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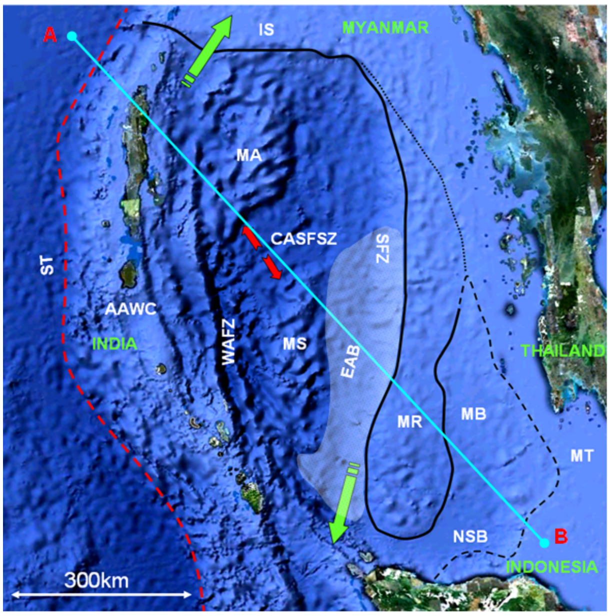
Seismic & Sequence Stratigraphic Framework and Depositional Architecture of Shallow and Deepwater Postrift Sediments in East Andaman Basin: An overview

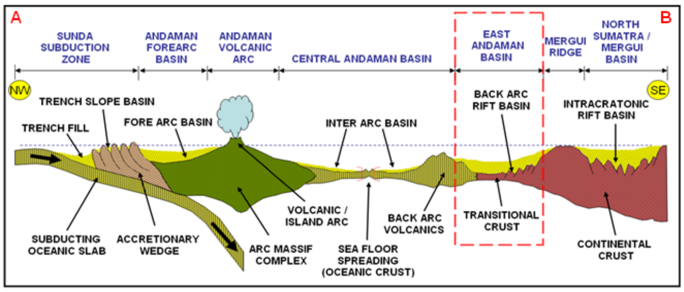
Introduction

The East Andaman Basin, which is located along the western flank of NE-SW trending Mergui Ridge running across the Andaman Sea, is currently under ultra-deepwater regime with water depth varying from 1000 m to 3000 m. Exploration efforts by Eni India have already established a plausible petroleum system in its synrift sediments (Jha et.al, 2008, 2010). However, keeping in mind the global exploration efforts on deepwater petroleum systems over the last decade, the postrift deepwater setting of East Andaman Basin deserves critical attention by its own merit.

Seismic data show that the basin has a thick pile of postrift sediments (reaching up to 2500 m at places), deposited since Middle Miocene in shallow and deep marine environment under a restricted/ ponded setting. In this work, we put forward our interpretation to highlight the influence of the regional/ local tectonic events on postrift sedimentation in the East Andaman Basin study area. Careful analysis of the seismic data reveals typical shallow marine and deepwater deposition elements in the system (e.g. channel-levee complexes, incised valleys, canyon cuts, gullies, sheet sands, slumps, fan/ lobes, gravity flows/ mass transport complexes etc.) which can be directly associated with regional tectonic events. Using all these indications and by analyzing the seismic facies characters of the sediments, a comprehensive sequence stratigraphic model have been proposed, followed by a discussion on the plausible deepwater petroleum system of the basin. All these efforts point towards the fact that tectonics plays the most significant role in the basin building process.

Tectonics during Postrift East Andaman Basin





AAWC-Andaman Accretionary Wedge Complex; **CASFSZ**-Central Andaman Sea Floor Spreading Zone; **EAB**- East Andaman Basin; **IS**- Irrawaddy Shelf; **MA**- Mount Alcock; **MB**- Mergui Basin; **MR**- Mergui Ridge; **MS**- Mount Sewell; **MT**- Mergui Terrace; **NSB**- North Sumatra Basin; **SFZ** –Sagaing Fault Sone; **ST**- Sunda Trench; **WAFZ**- West Andaman Fault zone

Fig. 1: Regional map of Andaman Sea with major tectonic - geographic elements and a schematic cross section along the profile AB as shown in the map. The study area is shown shaded. The green arrows indicate the present pull-apart movement direction, whereas the red arrows show the recent sea-floor spreading direction.

The closure of Tethys at the present Sunda Subduction Zone caused back-arc extension along the margins of Sundaland to generate a number of rift basins. Western part of Sundaland now hosts roughly N-S/NNE-SSW trending basins (North Sumatra, Mergui, East Andaman etc.) which most likely originated during Late Eocene/Early Oligocene as pure extensional back-arc troughs (Jha et.al, 2008, 2010). However, since Early/Middle Miocene, the oblique subduction at Sunda Subduction Zone added a dominant right-lateral transtensional component into the pre-existing stress regime (Curray 2005) which resulted in regional pull-apart tectonics and strike-slip movements. The latest and most prominent manifestation of this can be seen at the Central Andaman Basin, which is a nascent sea-floor spreading zone that supposedly was initiated as a marine rift in Late Miocene and started drifting at Early Pliocene (Raju, 2005). The tectonic elements of the region are illustrated schematically in Fig. 1.

All the above-mentioned tectonic events are manifested in the rock column of the East Andaman Basin, though the clarity varies from place to place. It can be assumed (since no drilling record is available in the basin) that the postrift deposition of East Andaman started with a major fall in sea-level (possibly simultaneously with Late Oligocene fall at North Sumatra) as a result of thermal subsidence and shallow marine setting prevailed around the area. Later, during tectonic quiescence, regional transgression inundated the area in natural course, and East Andaman Basin went into deepwater regime during Early-Middle Miocene. However, since this time, the East Andaman area can be considered as a restricted/ ponded basin, with Mergui Ridge acting as the shelf-edge / shelf-barrier at the east and Mount Sewell rising at the western flank of the basin. During Late Miocene, the Central Andaman Rift initiated due to the interplay of oblique tectonic forces in the region and this event turned a normal back-arc extension area into a rotating right-lateral pull-apart region. Intense clock-wise rotation of the area eventually guided massive subsidence in the East Andaman. It appears from the seismic that the motion was restricted to the east, i.e., at the western margin of the Mergui Ridge, which the authors believe as the extension of Sagaing fault System. Later, during Late Pliocene, a nascent sea-floor spreading centre came into existence at the Central Andaman Basin area (NE-SW trending), which caused another forced subsidence in the East Andaman Area.

Depositional Architecture of Deepwater Sediments

The postrift sediments of the East Andaman Basin exhibit distinctive shallow and deepwater depositional elements throughout the study area. These are primarily controlled by the shelf-edge delta progradations at the upper slope of Mergui Shelf and subsequent lower slope/basin floor sedimentation; and gravity flows corresponding to the huge tectonic subsidence following the opening of Central Andaman Sea-Floor Spreading and related slope instability. Other processes that might have contributed in the system are contour currents and pelagic sedimentation, understandably least dominant processes in East Andaman basin floor until Late Pliocene. Some of these typical deepwater depositional architectures (Fig. 2) are briefly described in the following section.

- **Channel, Incised Valleys & Fill Deposits:** A number of submarine channel and incised valley features were identified throughout the section and they vary quite a lot in dimension depending upon the slope of basal surface and related sediment influx from Mergui Shelf. Most of the channel is devoid of sinuosity though and appear to be smaller due to restricted nature of the basin. Some of them, especially at the lower part of the postrift fill, they are mostly tectonically (fault) controlled.
- **Channel-Levee and Overbank Sediments:** Typical channel-levee and overbank deposits are present especially at the lower part of the sequence, and often show stacked channel-levee pattern.
- **Submarine Canyons Fill:** Canyon fill sediments are observed in the basin in two categories, 1) the slope-defined canyons which run perpendicular to the Mergui Ridge trend in a roughly NW-SE direction; 2) the tectonic-controlled one which runs parallel to the strike of Mergui (NE-SW) before terminating against the regional strike slip fault system at the western limit of the basin.
- **Submarine/Basin Floor Fans:** A number of fan deposits can be seen in the area, deposited in the lower part of the sequence in response to the sea-level changes at the upper slopes.
- **Sheet Sands:** Some of the features in the area appear to be like the sheet-sands.
- **Mass Transport Complexes & Mud flows:** The mass transport complex in the Basin requires special attention for its enormity. Several mud flow units can be observed basin-wide, as well as typical turbidites.

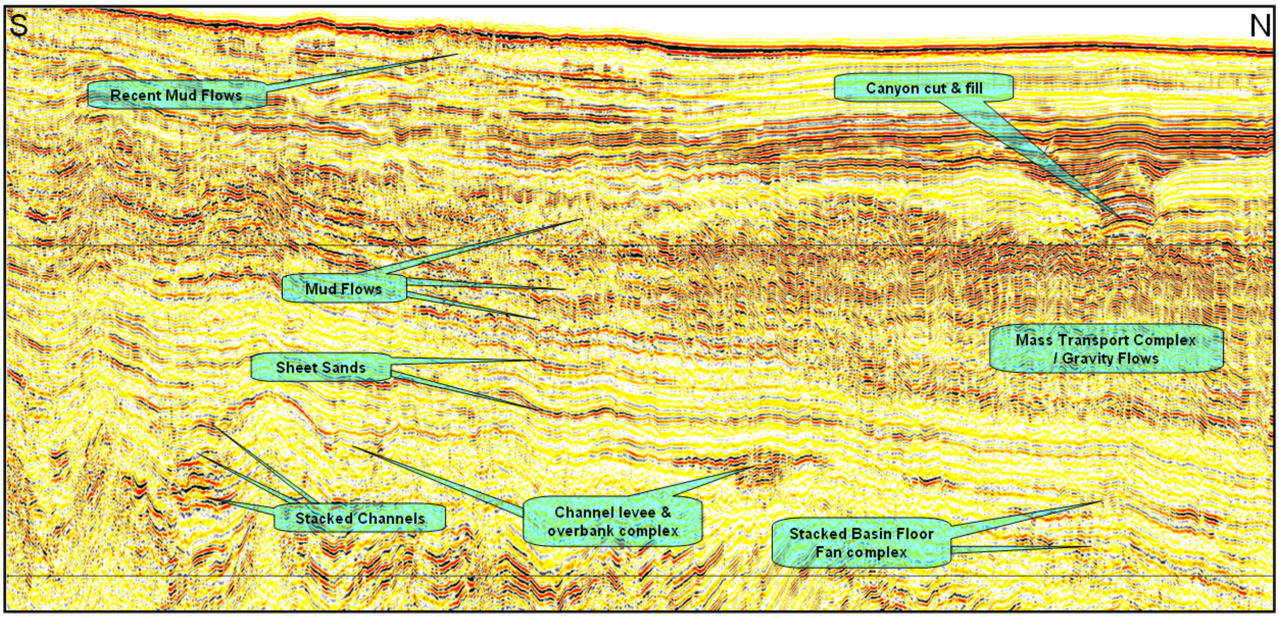


Fig. 2: Representation of shallow and deepwater depositional elements as identified in the seismic data in the S-N direction, which is close to the regional strike (NNE-SSW) of the basin.

Seismic Facies Identification

The analysis of seismic parameters (amplitude, continuity, frequency), reflector terminations (onlap, downlap, truncation) and external geometries (tabular, lenticular, mounded, wedge etc.) allowed the recognition of four main seismic sequences in the postrift sediments of the East Andaman Basin. Each of these seismic sequences is then further sub-divided into two seismic facies after analyzing the characters. Brief descriptions of each of them are provided below.

• ***Seismic Sequence 1*:** This is the bottom-most seismic sequence which represents the infilling of rift mini-basins during the earliest postrift sedimentation.

Facies SF1A: Reflections with low-medium values of amplitude, medium values of frequency and continuity.

Facies SF1B: Wedge shaped with parallel internal reflection usually with erosive top; very low values of amplitude, continuity and frequency; higher values at channel infillings and fan lobes.

• ***Seismic Sequence 2:*** This sequences onlaps onto the SF1B and is more or less continuous and undisturbed.

Facies SF2A: The main onlapping facies, wedge shaped with parallel internal reflection with an undulating basal surface; low to medium values of amplitude, continuity and frequency.

Facies SF2B: Wedge shaped with parallel internal reflection; low values of amplitude and medium values of frequency, higher values at channel infillings and fan lobes.

• ***Seismic Sequence 3*:** This is most chaotic and disturbed sequence overlying the SF2B.

Facies SF3A: High frequency-moderate continuity facies with medium to high amplitude values. At places lenticular in shape, heavily disturbed by gravity faults.

Facies SF3B: Chaotic seismic character, with almost zero frequency, very low amplitude and very low continuity. Basal surface erosive, indicating mass transport complexes.

• ***Seismic Sequence 4:*** Topmost seismic facies, with occasional bright reflections with moderate to high amplitude, moderate to low continuity and frequency.

Facies SF4A: Wedge shaped usually parallel reflections with medium values of frequency and continuity and low values of amplitude. Some onlapping events are also seen.

Facies SF4B: Typical mass transport complex characters with almost zero frequency, very low amplitude and very low continuity, few smaller channel geometries.

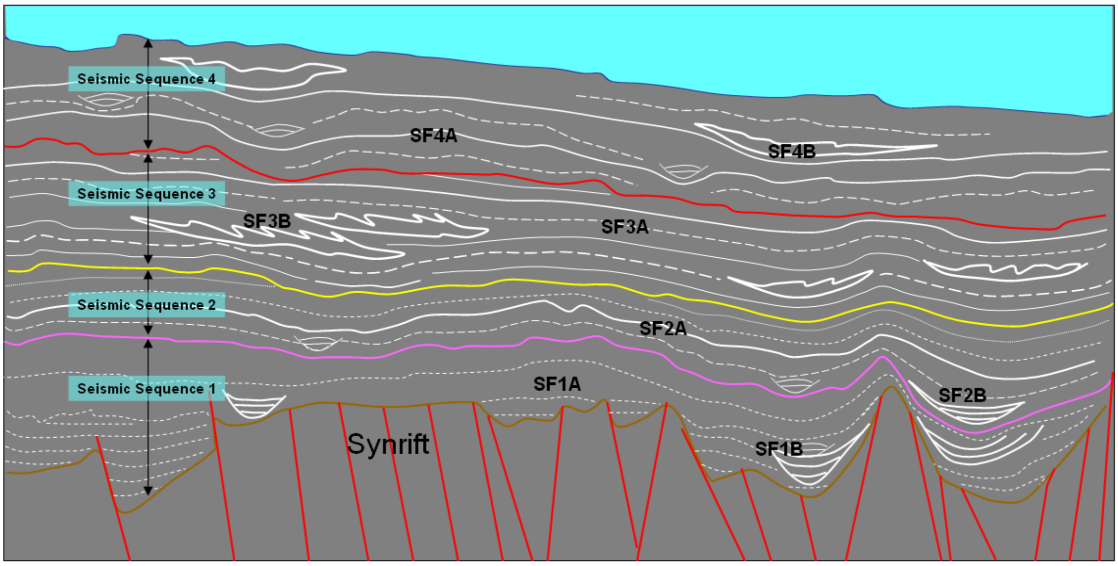
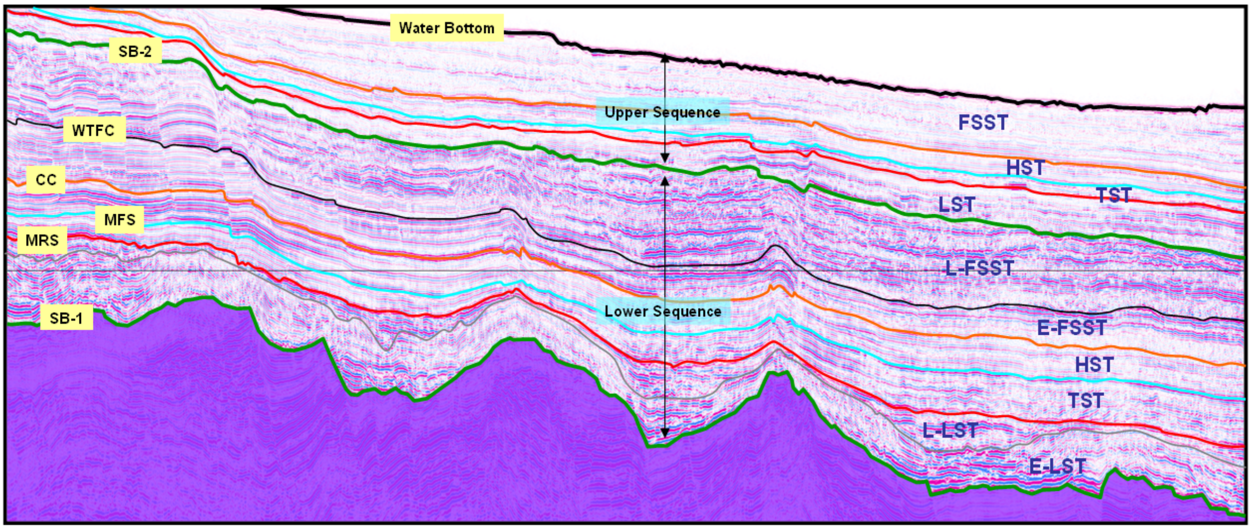


Fig. 3: Representation of seismic facies as seen in the seismic data along the strike of the basin.

Sequence Stratigraphic Analysis

Recognition of the sedimentary bodies and identification of seismic facies facilitated the understanding of the sedimentation processes and a comprehensive sequence stratigraphic model building. The postrift sedimentary column of East Andaman Basin can be grossly divided into two sequences (Upper & Lower Sequence), each starting with the erosive lowstand systems tracts. Each of the sequences can later be sub-divided into the other systems tracts, namely lowtstand (LST), transgressive (TST), highstand (HST) and falling stage systems tracts (FSST) in the same order of development in response to the sea-level fluctuations and sedimentation pattern at the slope/shelf of the basin. However, it is not possible to build the complete fluvial-shallow marine/shelf- deepwater sequence stratigraphic model due to lack of data restricting the reconstruction of shelf-edge around the Mergui Ridge. A rather simplistic approach, through the identification of the typical process sedimentology and depositional features, was applied to work out the sequence stratigraphic model in the basin. A comprehensive model is shown in Fig. 4 with anticipated systems tracts and bounding surfaces.

• ***Lower Sequence:*** Soon after the cessation of the rifting, the synrift sediments of the basin were exposed due to typical marine regression and erosion which is demarcated by the conspicuous angular unconformity. This unconformity is the basal sequence boundary (green marker in Fig. 4). Earliest postrift sedimentation in the basal LST is marked by the presence of numerous channels/incised valleys and their fill deposits, as well as frontal fans/lobes deposited in a shallow marine to upper slope setting. Early LST in the basin could be differentiated from the Late LST by the presence of straighter channels and bigger lobes (gray marker). This systems tract probably corresponds to the Late Oligocene sea-level drop and is bounded by the maximum regressive surface (red marker) at the top. By Early Miocene, sea-level rise towards the Mergui Ridge/Shelf area lowered the sediment input into the deeper part of the basin, as accommodation space shifted considerably east-wards as represented by strong shelf-edge delta sedimentation in Mergui and North Sumatra Basin. In East Andaman area, the TST probably corresponds to the lower slope region in a deeper water environment, which can be identified through marine onlaps over the maximum regressive surface. The maximum flooding surface (indigo marker) defines the top of the TST, and then it gradually transcends into the HST. Throughout the Middle Miocene, minor fluctuations in sea-level represent the HST and is typically an eventless section. Being in deepwater lower slope or in abyssal plane, HST in East Andaman basin is sediment-starved (as the accommodation space remained at the shelf) and is represented by condensed sections (orange marker). In response to the rift opening at the Central Andaman Basin during Late Miocene, massive forced regression caused rapid subsidence in the East Andaman which in turn is characteristically demonstrated by the massive influx of mass transport complex sediments/gravity flows/mud flows (FSST). The early FSST started with some mud-flows and scouring of the HST condensed section and became more dominant at the later stage with increased mass transport movements. The two stages of FSST can be differentiated by the seismic characters (black marker).



LST- Lowstand Systems Tract (E-Early, L-Late); **TST**- Transgressive Systems Tract; **HST**- Highstand Systems Tract; **FSST**- Falling Stage Systems Tract (E-Early, L-late); **SB**- Sequence Boundary; **MRS**- Maximum Regressive Surface; **MFS**- Maximum Flooding Surface; **CC**- Condensed Section; **WTFC**- Within Trend Facies Trend;

Fig. 4: Representative seismic section showing the interpreted sequences and systems tract in the deepwater setting. The section is oriented roughly along SSE-NNW direction. The purple shaded area corresponds to the synrift sediments of East Andaman Basin.

• ***Upper Sequence:*** End of the FSST is marked by the LST at the onset of the Upper Sequence, which can be matched with the early stage of Late Miocene sea-level fall, and is quite uncharacteristic compared to the Lower Sequence since the dominant sedimentation process got shifted to typical abyssal plane/ basin floor setting with contour currents, suspension fall-out and pelagic settling. The LST (top as red marker)at the Upper Sequence still exhibits few entrenched channels and related events, the most important feature though being an enormous erosional canyon cut and its gradual filling (see Fig. 2). This canyon probably started as a slope dependent one, running in the basinal dip direction (NW), but soon it got entrapped into the vigorous strike slip movement at the restricted basin margin towards west and ended up flowing at roughly N-S direction as a tectonics-controlled canyon. Since upper part of Late Miocene, successive transgression and stand-still reigned over the basin for some time, which can be correlated to the thin eventless TST (top as indigo marker) and HST (top as orange marker) units, understandably as the condensed sections in ultra-deepwater setting. The last activity in basin occurred during the Late Pliocene-Pleistocene disturbance in the system, caused by the sea-floor opening at the Central Andaman Basin. This is now represented by the FSST with typical erosive events, mud flow features and other mass transports.

Petroleum System

The petroleum system in this particular deepwater setting cannot be discussed in detail since there is no “direct evidence” through drilling about the potential elements. However, seismic facies analysis and sequence stratigraphic framework allow conceptualization of a few elements of a working petroleum system. It was observed that the basin have attained considerable depth at the western and northern part. With a higher heat flow estimated in the region (around 4.5°C/100m), maturity of the petroleum system can be envisaged. In addition, the restricted marine environment and rapid deposition of the deepwater sediments could lead to a plausible biogenic gas play as well.
1) **Source**: The TST and HST units in the Lower Sequence are most likely to possess good source potential, as they seem to be deposited in a restricted marine setting. Most importantly, the early transgressive rocks in the North Sumatra and Mergui Basin have been found to hold excellent

source potential (Type II/III kerogen, TOC 0.4-2.6), which further enhances the possibility of finding a good source in East Andaman.

2) **Reservoir**: The LST & FSST sand accumulations in channel fills and levee/ overbank, submarine/basin-floor fan, sheet sands and turbidites (preferably originating from the high-density turbidity flows) are strong contenders for good quality reservoirs. Early postrift reservoirs in North Sumatra and Mergui are found to be the most prolific, as they hold a large number of discoveries, quite a few being giants within them.

3) **Seal**: Being in the deepwater environment, sealing is quite evident through out except the LST and FSST units of Lower Sequence.

4) **Trap:** Mostly stratigraphic traps are expected, though at places structural traps can work where reactivations of earlier structural system have taken place.

5) **Charge & Migration**: Source intervals, once matured, can charge the nearby reservoir intervals through short-distance horizontal and vertical migration processes.

Conclusion

Regional geological understanding and seismic interpretation results conclusively indicate that the postrift sediments of East Andaman Basin were deposited in a shallow marine environment during early postrift stage before gradually passing into the deepwater to ultra-deepwater setting at present time. Depositional architecture, as conceived from the seismic data, establishes the close relation between tectonic control and sedimentation in the region. Regional plate tectonics, especially the creation and development of Central Andaman Sea-floor Spreading Zone, played a pivotal role in building the East Andaman Basin. The speculative petroleum system, as discussed, also depends largely on the tectonics-controlled processes and hold significant potential in this frontier exploration area.

Acknowledgement

The authors are grateful to Eni management and JV partners for the permission to publish the material contained in this paper and express their special thanks to exploration colleagues of Eni India (Delhi) and Eni Head Quarters (Milan) for their kind review and comments.

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