Seismic insights: unveiling potential play types in the Andaman-Nicobar Basin via paleo-tectonic and paleo-environment analysis

Surajit Gorain, Directorate General of Hydrocarbons under the Ministry of Petroleum and Natural Gas, India*

Summary

The Andaman-Nicobar Basin, an active margin basin in the northeastern Indian Ocean, is characterized by a rich and complex tectonic and evolutionary history. The recent acquisition of seismic data by the Indian Government has opened a unique opportunity to resolve the geological mystery of the basin evolution and envisage its potential play types. This basin is a classic example of an arc-trench system, where the Indian plate subducts beneath the Sunda plate. Paleo-tectonic and paleo-environment analysis suggests that the basin underwent a rift and extensional faulting during the late Eocene-Oligocene period. This process was driven by transtension and pull-apart tectonics, with sedimentation transitioning from fluvial-lacustrine to fluvial-marine deposits. During the early post-rift phase, the basin experienced regional post-rift thermal subsidence, leading to marine transgression and the influx of shallow marine clastic and carbonates. In the later post-rift phase, compression and inversion tectonics induced notable subsidence, driven by late Miocene rifting and seafloor spreading in the central Andaman Basin. This process led to the development of a deeper marine environment. The study anticipates four potential play types in the Andaman Basin: syn-rift clastic, early post-rift carbonate, early post-rift clastic, and late post-rift clastic. Each play type presents unique exploration opportunities in the future.

Introduction

The Andaman-Nicobar Basin, depicted in Fig.1, is a geologically significant area situated in the southeastern corner of the Bay of Bengal. It spans an extensive area exceeding 225,000 square kilometers, encompassing both shallow and deep-water regions (Curray 2005; Mohan et al. 2006; Srivastava, Dave, and Dangwal 2021). This basin stretches from Myanmar in the north to Sumatra in the south and is an active marginal basin consisting of all elements of an arc-trench system (Curray et al. 1982; Kamesh Raju, Aswini, and Yatheesh 2020). The basin is classified as a frontier basin in terms of oil and gas exploration (Das and Srivastva 2015). Despite being a frontier, the basin attracts the interest of geoscientists due to its proximity to hydrocarbon-rich regions such as North Sumatra, Mergui, and Irrawaddy, which exhibit analogous geological characteristics (Morley and Searle 2017). The basin is believed to contain large reserves of hydrocarbons (Mohan et al. 2006). The presence of oil seepages and the discovery of hydrocarbon gas from mud volcanoes in the middle Andaman region stimulated the commencement of hydrocarbon exploration in the 1960s (Das and Srivastva 2015). Since then, exploration efforts in this basin have progressively increased. The basin has good seismic coverage of over 55,778 LKM of 2D seismic data, 20,639.7 SKM of 3D seismic data, and 19 wells (Fig. 1). Out of these wells, only one well, situated east of Andaman Island encountered hydrocarbon from the Miocene sediments. These exploration activities mainly targeted the back-arc region, i.e., the eastern part of the basin, while the western part was largely unexplored. To bridge the data gaps and enhance exploration, the Government of India (GOI) has taken proactive steps. Recently, during the fiscal years 2021-23, the GOI acquired an additional 23,500 LKM of 2D seismic data (Fig. 1), focusing on both the back and fore-arc basins. The GOI also plans to launch an extensive drilling campaign. This strategic initiative undertaken by the GOI has boosted the exploration drive and motivated us to reassess the existing and newly acquired seismic data with a fresh look. The recently obtained dataset provides an exceptional opportunity to explore the tectonic intricacies of the basin and decode its evolutionary history. The primary objectives of this study are:

- To examine the basin's paleo-tectonic evolution and prediction of the paleo-sedimentary environment.
- To conceptualize the key play types to gain a deeper understanding of the geological dynamics and guide future hydrocarbon exploration efforts in the basin.

Geological setting

The Andaman-Nicobar Basin took shape during the Cretaceous period as a result of intricate tectonic processes, notably the subduction of the Indian plate beneath the Burmese microplate along the Andaman Trench (Curray 2005; Pal et al. 2003; Ghosh, Bandyopadhyay, and Morishita 2017; Mukhopadhyay 1984). This subduction process resulted in the formation of the outer high arc complex, which led to the creation of a forearc basin located between the volcanic arc and the outer high arc (Morley and Searle 2017; Cochran 2010; Arora and Misra 2011). Subsequent tectonic activity led to the uplift and formation of the Andaman-Nicobar Ridge, a chain of islands that constitutes a significant part of the Andaman-Nicobar Basin (Arora and Misra 2011; Kamesh Raju et al. 2004). In addition to its geological significance, the Andaman island chain plays a pivotal role in the broader geotectonic framework referred to as "The Great Indonesian Island Arc System" of the East

Mapping potential play types through paleo-tectonic and paleo-environment analysis in the Andaman-Nicobar Basin

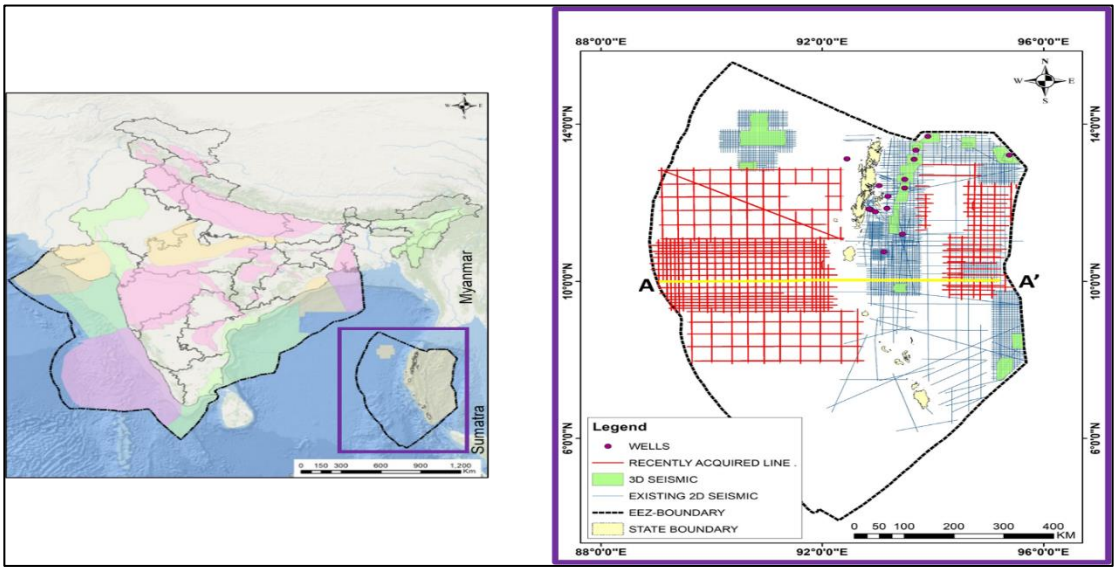

Figure 2:Geographical Map of the Andaman Basin and the Database

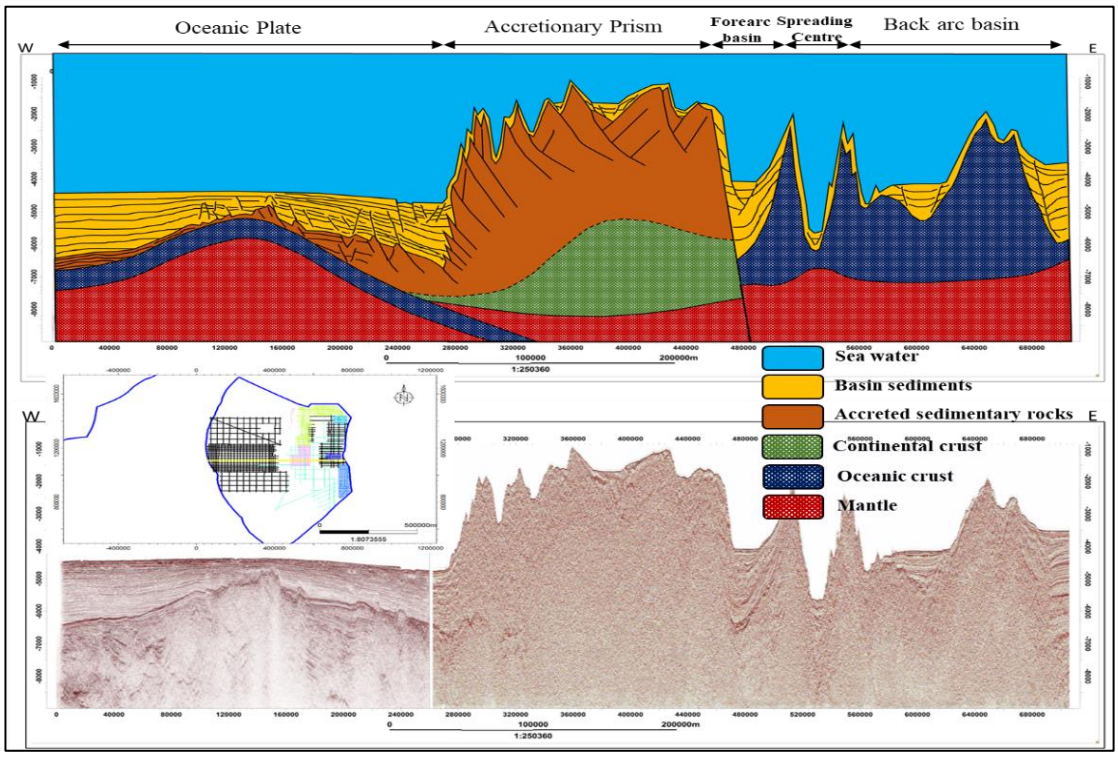

Figure 2:Distinctive Features of a Trench-Arc System Illustrated on a West-East Profile through the Andaman Basin.

Indies (Curray 2005; Curray et al. 1982). This arc system is characterized by geological processes like plate subduction and volcanic activities, which profoundly influence the geology and its associated representation of arc-trench

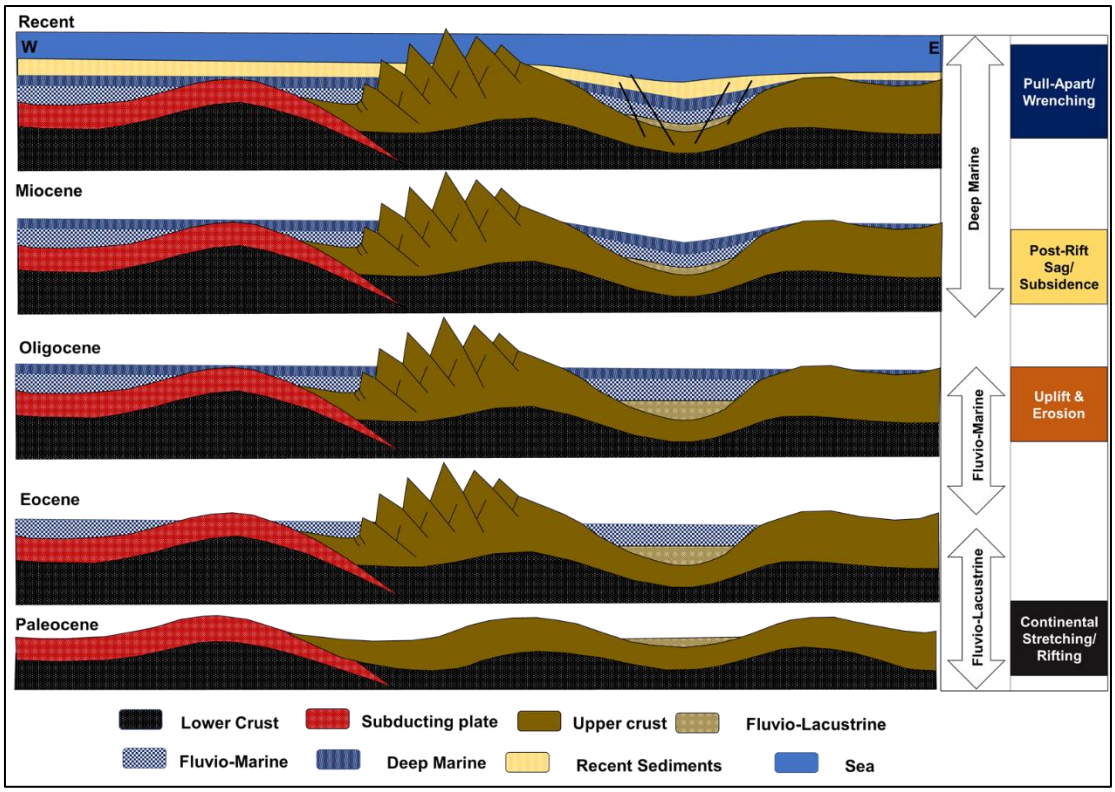

Figure 3: Schematic Diagram for Paleo-Structure Analysis of the Andaman Basin: Insights from a Selected W-N Seismic 2D Line. The maps provide a visual representation of paleo-structures, basinal configuration, and sedimentation patterns within the study area during different time periods: a) Early Eocene b) Early Oligocene c) Late Oligocene d) Early Miocene e) Recent.

system features. Fig. 2 provides a comprehensive schematic, offering valuable insights into its fundamental components and interconnected features. This diagram reveals the distinctive elements of the system, enhancing our understanding of its intricate nature and the involved geological processes.

Methodology

The identification of potential play types within the Andaman Basin is carried out using the principle of paleo-flattening to build the conceptual paleo-tectonic evolution of the basin over geological time. Concurrently, a comprehensive paleo-environmental analysis is conducted to understand the paleogeography and significance of different geological events that play a pivotal role in identifying potential play types within the basin.

The Andaman-Nicobar Basin has undergone a complex tectonic history, characterized by multi-phase structural evolution. Key contributors who have built the tectonic framework and discussed the tectonic evolution of the basin include Arora & Misra (2011); Chakraborty & Pal (2001); Cochran (2010); Curray (1989); Dasgupta & Mukhopadhyay (1993); Diehl et al. (2013); Ghosh et al. (2017); Mukhopadhyay (1984); Pal et al. (2003); Scotese et al. (1988). A conceptual schematic diagram (Fig.3) depicting various stages of the paleo-environment and its evolution over geological time has been prepared using the paleo-flattening principle and the hypotheses drawn by various authors over time. The intricate tectonic history of the Andaman Basin manifests in three distinct basin development phases – the syn-rift, the early post-rift, and the late post-rift.

Syn-rift phase: The initiation of basin formation started during the late Eocene-Oligocene period through rift and extensional faulting, driven by transtension and pull-apart tectonics along NW-SE-oriented strike-slip faults (Kamesh Raju, Aswini, and Yatheesh 2020; Kamesh Raju et al. 2004). Sedimentation was potentially initiated by the end of the Eocene, persisting throughout the early Oligocene (Kamesh Raju et al. 2004). The paleo-environmental analysis suggests a during the earlier phase of the syn-rift fluvial-lacustrine sediments were deposited and as time progressed fluvial-

marine deposits became prominent (Srivastava, Dave, and Dangwal 2021).

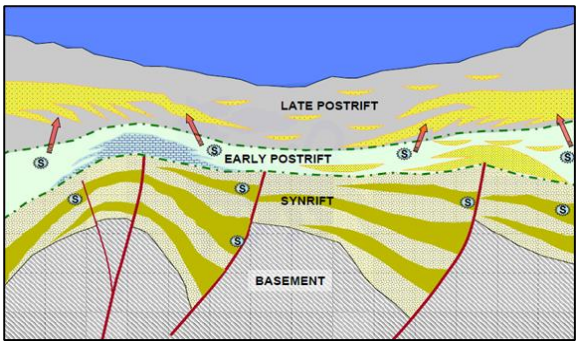

Figure 4: Schematic of the possible play types with the Andaman Basin.

Early post-rift phase: During the late Oligocene-early Miocene the basin witnessed regional post-rift thermal subsidence and sag(Kamesh Raju et al. 2004). As a result, the basin was flooded with marine transgression from the northwest in east Andaman which brought the shallow marine clastic and carbonates on intra-rift basement highs (Srivastava, Dave, and Dangwal 2021). During the late Oligocene, the basin also saw localized basin inversions.

Late post-rift phase: The late post-rift phase was characterized by compression and inversion tectonics. The amalgamation of the Indian plate with the Eurasian plate led to a compressional setting in the back arc (Kamesh Raju, Aswini, and Yatheesh 2020). The east Andaman Basin experienced significant subsidence due to middle-late Miocene onward rifting and seafloor spreading activity in the central Andaman Basin. Consequently, the late post-rift stage in the east Andaman Basin likely developed in a deeper sea setting (Srivastava, Dave, and Dangwal 2021).

Results and discussion

The evolutionary history of the basin indicates that the basin has undergone three distinct phases of rifting, i.e., syn-rift, early post-rift, and late post-rift (Fig 3). The syn-rift phase involved late Eocene-Oligocene rift and extensional faulting, transitioning sedimentation from fluvial-lacustrine to marine. The early post-rift phase, marked by late Oligocene-early Miocene activity, saw thermal subsidence, sag, and basin inversions. The late post-rift phase, influenced by the Indian-Eurasian plate amalgamation, featured compression, inversion tectonics, and significant subsidence. The integration of the paleo-tectonic and paleo-environmental analyses helps in identifying the possible play types within the basin. As per the analysis, four major play types can be envisaged within the Andaman Basin (Fig. 4).

Syn-rift clastic play: The paleo-environment study reveals that during the syn-rift phase, there was a transition from fluvial-lacustrine to fluvial-marine sediments. These transitional sediments are crucial in oil and gas exploration as they influence source rock quality, hydrocarbon potential, and reservoir characteristics. Therefore, any traps (structural or stratigraphic) within these sequences can be considered ideal for hydrocarbon generation and accumulation.

Early post-rift carbonate play: The post-rift thermal subsidence and sag during the late Oligocene-early Miocene make the carbonate play important. The syn-rift lacustrine shales and shallow marine shales act as prolific source rocks to the early post-rift reefal carbonates deposited on existing structural highs. This play holds the potential for significant hydrocarbon reserves.

Early post-rift clastic play: The extensive shallow-marine deltaic sands in this play, make it a promising focus for future exploration. Intra-formational and transgressive-regressive shales acting as effective seals, combined with traps formed through draping over existing structural highs, present opportunities for successful discoveries.

Late post-rift clastic play: The late post-rift clastic play holds considerable promise for future hydrocarbon exploration. Reservoir intervals comprise late post-rift regressive delta sandstone and fan deposits, possibly charged by early post-rift transgressive marine shales. The presence of intra-formational regressive shales as effective seals adds to the appeal of this evolving play. Exploring these distinct play fairways in the Andaman Basin will open exciting possibilities for significant hydrocarbon discoveries in the future.

Conclusion

In conclusion, the thorough investigation of the Andaman Basin has yielded several significant insights:

- The intricate tectonic history of the basin has been further clarified, unveiling three distinct phases: syn-rift, early post-rift, and late post-rift.
- Analyses of paleo-tectonics and paleo-environments have pinpointed four major hydrocarbon play types within the basin. Each of these offers unique opportunities for exploration and the potential for significant hydrocarbon discoveries.

These findings not only augment our understanding of the geological dynamics of the Andaman Basin but also chart a course for future hydrocarbon exploration in the region. The potential for substantial hydrocarbon discoveries in these identified play types bodes well for the future direction of oil and gas exploration in the Andaman Basin.