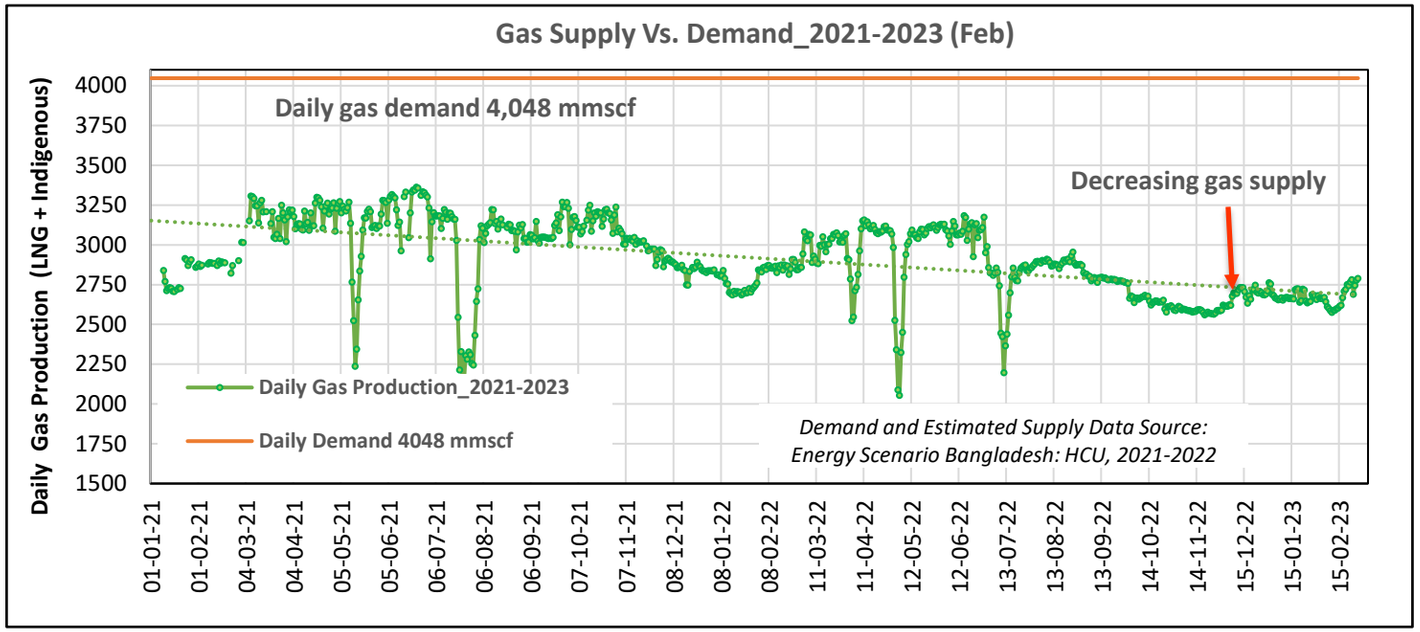
Bangladesh – Location Map

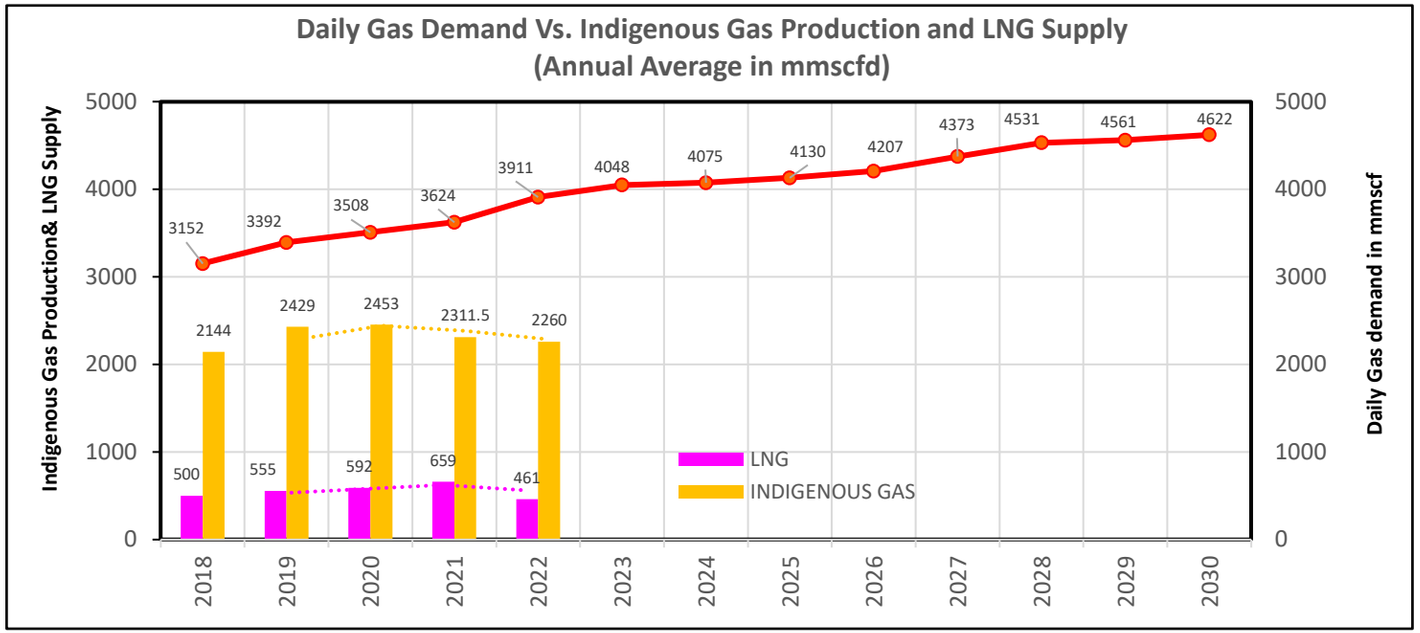


Type of Ex. Blocks	Total No. of Blocks	IOC's, NOC's & Blocks	Activities
Onshore Blocks	**22**	Chevron: Blocks:12, 13 & 14 (Fenced Acreages)	Produces (1330 mmscfd) more than half of the total indigenous gas (2250 mmscfd) production from three gas fields, i.e., Bibiyana (highest producing), Moulavi Bazar and Jalalabad.
		KrisEnergy: Block-9 (Fenced Acreage)	Produces 50 mmscfd from Bangora Gas Field. Recently relinquished SS-11, PSC contract for SS-11 expired on March, 2021.
		BAPEX: Blocks 8 & 11), BGFCL & SGFL (3 NOCs)	Three NOC's produces 900 mmscfd from fifteen gas fields. Fields located along eastern margin.
Shallow Offshore (SS)	**11**	ONGC Videsh Ltd. Blocks: SS-04 & SS-09	In exploration phase. Drilled Kanchan -1 in Sept. 2021 at SS-04. Committed to drill 2 more wells. PB has extended the tenure of OVL's PSC for 2 more years, i.e., 2025.
Deep Offshore (DS)	**15**	None	None

- Study area: South-eastern shallow offshore block. Area 4475 km^2, mostly <200m water depth.
- Data: Seismic: 2D: 3146 lkm, 3D: 305km^2, Offset wells: BODC & BINA (vintage logs)
- Gas pipe line network: 2200 Km, existing gas pipelines are about 120 km away.

Bangladesh – Gas Supply and Demand

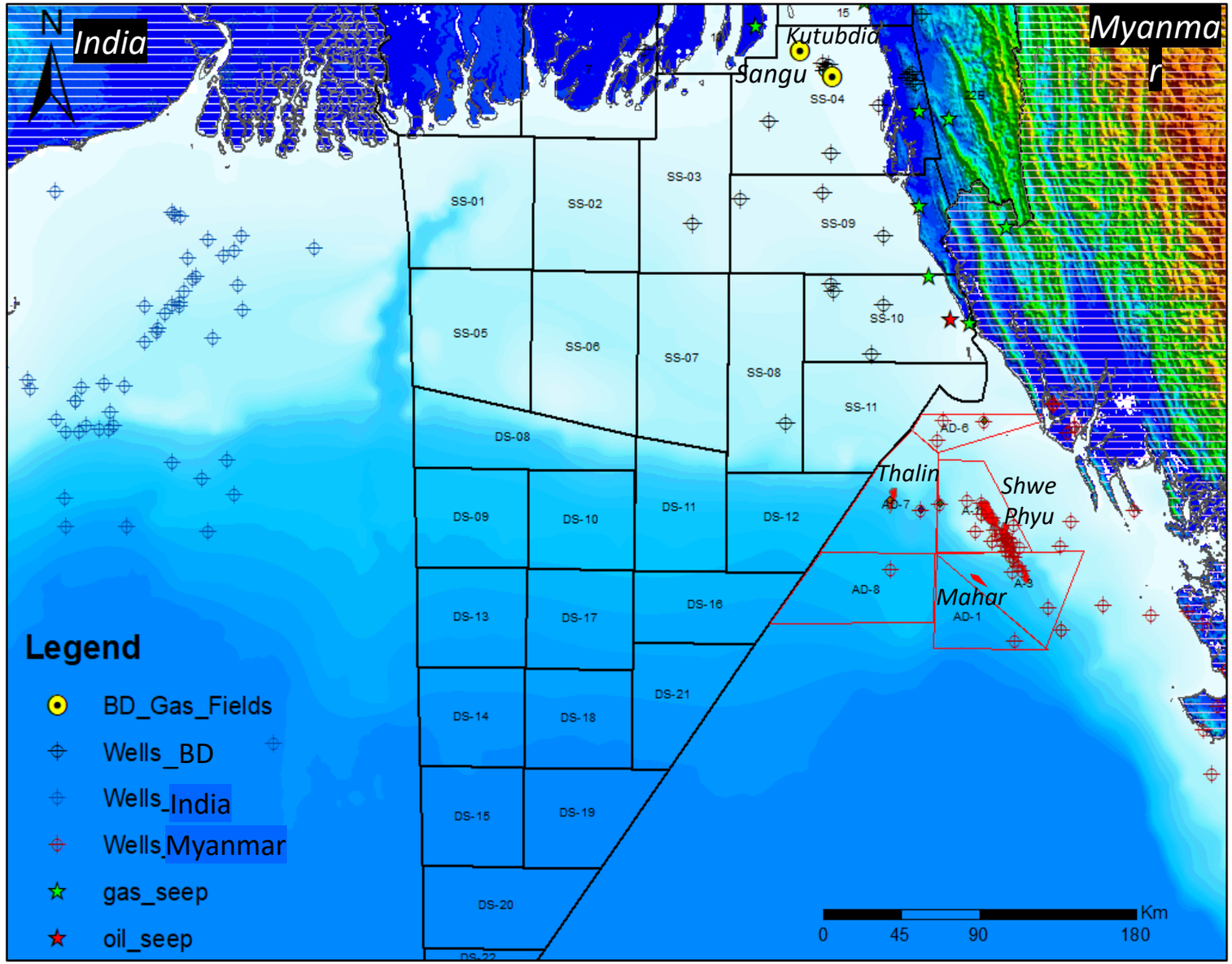




- Total gas production of the country is about 2800 mmscfd (Indigenous 2250 + LNG 550). Demand ~4048 mmscfd. Daily gas shortage 1250 mmscf.
- Rapid economic growth and gas dependent power/industry sector resulted into huge gas demand. The gas demand may reach 4622 mmscfd by 2030.
- Gas production has been significantly decreased since 2018, due to depletion of indigenous gas fields and govt. decision to limit the import of expensive LNG from spot-market since June 2022.
- Although the country has been considered petroliferous, both onshore and offshore drilling activities has been sloth for last two decades.
- Apart from maritime boundary conflicts with Myanmar and India, issues related to a lack of governmental policies, prioritizing bureaucrats over the technocrats, failure in attracting IOCs, over dependency on import-based energy, and an obscure energy strategy are the primary reasons that restricted exploration activities.

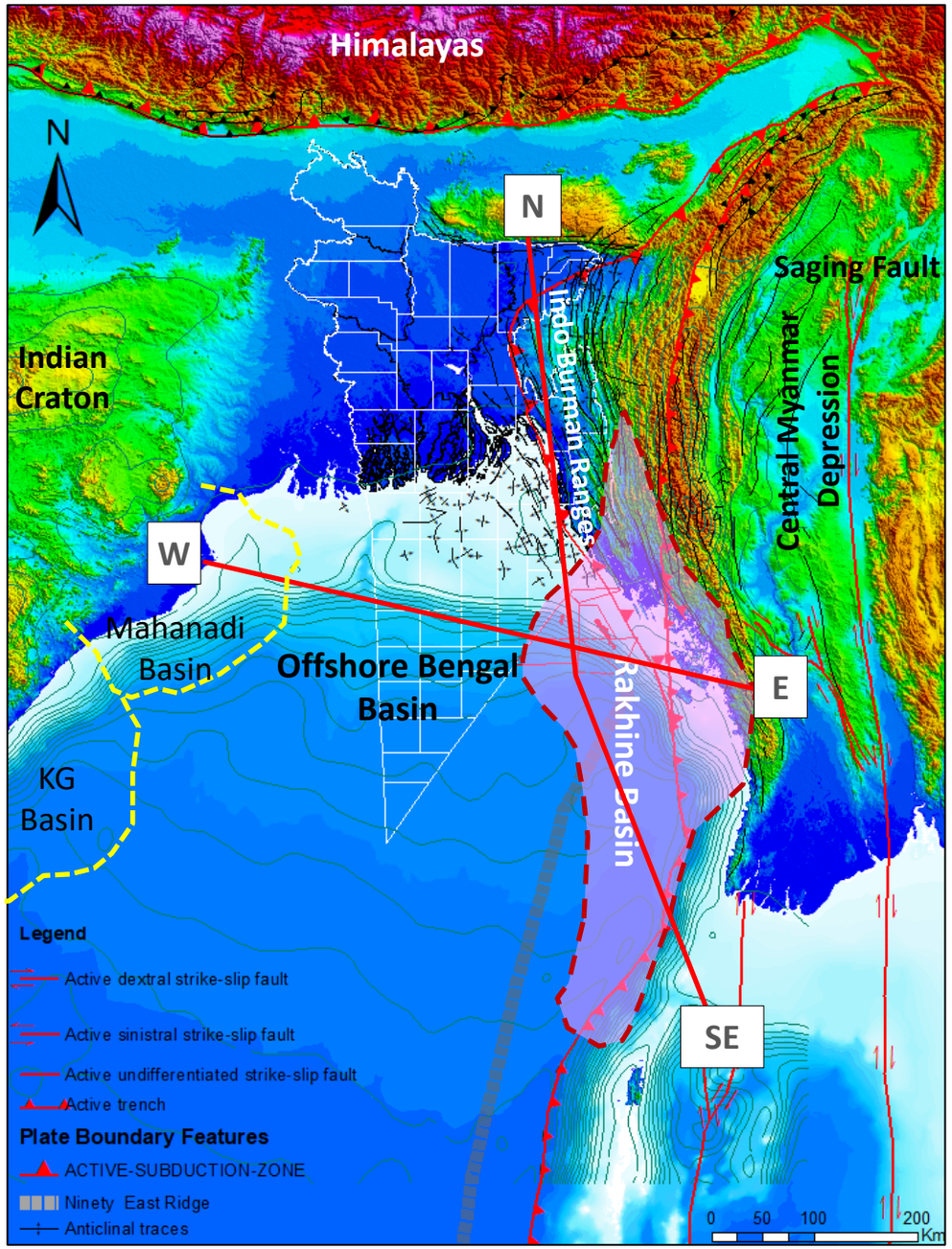
Exploration History – Offshore Bengal and Rakhine Basins

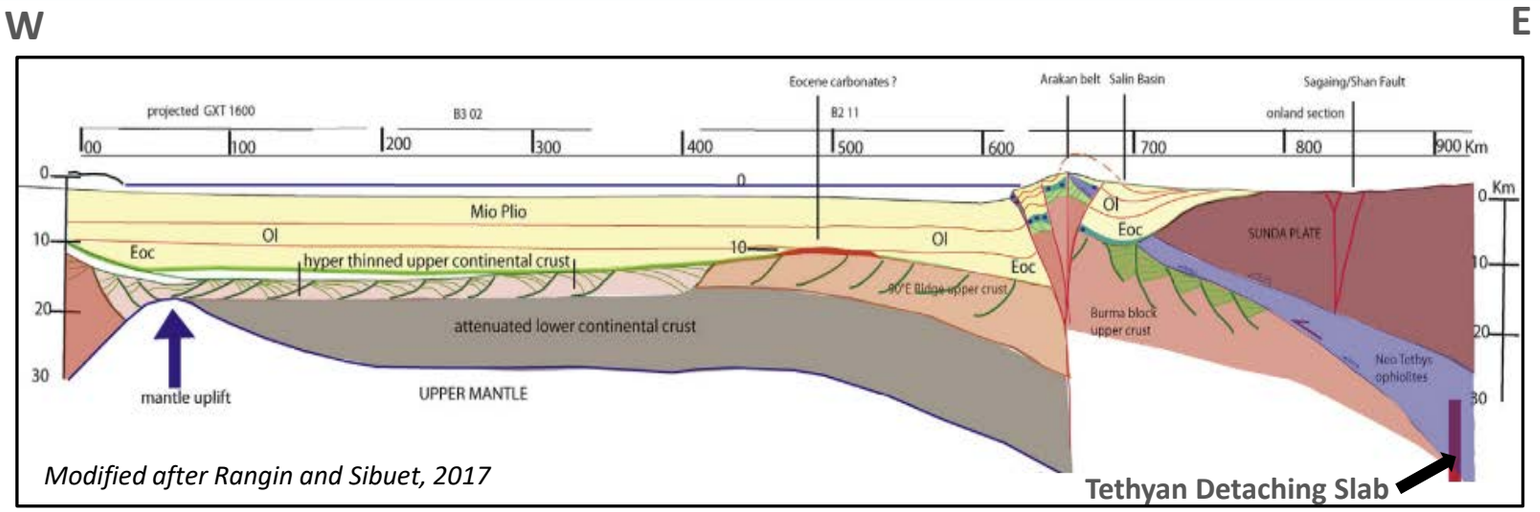
Exploration activities in the Offshore Bengal Basin (OBB) and Offshore Rakhine Basin (ORB) commenced in the mid-1970s



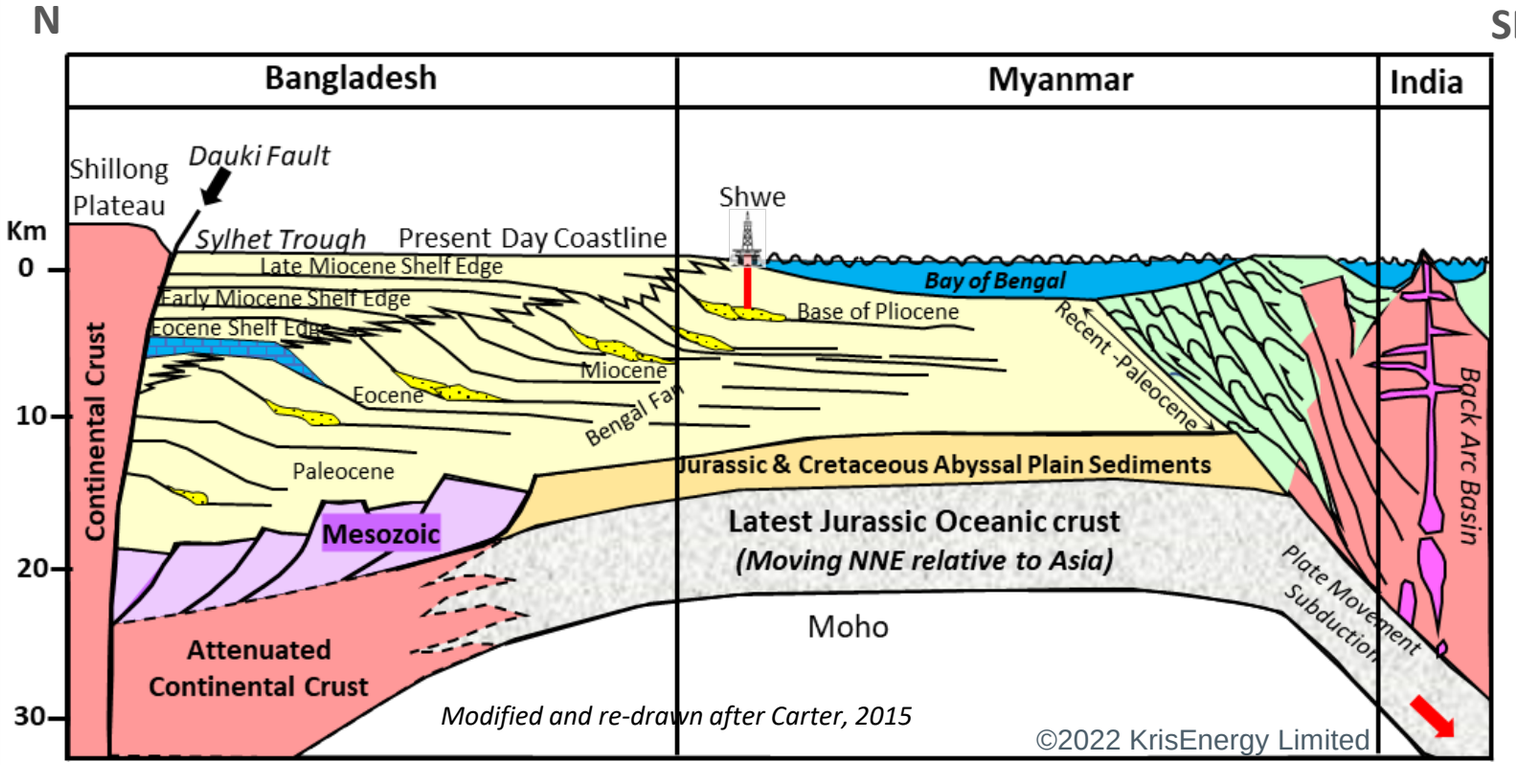
- 1974-1979 – Nine (9) offshore wells were drilled in the OBB, with Kutubdia (1976) the first discovery.
- 1974-1979 – Seven (7) wells were drilled in the ORB, with most abandoned because of drilling hazards related to overpressure.
- 1980-mid 1990s – Exploration activities in abeyance / limited in both the OBB and ORB
- 1996 - The sole commercial discovery, Sangu was made by Cairn Energy in the OBB. Since 1996, a major portion of the shallow and deepwater offshore OBB remains unexplored or severely underexplored.
- 2003-present – In the ORB exploration drilling re-started in 2003 with over 50 exploration and appraisal wells were drilled; first commercial discovery was made in Shwe-1ST-1 in early 2004. Later with further large discoveries e.g., Shwe-Phyu, Mya, Thalin and Mahar were made.

General Geology – Offshore Bengal and Rakhine Basins



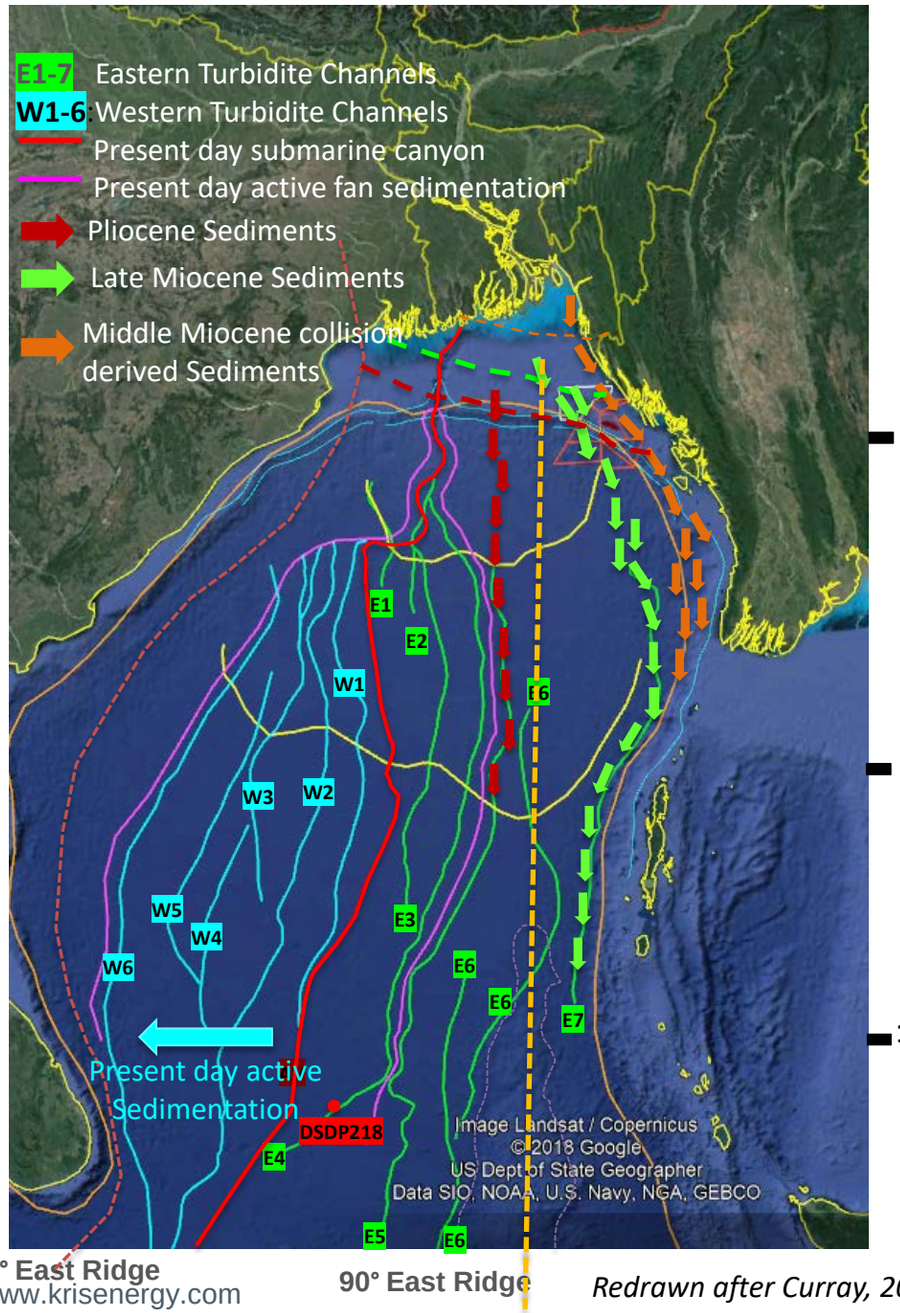


Modified after Rangin and Sibuet, 2017

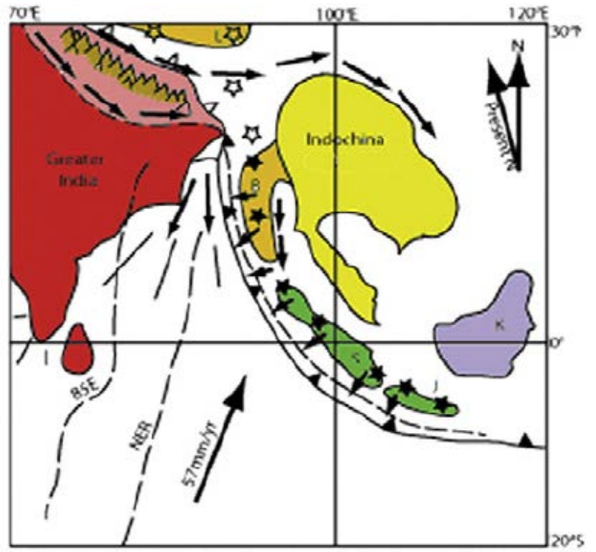


Modified and re-drawn after Carter, 2015

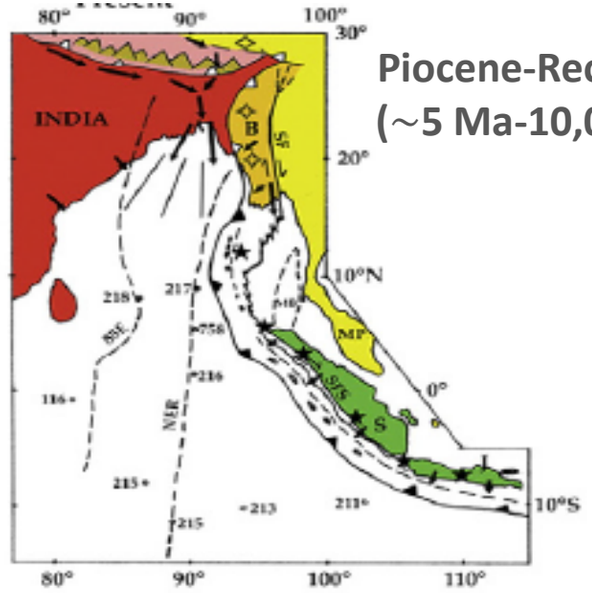
Bengal Fan Development



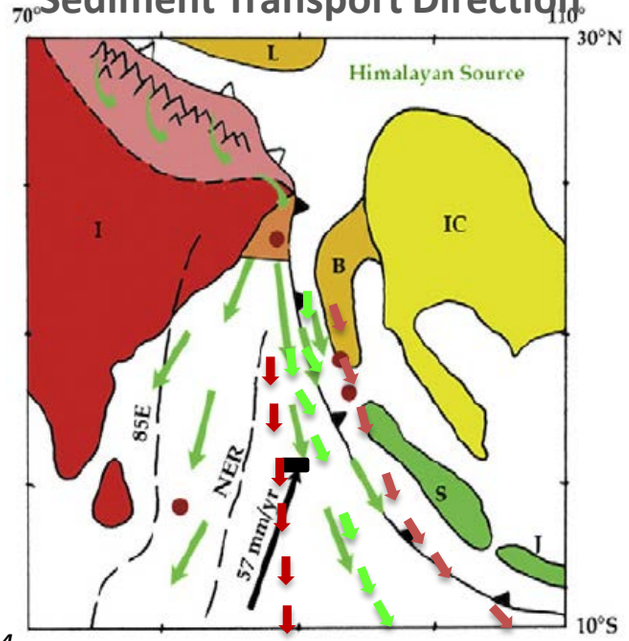
Early to Middle Miocene (~21-12 Ma)



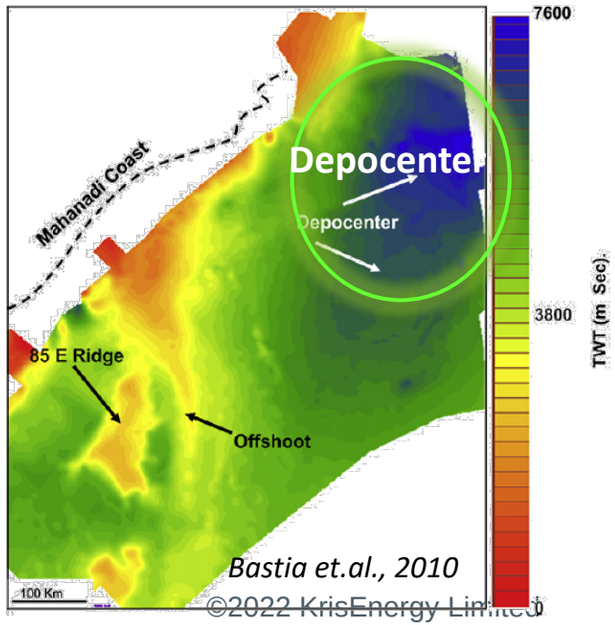
Piocene-Recent (~5 Ma-10,000)



Sediment Transport Direction

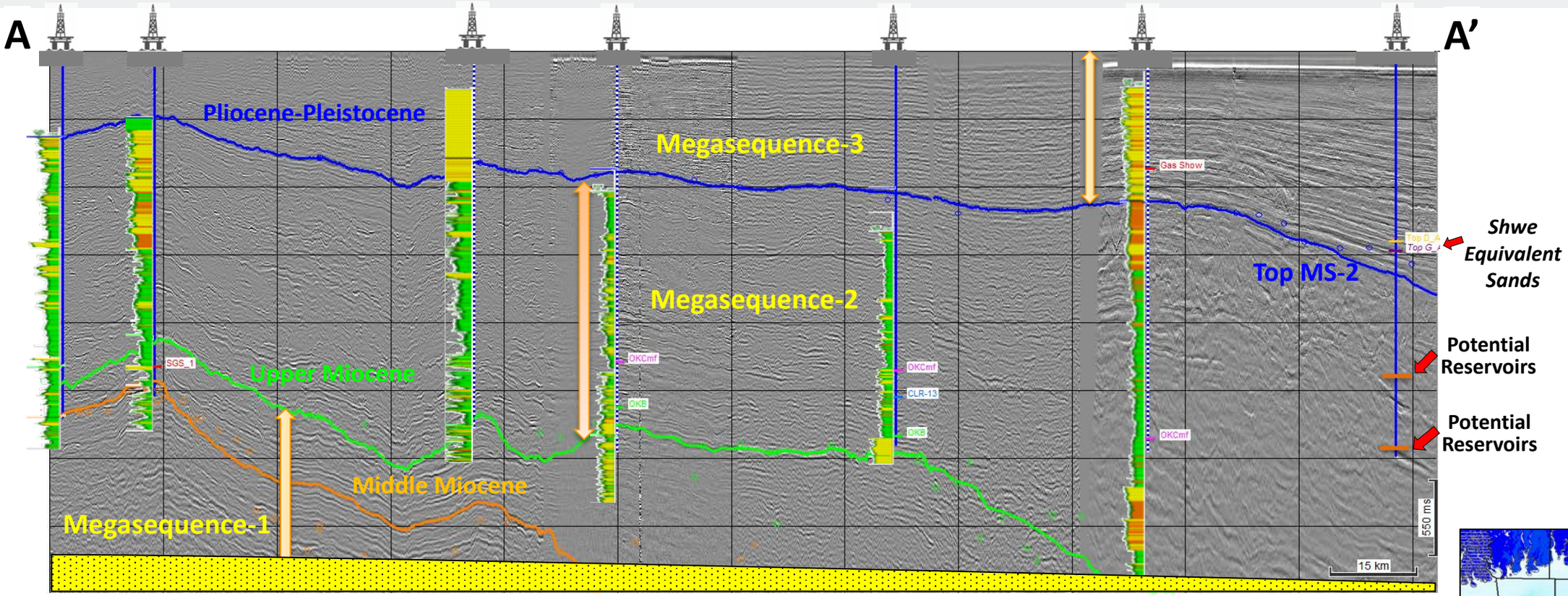


Sediment Depocenter



Redrawn after Curray, 2013, 2014

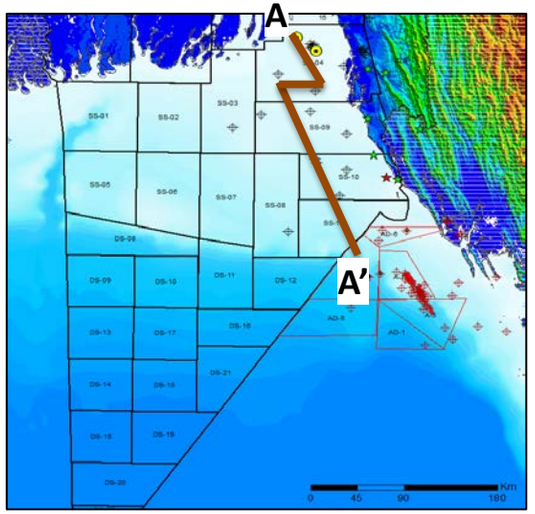
Seismic Stratigraphy – Offshore Bengal Basin (OBB)



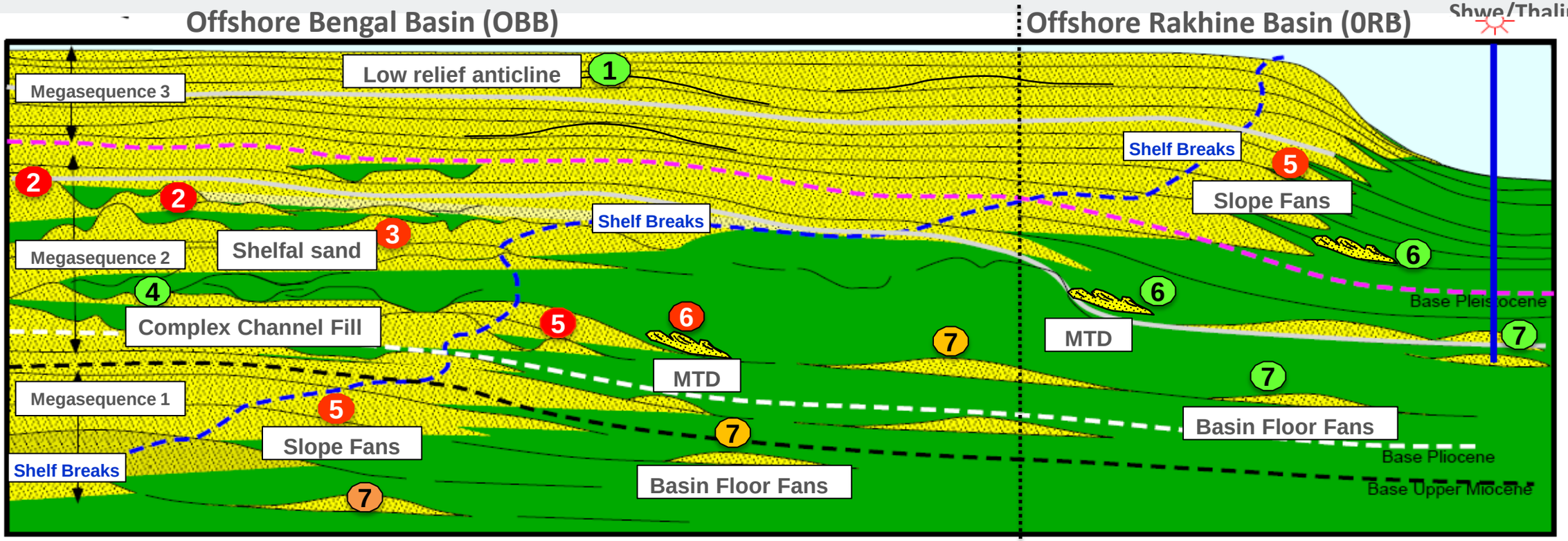
- **Megasequence-1**: Laterally continuous events, high amplitude reflectors, and minor channel incisions. Southernmost area represents the Miocene shelf-edge. Laterally continuous reservoir with minor channel incisions. Sangu reservoirs lies in Megasequence-1. Gas shows in all wells.

- **Megasequence-2:** Abundant large-scale erosive canyons; filled with seismically different reflectors. Laterally discontinuous sand bodies, low net to gross ratio where sand content decreases within the deeper part of the basins

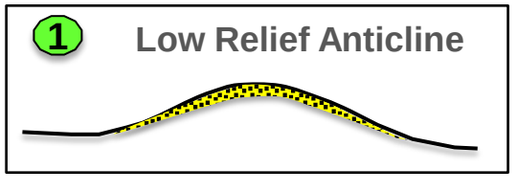
- **Megasequence-3:** High amplitude, laterally continuous reflectors with many small-scale mud-filled erosive canyons. Well logs suggests sand rich, stratified Plio-Pleistocene self-sedimentation. The southernmost extension represents the present-day shelf-edge with well developed clinoforms.



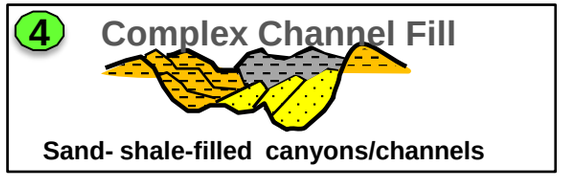
Stratigraphy and Play Concepts – Offshore Bengal and Rakhine Basins



Proven Play (Offshore Bengal Basin)

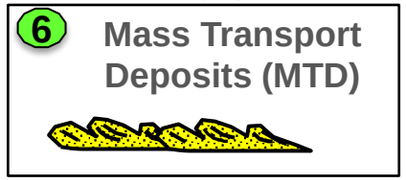


Low Relief Anticline: Kutubdia

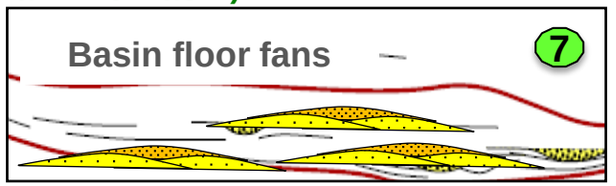


Stratigraphic+ Structural: Sangu

Proven Play (Offshore Rakhine Basin)

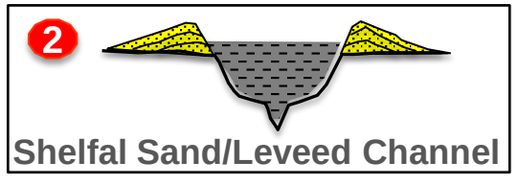


Stratigraphic (Thalin)

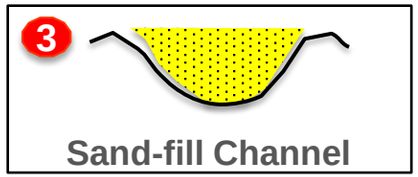


Stratigraphic (Shwe Basin Floor Fan)

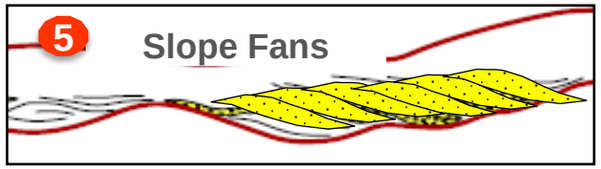
Unproven Play (Offshore Bengal Basin & Rakhine Basin)



Unproven: Stratigraphic



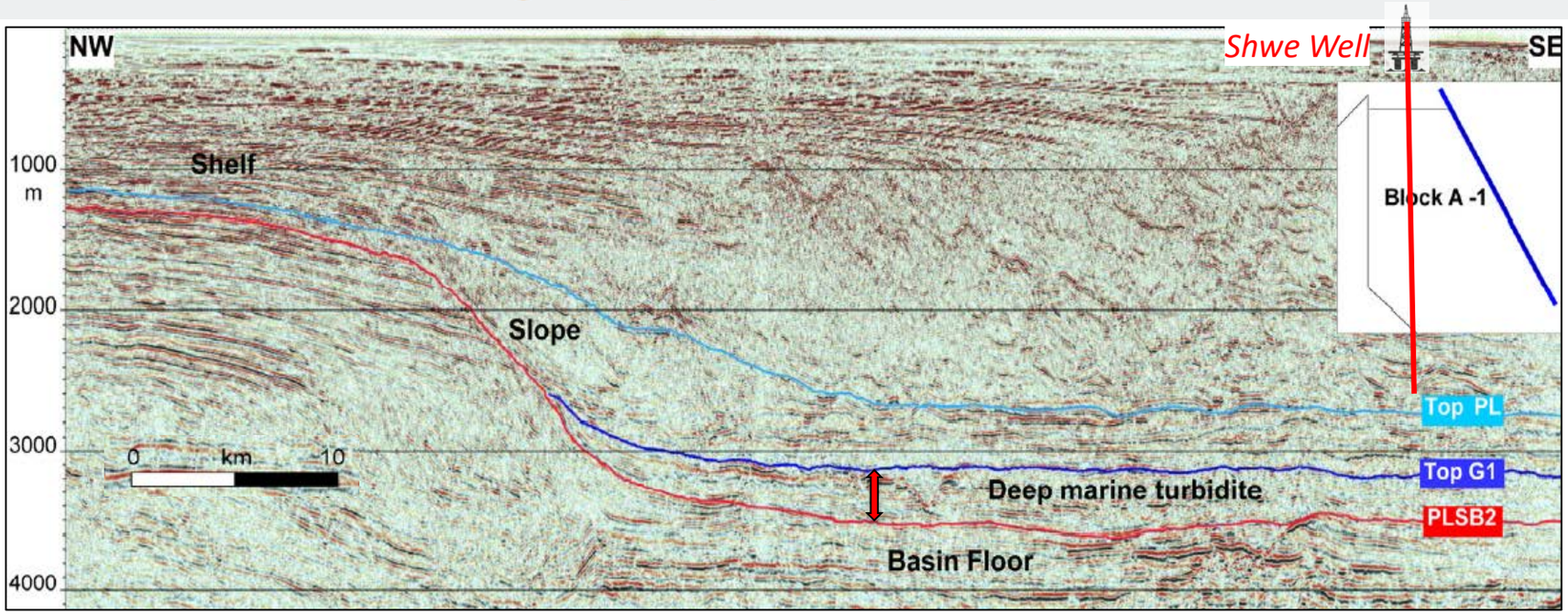
Unproven: Stratigraphic

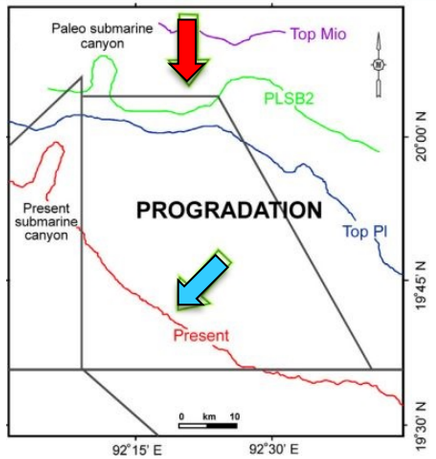


Unproven: Stratigraphic

Modified after Carin Energy and J & J, 2019

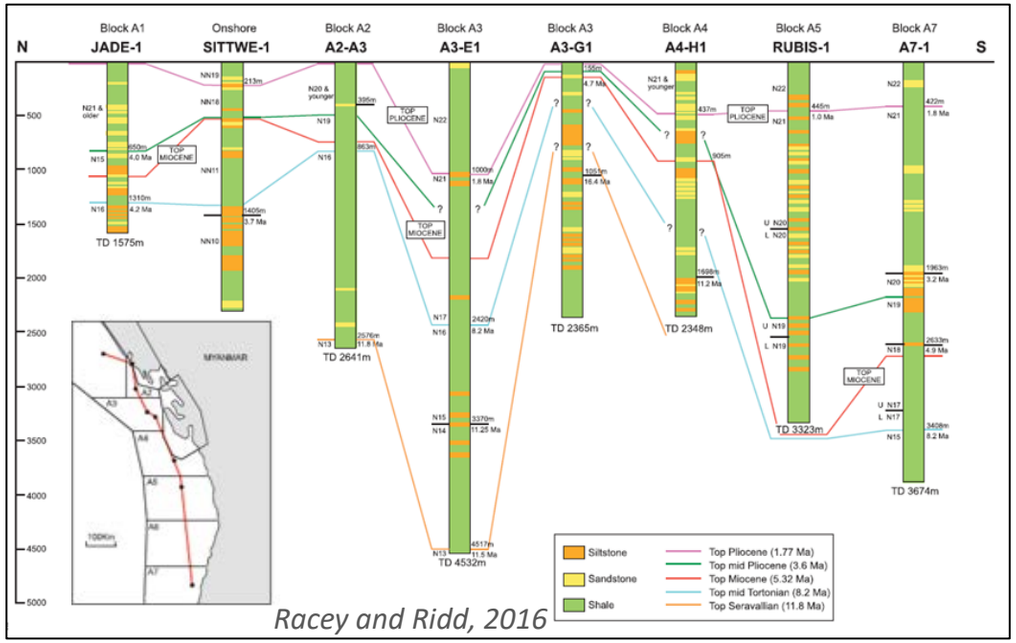
Seismic Stratigraphy – Offshore Rakhine Basin (ORB)



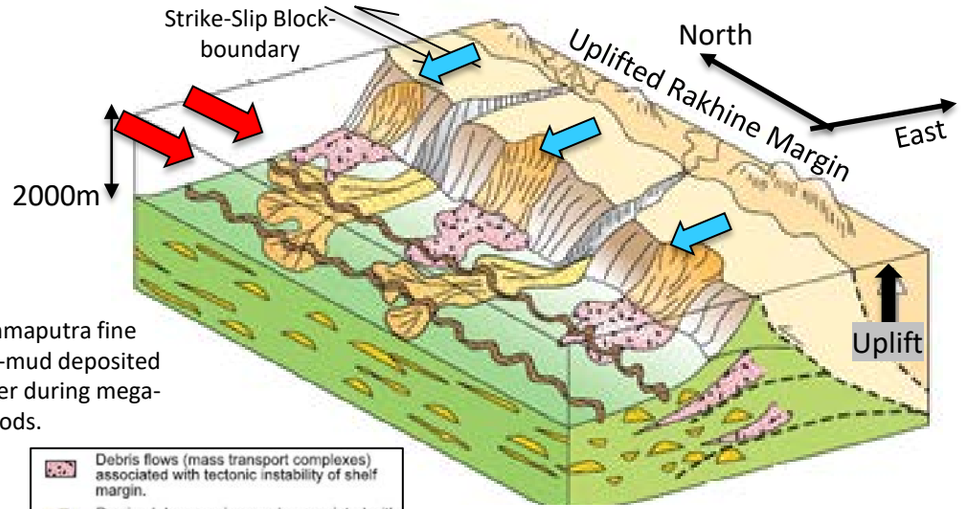


Yang and Kim, 2013

Late -Pliocene deepwater sediment is RB probably has two dispersal systems – i) a distal muddy/silty NS palaeo-Brahmaputra depositional system from , ii) more proximal, sandy, deep-marine fans and debris flows from the uplifted Rakhine margin from E-W.



Racey and Ridd, 2016



Palaeo-Brahmaputra fine grain sand-silt-mud deposited into deep water during mega-floods.

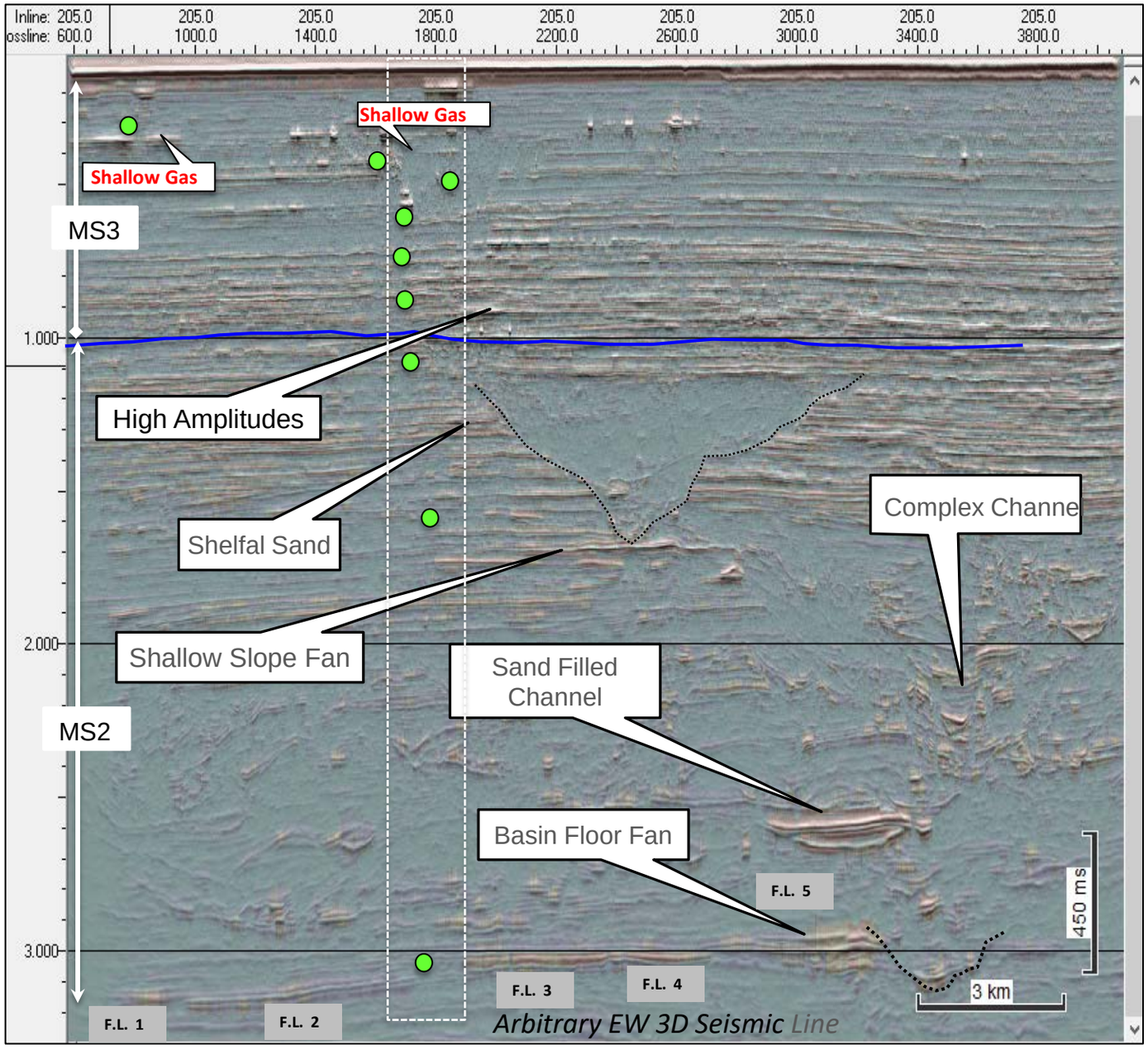
Debris flows (mass transport complexes) associated with tectonic instability of shelf margin.

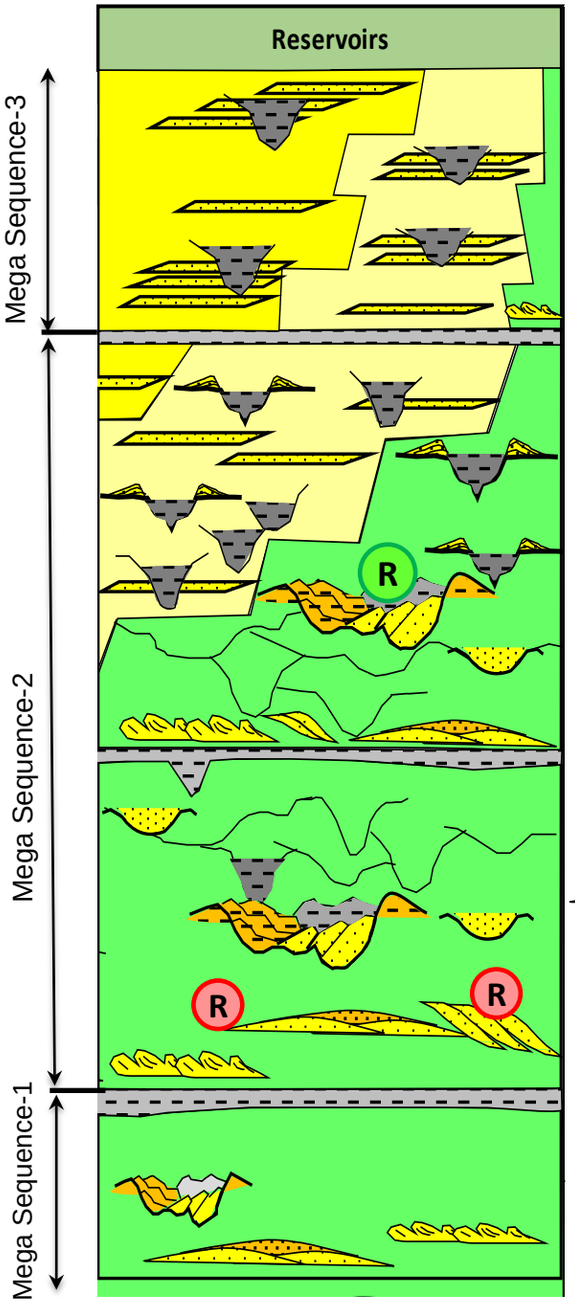
Proximal deep marine sands associated with uplift of Rakhine Margin.

Brahmaputra fan channels (distal).

Modified from Racey and Ridd, 2016

Reservoirs – Offshore Bengal Basin (South-eastern area)





Legend

Leveed Channel/Shelfal Sand

Channel Fill Sand

Complex Channel Fill

Mass Transport Deposit

Prograding Wedge/Slope fans

Basin Floor Fan

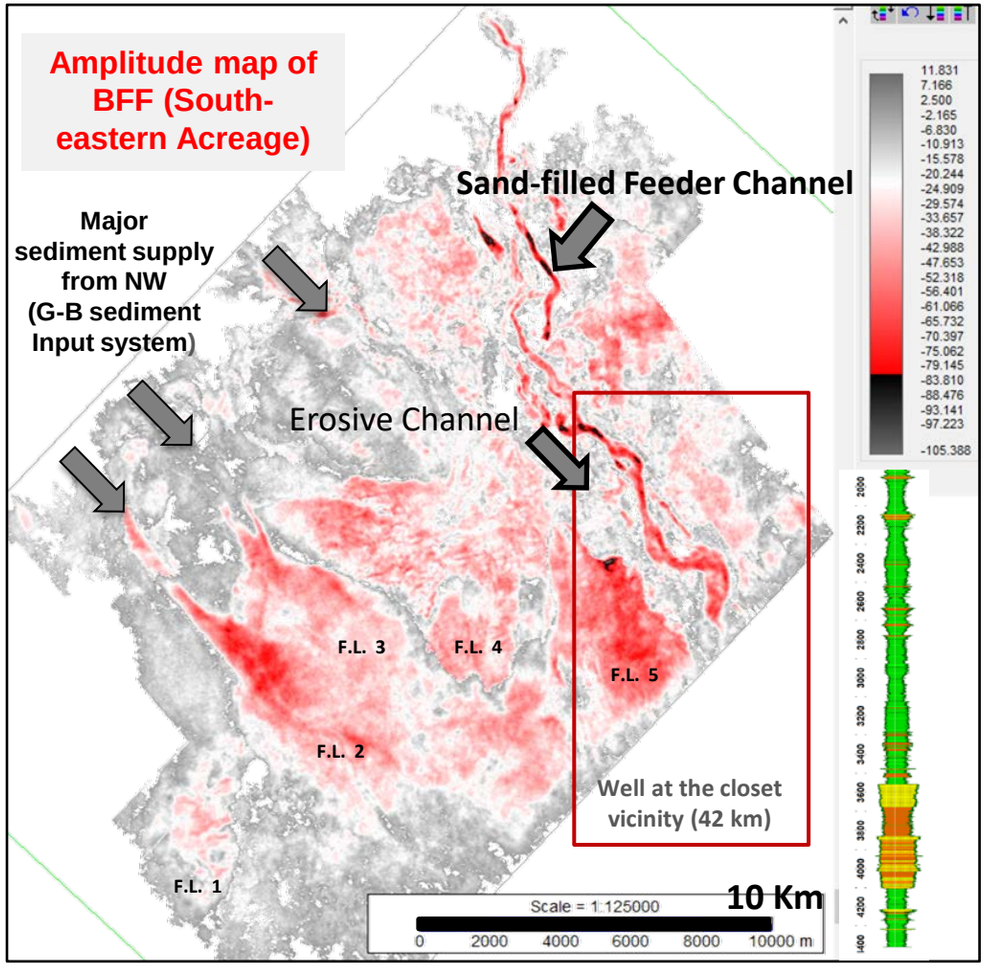
R

Proven Reservoir

R

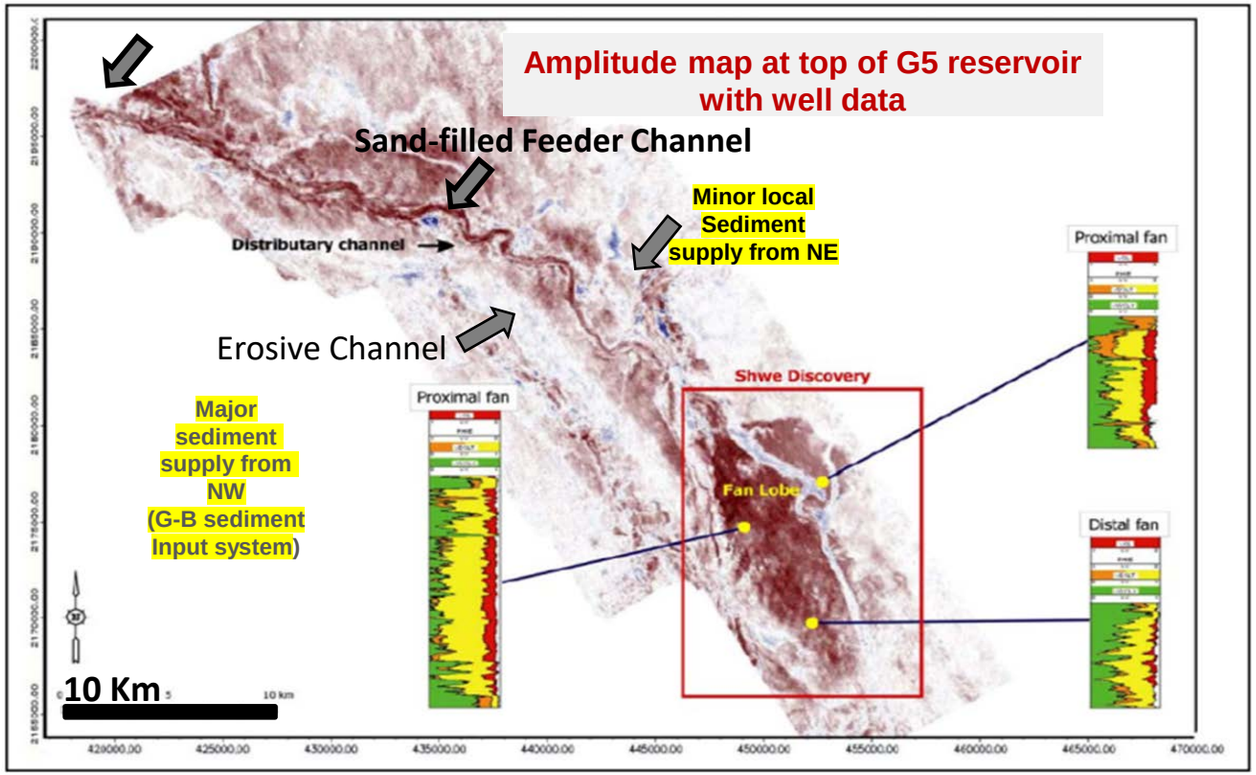
Unproven Reservoir

Basin Floor Fans – OBB Basin Floor Fan v. ORB Shwe Fans

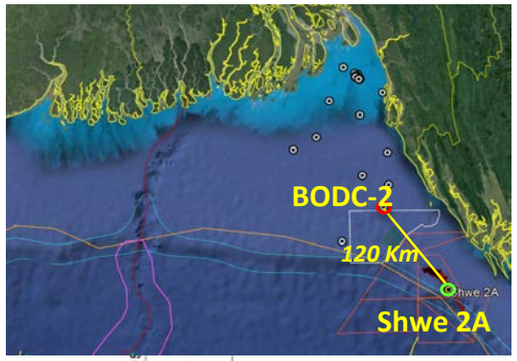


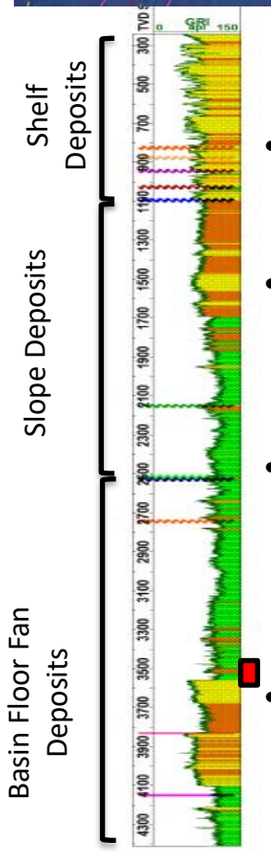
- Basin Floor Fans are of Mio-Pliocene age, older than Shwe BFF
- BFF follow similar progradational (NNW-SSE) direction; individual lobes are 5-14 km long, 3-5 km wide, sand bodies are 30-80m thick.
- OBF sediments have longer transport path compared to ORB fan.
- Likely to be more silty-muddy, good to moderate reservoir quality.

- Shwe Fan complex comprises of three back stepping fan system (Shwe Phyu, Shwe and Mya); proximal; near proximal and distal.
- The fan lobes are 12-15km long, 4-6 km wide, prograded along SSE direction.
- Fan complex along the west flank of NNW-SSE trending anticline provided structural component which played a positive role for trapping
- The gas sand intervals are 14-150 m thick, with an average N/G ratio of 33-86%, 21-25% porosity and 97-278mD permeability (*Yang and Kim, 2013*)
- These sediments were deposited as amalgamated sheet sands/fan sands or thinly bedded overbank turbidity sands.



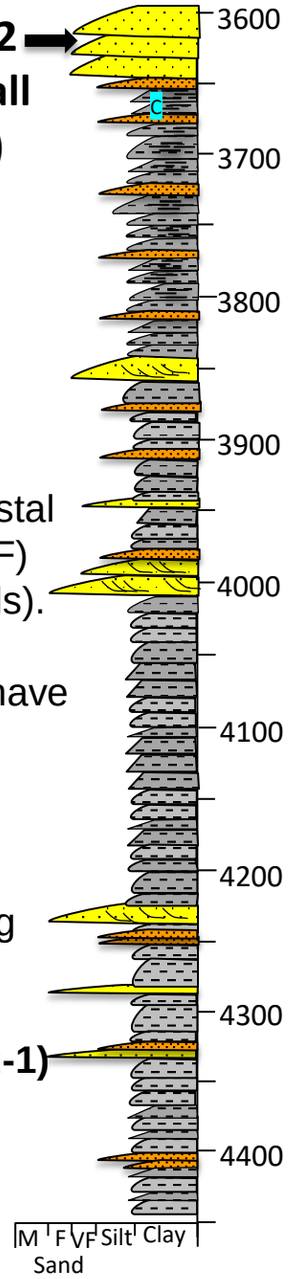
Reservoir Quality – OBB Basin Floor Fans v. ORB Shwe Fan



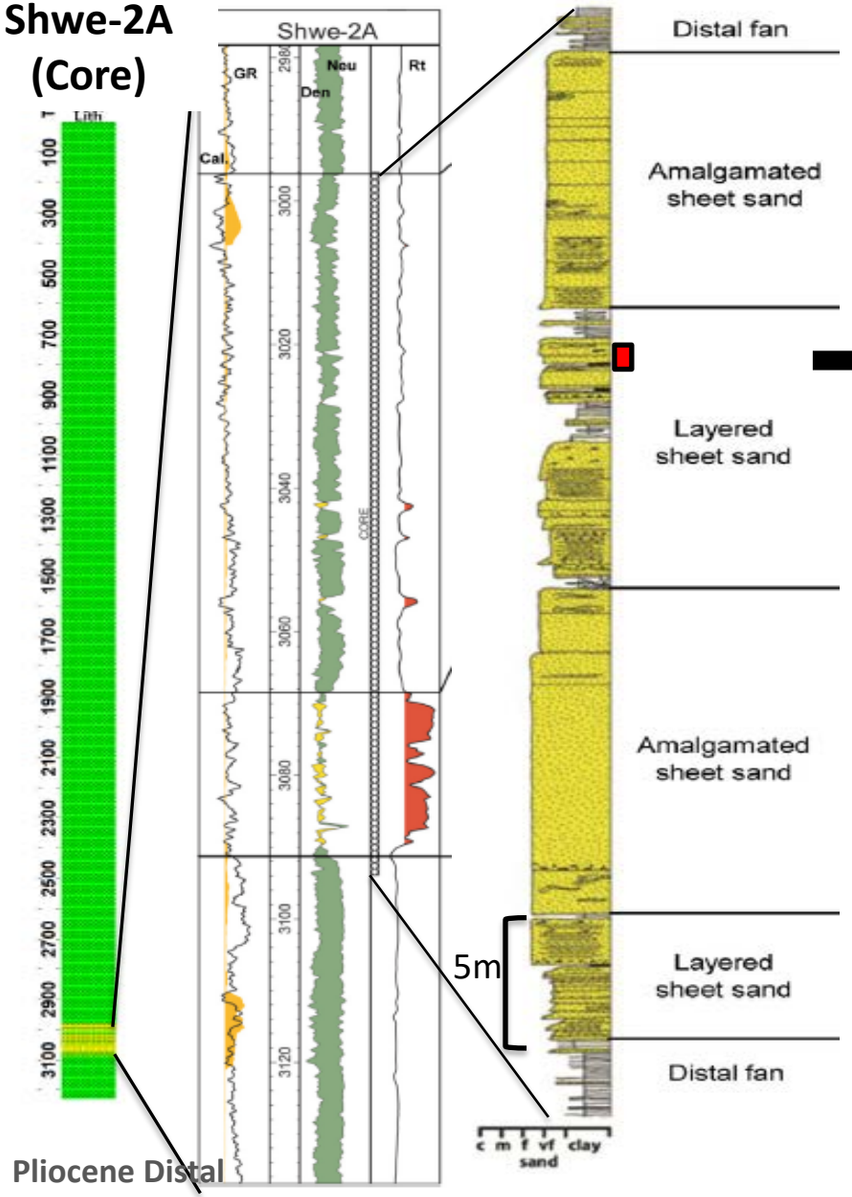


- Miocene mud-rich distal Basin Floor Fan (BFF) deposits (BODC wells).
- Thin-bed turbidities (sheet sands), may have significant lateral continuity.
- **Porosity: 10-12%** (compaction curve analysis from existing wells and BODC & Sangu Wells)
- **Perm: 8 mD (Sangu-1)**

BODC-2 (Sidewall Cores)

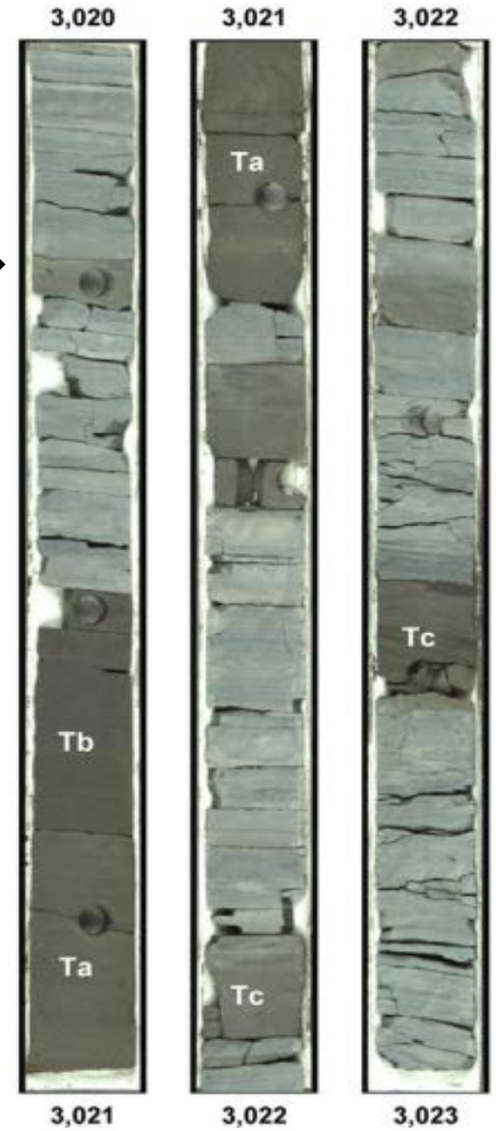


Shwe-2A (Core)

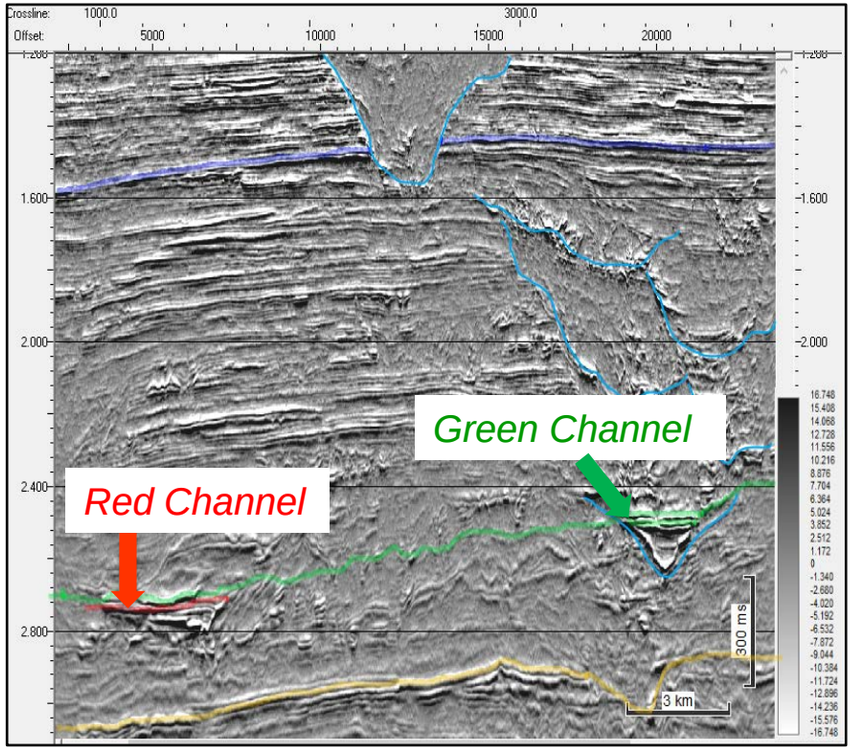


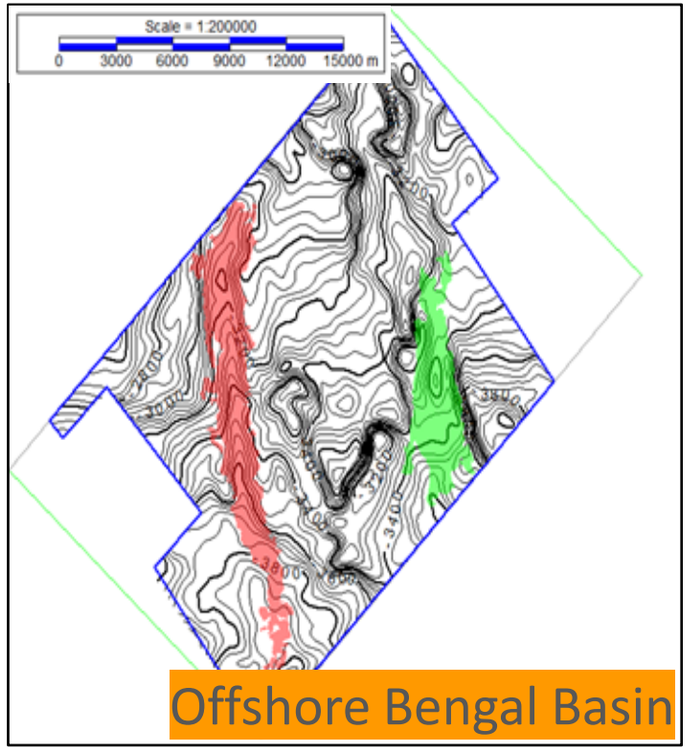
Pliocene Distal Basin Floor Fan Deposits

- **Porosity: 21-25% (G-3 & G-5 sst.)**
- **Perm.: 97-278 mD (G-3 & G-5 sst.)**



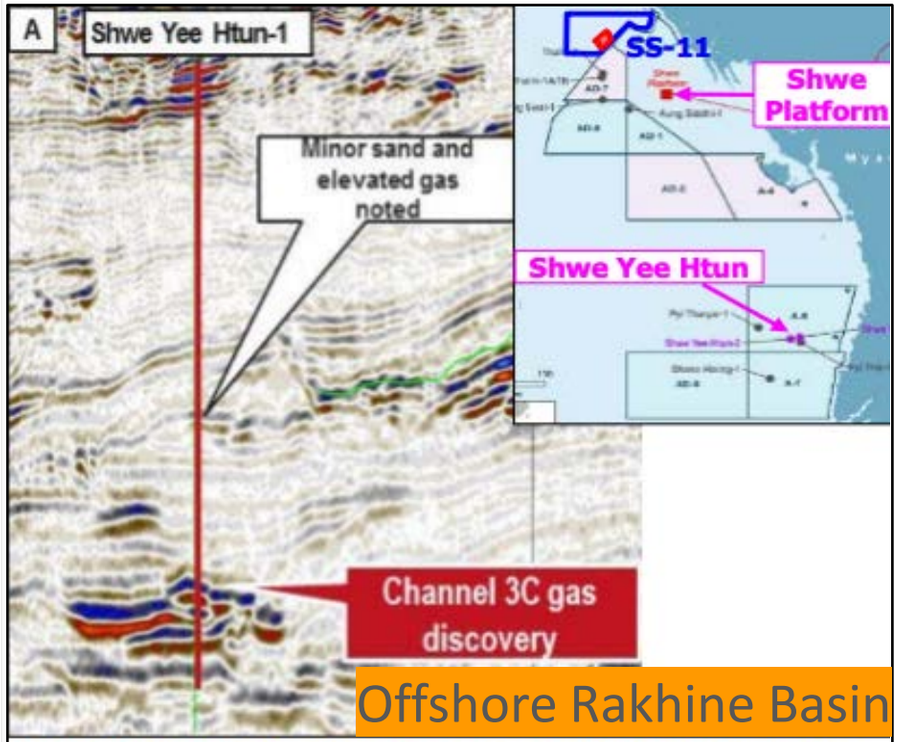
Sand-filled Channels – Offshore Bengal Basin v. Rakhine Basin





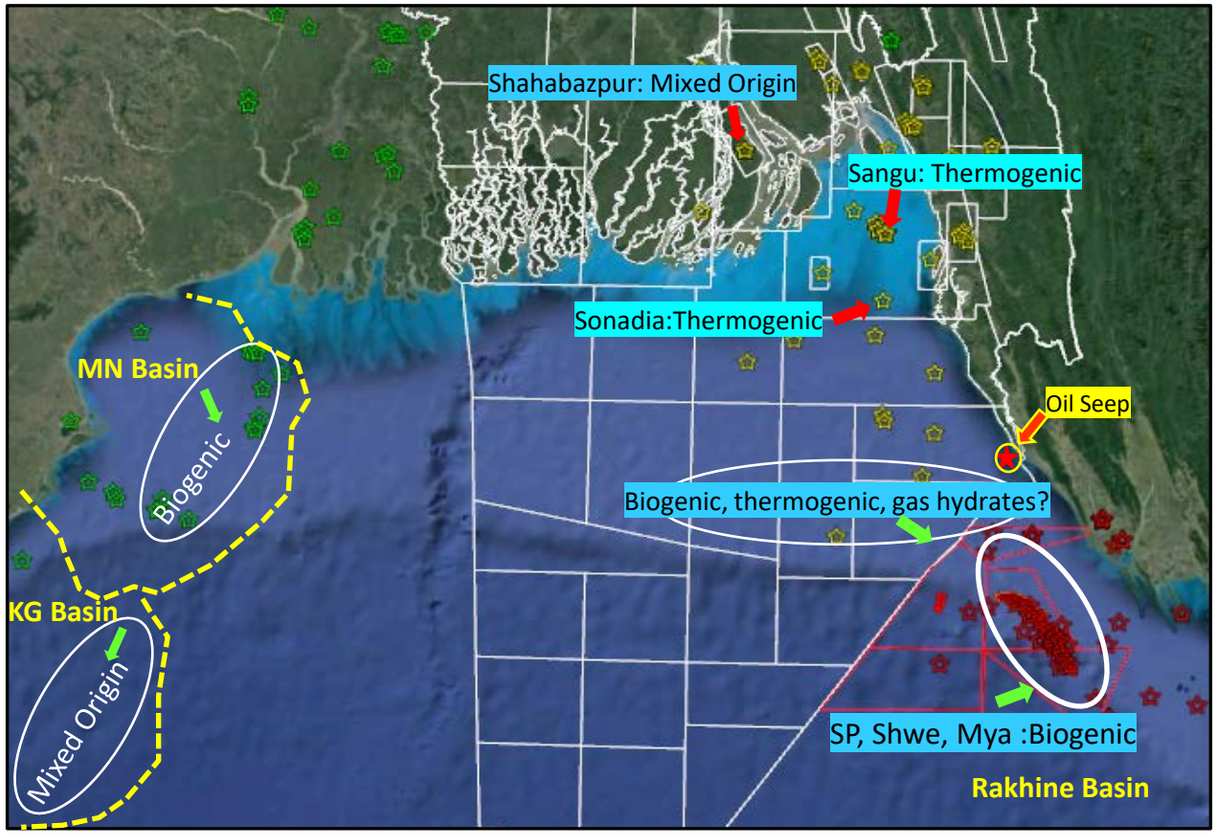
- Sand-filled channels were mapped in Megasequence-2.
- These channels include extensive bright amplitudes, continuous-parallel reflectors inside it.
- Does not have pronounced levees. Incised, V or U shaped, often isolated.
- Low sinuosity channels, eroding fan lobes and prograding across the pre-exiting fan lobe.
- The channel fills have different morphology, unlike the seismic signature compared to complex channel fill or mud-filled canyons.
- Seismic signature of these channel-fill indicate an heterolithic composition.
- The channel bodies are 6-16 km long and 2-3 km wide.
- These prospects have shallower drilling depth (2400-300m) compared to basin floor fans.

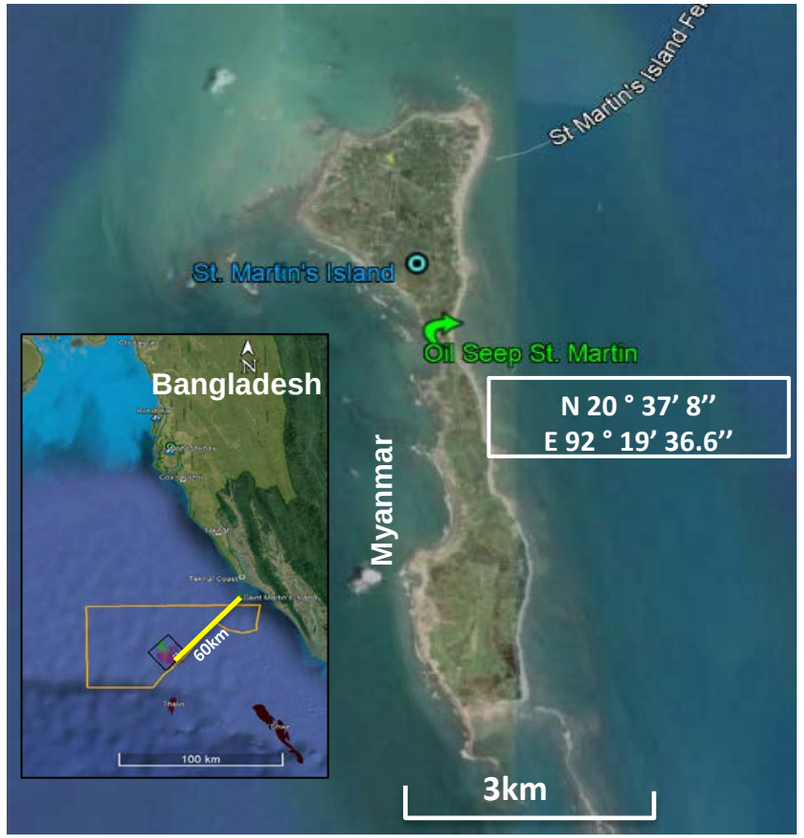
- **Shwe Yee Htun, Myanmar –** Sand-filled channels are a few meters to 7m thick, occurring as isolated distributary channels or stacked sequences (channel complexes or feeder lobes).
- Occasional large erosional channels up to 20 m thick are noted, potentially forming seals.



SYH-2 down-dip from SYH-1 - gross gas column 143mTVT with 41mTVT of net pay in high quality-reservoir. DST over 35m reservoir flowed at ~53 mmscf/d on a 40/64" choke

Source Rock – Offshore Bengal Vs. Offshore Rakhine Basin

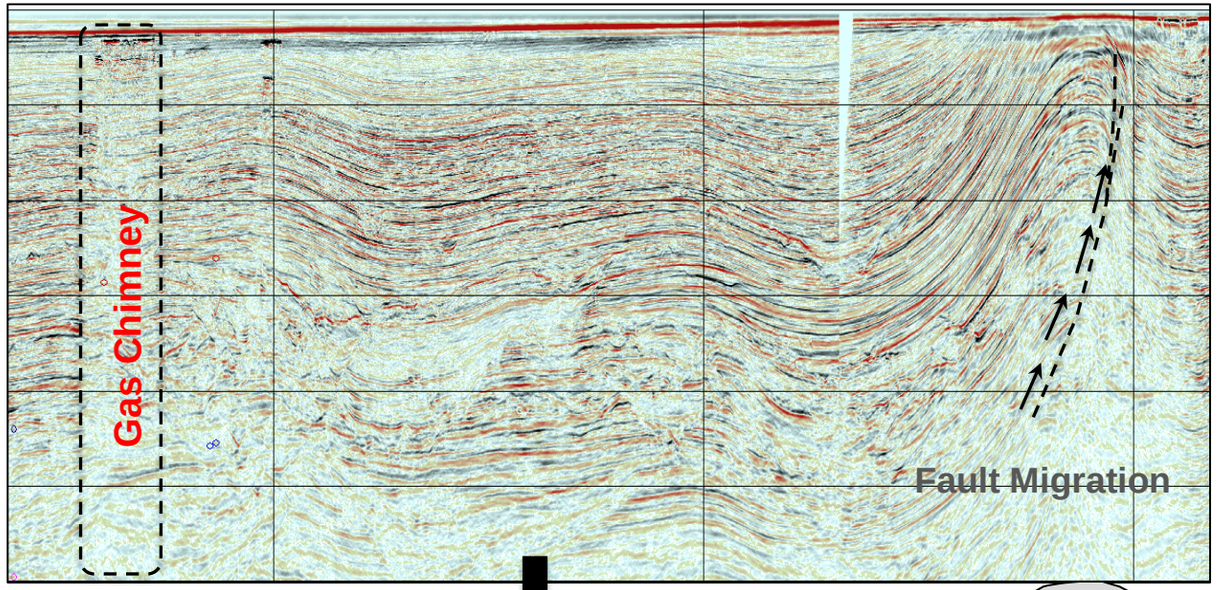




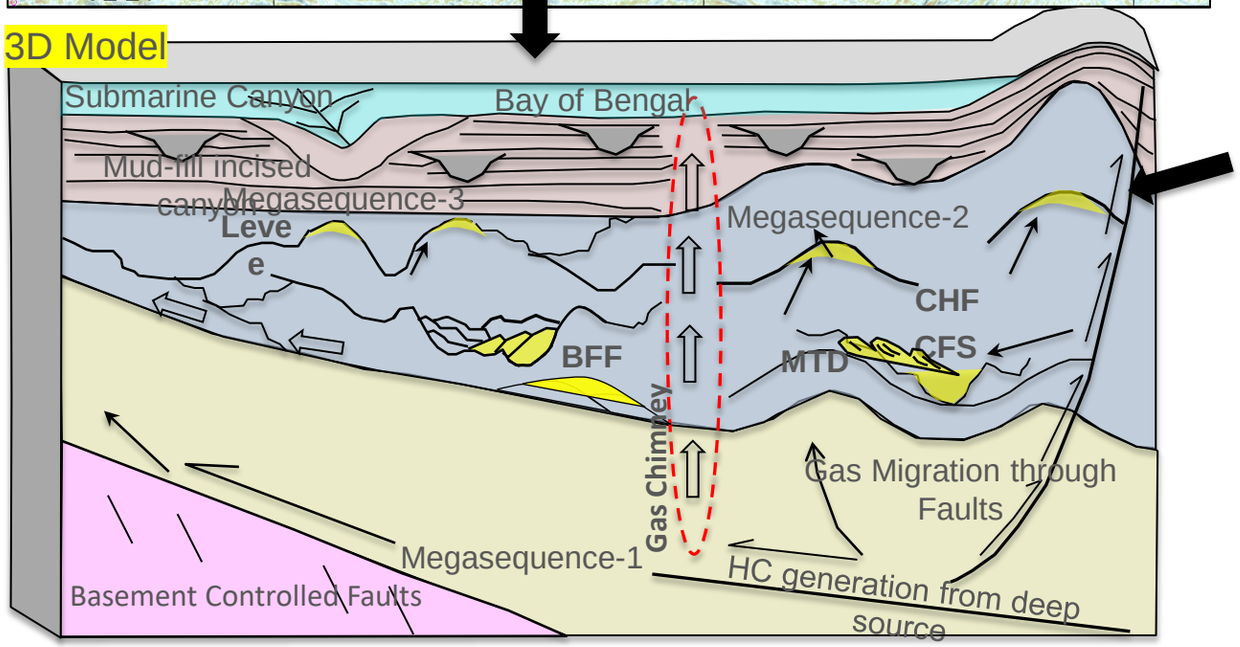
- The average TOC content of the Mio-Pliocene Surma Group is 0.2-0.78%. In neighbouring wells (BODC and BINA) it is 1-1.5%
- Hydrocarbon is likely to be sourced from Miocene to Pliocene organic rich shales.
- Recent studies (Rangin & Sibuet, 2017) indicated that the source rock could also be below the regional Late Cretaceous unconformity.
- Gas prone Type-III Kerogen (δ13 C) confirmed thermogenic gas in the Sangu, Sonadia, Hatiya and Kutubdia wells.
- GC geochemical analysis indicates that the St. Martin seeped oil to be crude oil. The seep oil contain Carbon Isotope (δ^{13} C) of -28.09 ‰.
- It shows a close match with the Chebuda and Prome Oils (-23.22-,24.52 ‰) of Myanmar (Tullow Oil Plc, 2001)
- Late Miocene/Early-Late Pliocene biogenic origin confirmed in the adjacent Thalin and Shwe gas fields (δ^{13} C: -68 to -65 ‰) (Yang and Kim, 2013)

Regional Gas Charge and Migration

Indicative east-west seismic line

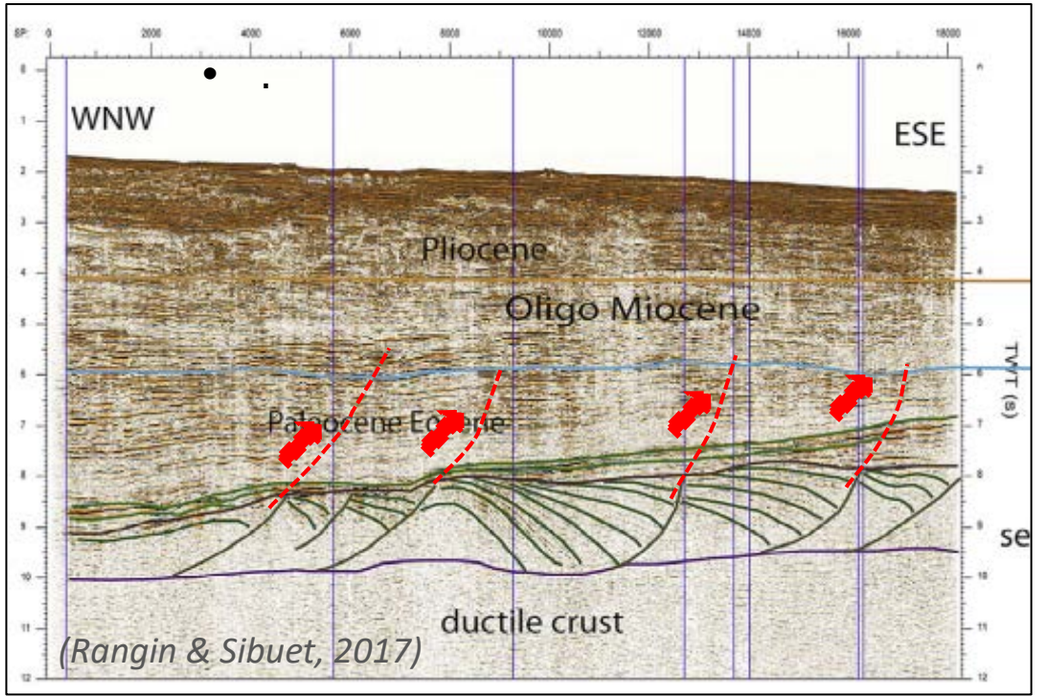


3D Model



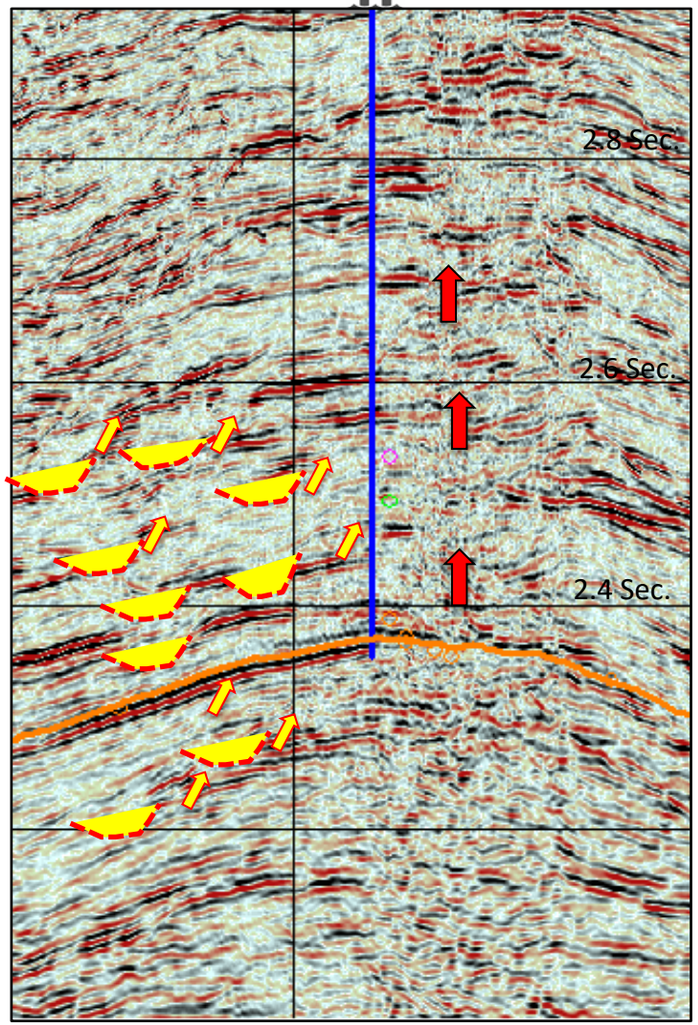
Modified from Matesic, 2012

- Multiple gas chimneys recognised in seismic sections from the OBB suggest an active petroleum system
- Preliminary modelling (Santos, 2016) indicates a regional hydrocarbon kitchen to be 5-6 km.
- Vertical gas migration appears to be via wrench faults, resulting in gas chimneys.
- Natural gas seeps found along the eastern part of our acreage.
- Basin-scale regional migration (lateral, up-dip lateral migration) can also be via basement-controlled faults *(Rangin & Sibuet, 2017).*



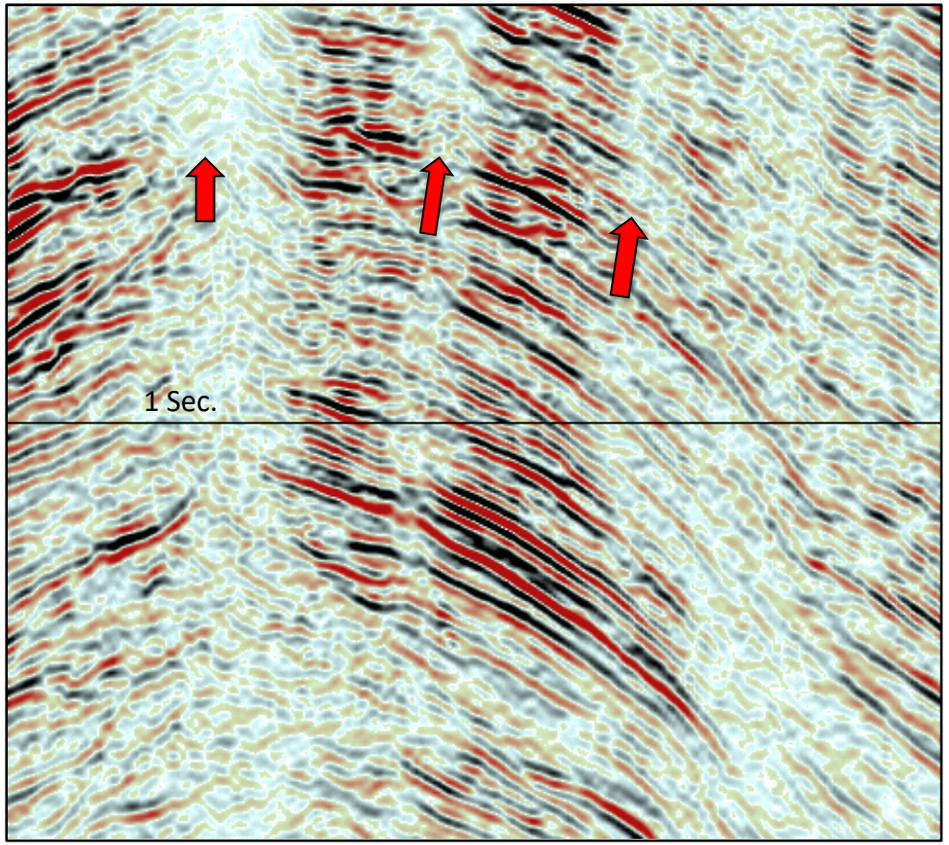
Local Gas Charge and Migration

Lateral and Vertical Gas Migration Sangu-1



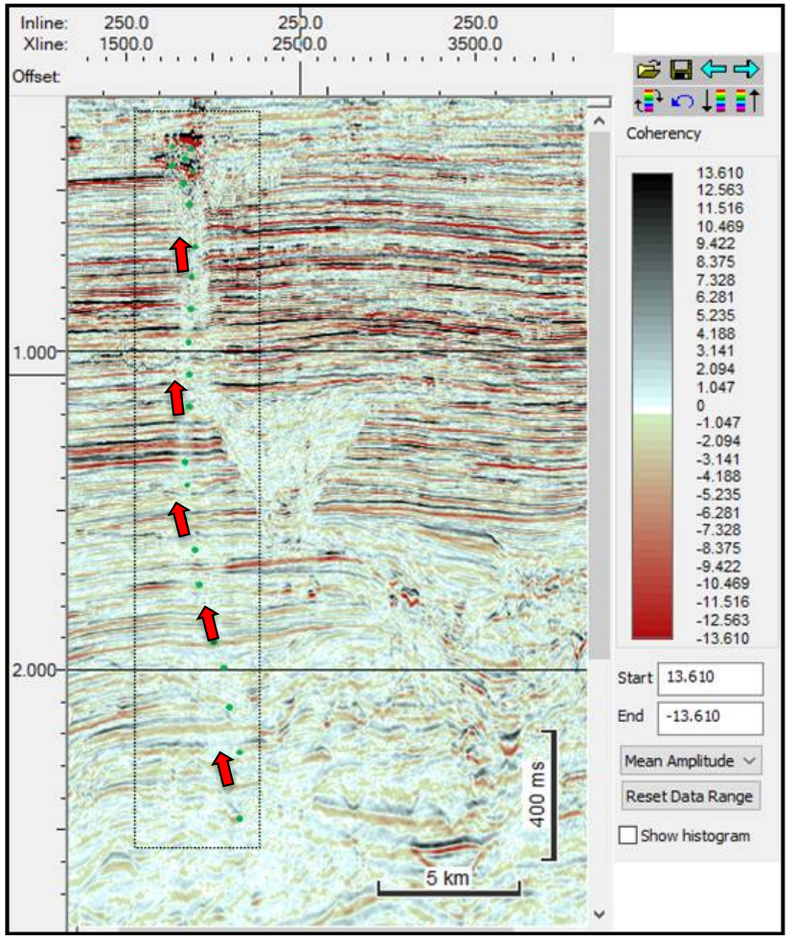
Lateral migration along the margins of erosive channels could be another possible mode of migration

Vertical Gas Migration (Magnama-1)



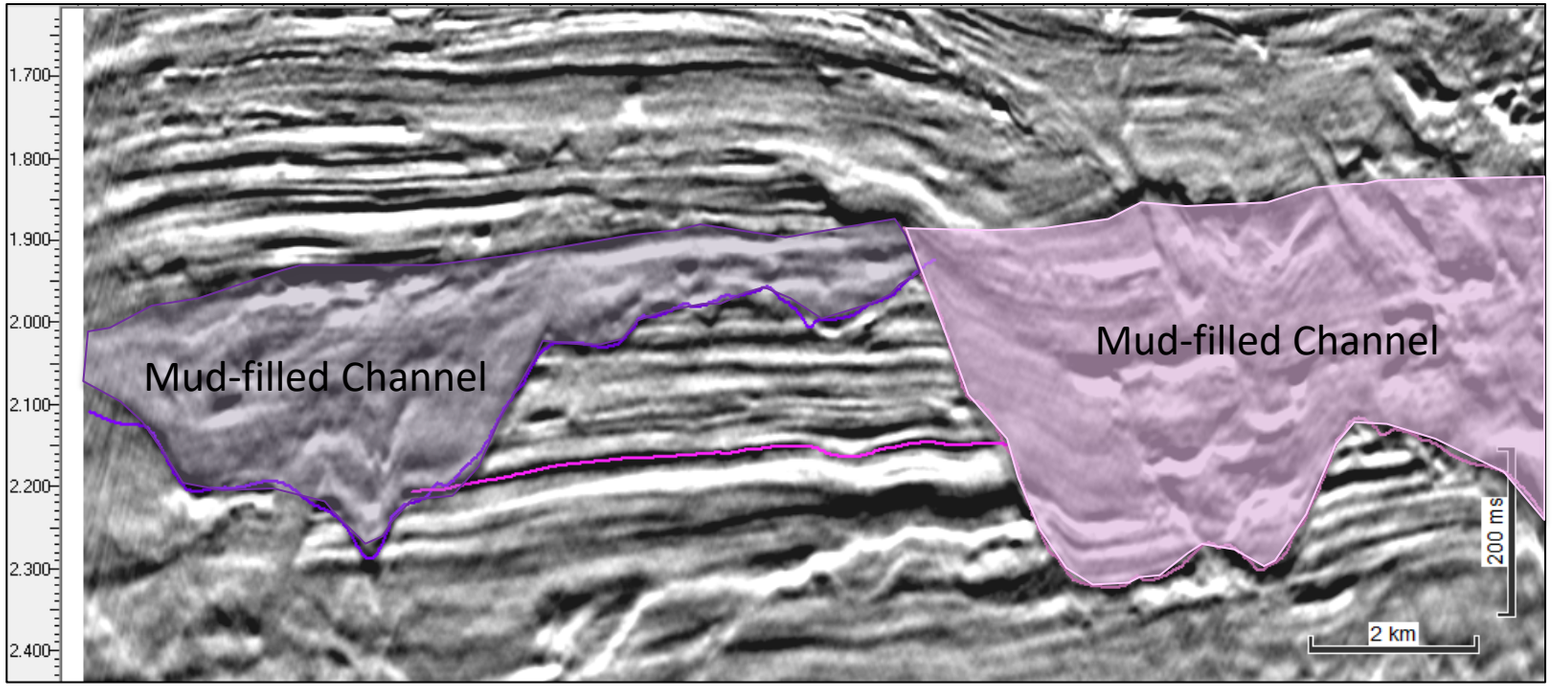
Vertical gas migration observed at the upper crestal part of the Magnama anticline; this is an equivalent position in comparison to the Sangu Field gas migration model

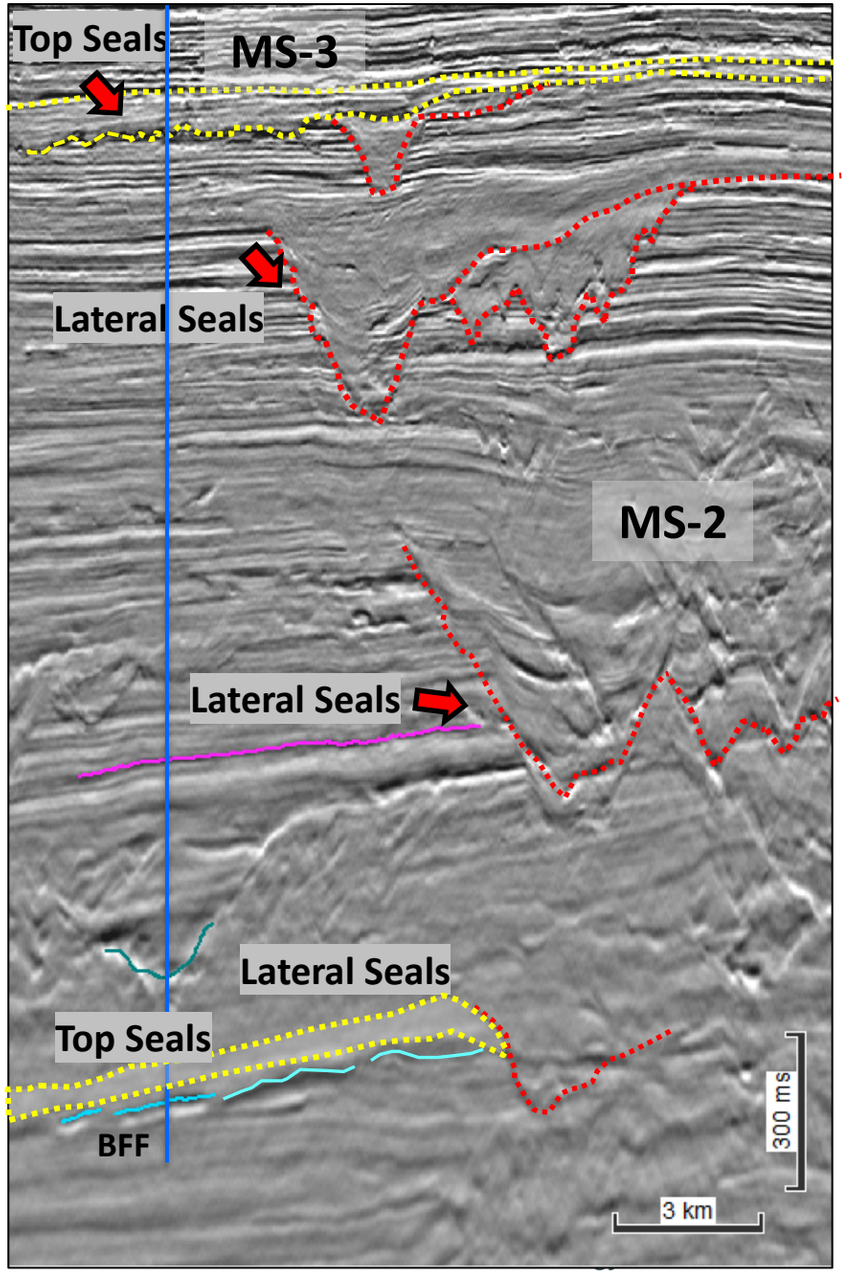
Vertical Gas Migration (Our Acreage)



Vertical gas migration has been observed in our acreage at the western side of the prospects.

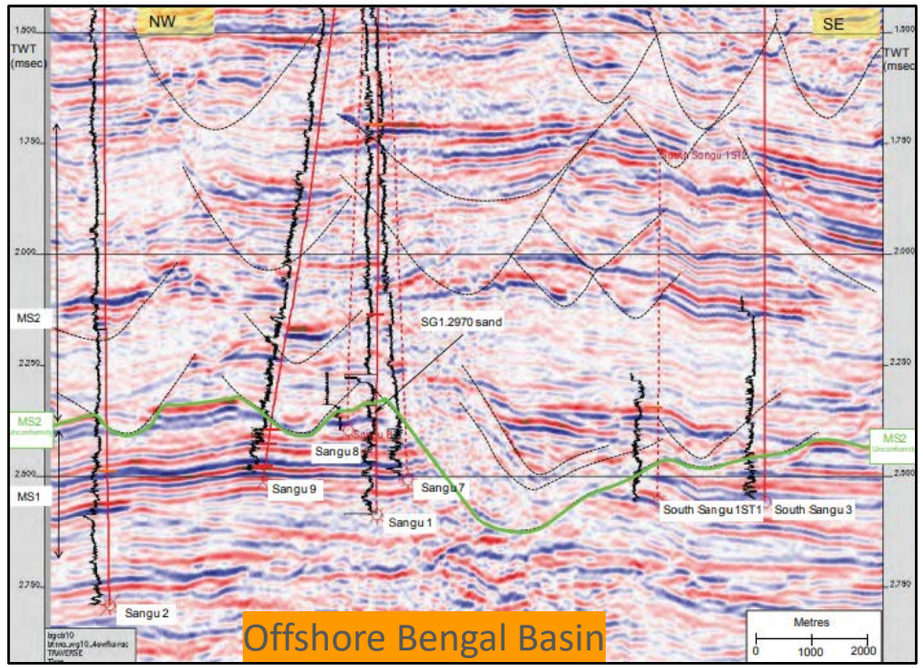
Seal – Offshore Bengal Basin (South-eastern acreage)



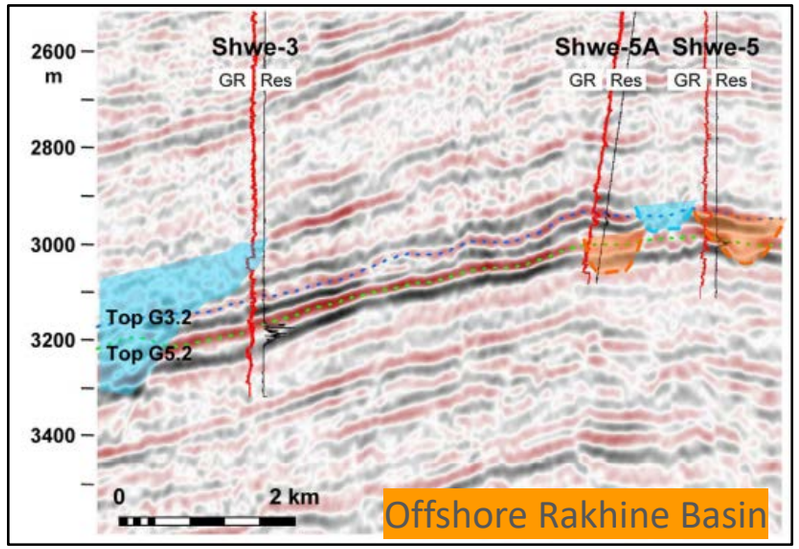


- Laterally continuous reflectors marked in Megasequec-3 may act as top regional seals.
- These shelfal muds are potentially time equivalent to the Pliocene Upper Marine Shale (proven regional seal for onshore gas fields), or the Plio-Pleistocene clays (Girujan Clay)
- Mud-fill channels, commonly delineated in Megasequence-2 and -3, and intraformational impermeable clay layer, can form additional lateral and/or top seals.
- The basin-floor fans may pinch-out laterally and/or up dip against mud-prone high stand (or low stand) slope facies or against clay-rich mass-transport deposits (MTD)

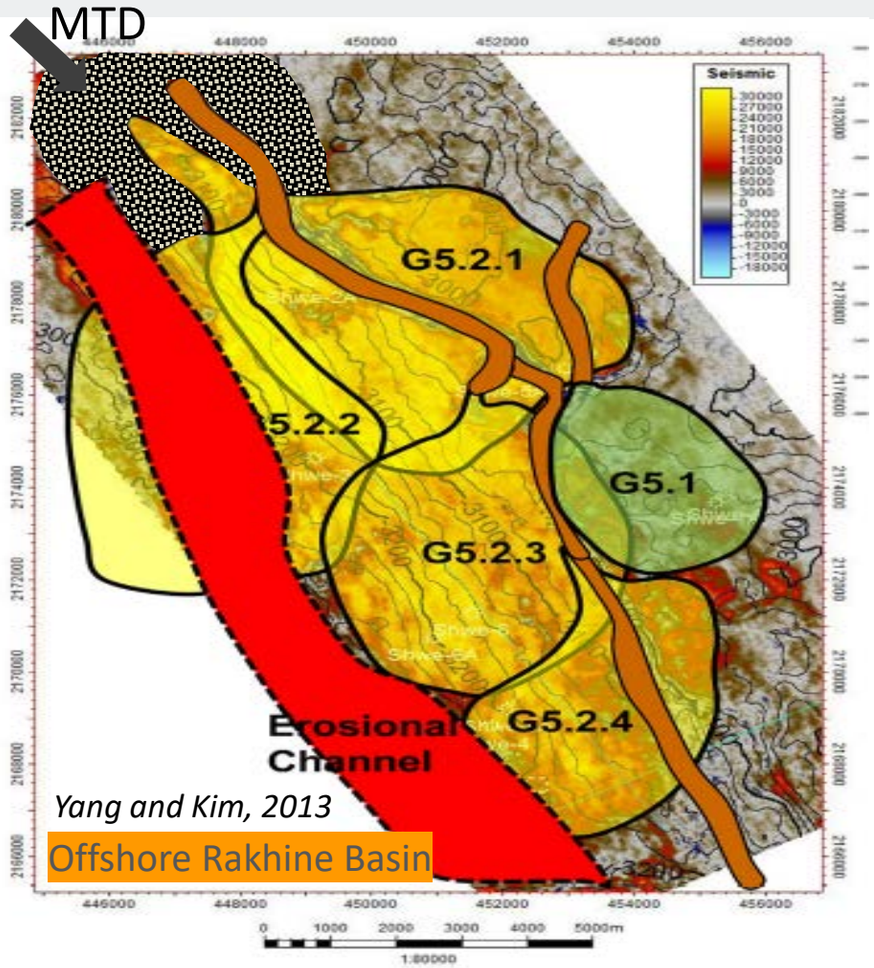
Seal – Offshore Bengal Basin v. Offshore Rakhine Basin



Sangu – Mud-fill erosive channel acting as lateral seal



The shale-filled erosional channel between Shwe-5 and 5A blocked gas migration resulting in gas pool and wet sand, either side of it.



- The basin floor fans may pinch-out laterally and/or up-dip against mud-prone high stand/low stand) slope facies or against clay-rich mass-transport deposits (MTD)
- Regional shelfal mud and palaeo-hydrates (calcite cement) formed as seal in the case of the Shwe/Thalin reservoirs

Conclusions

- Hydrocarbon exploration in the shallow Offshore Bengal Basin (OBB) presents excellent opportunities to test multiple deep-water prospects (basin floor fans, channel-fill sands, complex channel-fill sands and/or stacked channels, leveed channel, shelf sands, and slope fans).

- Basin floor fans and channel-fill sands are proven reservoirs in Myannar's Rakhine Basin (Shwe Phyue, Swe, Mya) and India's Krishna-Godavari Basin (Dhirubhai), essentially remain to be tested in the OBB.

- They are both believed to contain high poro-perm reservoir sands comparable to Sangu. Although Sangu reservoirs are located in a proximal setting (Miocene shelf) and deposited under high-density turbidity currents.

- The basin-floor fans appear to have a genetic link in sediment-source, transport directions and probably have similar play fairway to the Shwe fans in the Offshore Rakhine Basin (ORB).

- Occurrence of thermogenic/biogenic/mixed origin gas in neighbouring gas fields, (Sangu, Sahabazpur, Thalin, Shwe) supports the presence of potential source rock throughout the Late Cretaceous to Pliocene sedimentary section, either in organic rich shales or in potential carbonates.

- Large-scale, deep, near-vertical wrench faults should allow efficient vertical gas migration. Multiple gas chimneys, and gas/oil seeps in the adjacent onshore blocks of both Myanmar and Bangladesh, indicate an active hydrocarbon migration system.

- Top seals are believed to be Plio-Pleistocene regional shales, with erosive mud-fill channels also providing lateral sealing. The basin-floor fans may pinch-out laterally and/or up dip against mud-prone slope facies or against clay-rich mass-transport deposits (MTD).