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Original Paper

Cenozoic morphological evolution of the Tanintharyi Shelf carbonate platform, Andaman Sea Basin: Implications for hydrocarbon reservoir potential

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ABSTRACT

The Tanintharyi Shelf in the Andaman Sea Basin hosts a significant yet largely underexplored Cenozoic carbonate platform with substantial hydrocarbon potential. This study utilizes an integrated analysis of high-resolution 2D and 3D seismic reflection data, well data, and regional stratigraphic information to elucidate the morphological evolution of this platform and assess its implications for hydrocarbon reservoirs. The findings reveal that the platform started in the Early Miocene as isolated patch reefs on fault-bounded structural highs, eventually evolving into an asymmetric, westward-dipping rimmed shelf. Its development was influenced by the interaction of syn-sedimentary tectonics, which created accommodation space and a paleotopography that shielded the shelf from clastic influx, along with eustatic sea-level fluctuations that caused cycles of sediment buildup, subaerial exposure (leading to karstification), and back-stepping. Ultimately, the platform was drowned and buried during the Middle to Late Miocene due to accelerated post-rift subsidence combined with increased siliciclastic input, the latter driven by the Neogene uplift of the Tibetan Plateau. The reservoir potential varies across the platform, with the highest concentrations in wave-resistant reefal margin facies and potential dolomitized zones on paleo-highs, where primary porosity was enhanced by meteoric diagenesis. However, reservoir quality is compartmentalized due to tight cementation and mud-rich intervals. The widespread presence of gas chimneys and pockmarks indicates that the platform functions both as a reservoir and a conduit for fluid migration. Therefore, this study establishes a predictive tectonostratigraphic framework, emphasizing that successful exploration in this complex environment requires high-resolution mapping of facies boundaries, diagenetic features, and fault architecture, combined with seal integrity analysis. The findings offer a new model for understanding the evolution of carbonate reservoirs in tectonically active, rift-margin settings worldwide.
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1. Introduction

Carbonate platforms represent one of the most economically vital and geologically complex sedimentary systems on Earth, serving as the host for more than half of the world's conventional hydrocarbon reserves and sustaining critical marine ecological habitats (Jardine and Wilshart, 1987; Harris and Vlaswinkel, 2008; Joshi and Singh, 2019; Garland et al., 2025). Their exceptional reservoir potential stems from inherent high primary porosity and permeability in reefal, grainstone, and shoal facies, which can be further enhanced by post-depositional diagenetic processes such as karstification, dolomitization, and fracturing—features that make carbonate platforms a core target for global hydrocarbon exploration. Among Cenozoic carbonate systems, Miocene platforms stand out for their remarkable productivity, as exemplified by the Central Luconia carbonate province in the South China Sea, where large-scale reef-bank complexes have yielded giant gas and oil discoveries and have become a benchmark for understanding tropical carbonate deposition (Lü et al., 2013; Mathew et al., 2020; Bashir et al., 2021; Rankey, 2023; Henglai et al., 2024). However, the morphological evolution and reservoir architecture of carbonate platforms are governed by the intricate and non-linear interplay of multiple dynamic factors, including eustatic sea-level fluctuations, syn-depositional tectonic activity, climatic conditions, sediment supply, and biogenic productivity (Joshi and

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Fig. 1. **(a)** Geographical distribution of the Andaman Sea Basin in the Indian Ocean; **(b)** the spatial distribution of major sub-basins and tectonic elements of the Andaman Sea region associated with the Indo-Eurasian subduction zone, modified from Curray (2005), Morley et al. (2022), and Raveendrasinghe et al. (2024), showing the Tanintharyi Shelf study area. IBR: Indo-Burma Range.

Block, to the north by the M-14 Block containing the Yetagun Gas Field, to the northwest by the Total Energies and Eni-operated MD-4 Block, to the west by the Shell-operated MD-5 Block, and to the south by the MOGE-operated M-16 Block (Fig. 3).

3.2. Dataset

The M-15 offshore block in the Andaman Sea, Myanmar, has been covered by two distinct 3D seismic surveys to evaluate its hydrocarbon potential. In 2016, Shell plc acquired a 1500 km^2 3D seismic dataset using parameters consistent with subsequent industry standards in the region. A more extensive 5600 km^2 3D seismic survey was then executed by China National Offshore Oil Corporation (CNOOC) between February 6, 2018, and April 26, 2018, utilizing a CNOOC-operated seismic vessel. This 2018 campaign employed a marine towed-streamer 3D seismic reflection method, with a GI airgun array (4030 in^3 total volume, 7 m depth, 25 m shot interval) and 12 streamers (7050 m total length, slanted at 8–40 m

Fig. 2. Sequence stratigraphic framework of the study area, as controlled by the M15-B-1 exploration well synthesized from Bolton et al. (2013), Cao et al. (2015), Campbell et al. (2018), Jöhnck et al. (2020), Miller et al. (2020), Komar and Zeebe (2021), Mahattanachai et al. (2021), and Zhang et al. (2022). The stratigraphic architecture of the study area emphasizes major tectonostratigraphic transitions during Oligocene–Recent basin evolution. The figure highlights the phase of carbonate platform development approximately from Late Oligocene to Early Miocene in the Andaman Sea Basin under complex interactions among tectonic events and sea-level change.

depth, 564 channels, 12.5 m receiver interval). The recording system operated at a 2 ms sample rate, with a 2 Hz low-cut filter and 200 Hz high-cut filter, and a record length of 8192 ms. The final processed dataset for the block integrates both the 2016 and 2018 surveys, providing a comprehensive subsurface imaging framework for exploration and reservoir characterization (Fig. 3).

In addition to the 3D dataset, an extensive 2D seismic dataset covering 5100 km (Fig. 3), collected during three exploration programs from 1979 to 2004, was used. These 2D lines featured high-resolution parameters with 12.5 m channel spacing, 25 m gun spacing, and 2 ms sampling intervals. These data provide comprehensive coverage of the M-15 Block, effectively imaging major tectonic structures in various orientations, thereby establishing a solid framework for structural and stratigraphic analysis.

3.3. Methodology

This study employed an integrated analysis of 2D and 3D seismic reflection data (Fig. 3) to investigate the morphological evolution of the Tanintharyi Shelf carbonate platform and its implications for hydrocarbon reservoirs. The seismic data were processed and examined using the Petrel E&P® Software Platform. The approach began with a comprehensive review of existing literature to establish the regional geological context. Due to limited direct well control in the study area, the seismic stratigraphy was calibrated by incorporating data from exploration wells and published chronostratigraphic information from adjacent basins, specifically the Martaban and Mergui basins (Polachan and Racey, 1994; Racey and Ridd, 2015b; Morley, 2017; Raveendrasinghe et al., 2024) (Fig. 2).

Six key chronostratigraphic boundaries (TA to TF) were identified, enabling the mapping of five major seismic horizons ranging from the Quaternary to the Early Miocene periods. The interpretation of these horizons was carried out through a combination of automatic 3D tracking and manual refinement on a seismic grid with a spacing of 50 m $\times$ 50 m, extending from the seafloor to the basement. This process was further supported by data from the M15-B-1 exploration well. The horizons were then correlated with the region's established Cenozoic stratigraphy, facilitating the reconstruction of depositional sequences and environmental changes, especially sea-level fluctuations in the Andaman Sea Basin. Additionally, detailed seabed topography data were incorporated with subsurface seismic interpretations to map submarine geomorphological features and their relationships with underlying structures.

To clarify the internal architecture of the carbonate platform and the pathways of fluid migration, a set of seismic attributes was extracted and thoroughly analyzed. Root-mean-square (RMS) amplitude attributes were used to identify strong amplitude anomalies associated with significant unconformities and lithological contrasts (Chen and Sidney, 1997; Wang et al., 2025). Variance attributes were selectively filtered to improve the delineation of intervals mainly composed of carbonate lithologies and to detect structural discontinuities (Chen and Sidney, 1997; Wang et al., 2025). These attributes supported a spatial and temporal analysis of fault systems and features related to fluid

Fig. 4. **(a)** Uninterpreted and **(b)** interpreted M1507_07 seismic profile from the East Andaman Basin to the Tanintharyi Shelf (refer to Fig. 3 for detailed location information), illustrating the stratigraphic configuration with the carbonate platform along the shelf margin (Qiao et al., 2023; Jin et al., 2024; Raveendrasinghe et al., 2024).

stratigraphic foundation for carbonate platform initiation. This interval is characterized by deltaic sandstones lapping onto the eroded basement surface, with contemporaneous shallow-marine carbonates forming selectively on structural highs (Figs. 2 and 4). In the M15-B-1 stratigraphic section, the Early Miocene carbonate platform developed within this interval, enveloped by basal fanglomerate and fluvio-deltaic sandstones of the Kantang Formation, with local thin marine shale layers of the Yala Formation (~73 m thick) (Figs. 2 and 4). Subsequent tectono-sedimentary activity, particularly the transpressional episode during the Early Miocene, induced erosional modification and morphological fragmentation of the early platform, a stratigraphic response that influenced the platform's early growth pattern.

The Middle Miocene succession, demarcated by the PE-3 unconformity, consists primarily of shallow-marine shale (Trang Formation) with scattered deltaic sandstones (Surin Formation). This interval coincides with the transpressional tectonic regime on the Tanintharyi Shelf. The Late Miocene sequence, above the PE-3 unconformity, is dominated by marine silty shales with carbonaceous detritus and siltstones (Thalang Formation) (Figs. 2 and 4), recording accelerated basin subsidence linked to Andaman Sea seafloor spreading and a marked increase in siliciclastic flux—a stratigraphic change that directly triggered the drowning of the carbonate platform.

The Pliocene (TC–TB) and Quaternary (TB–TA) sequences, separated by the PE-5 unconformity, are composed of alternating marine silty shales and pro-deltaic Martaban siltstones (Takua Pa Formation) (Figs. 2 and 4) and represent the final stratigraphic stage of carbonate platform burial. This interval is characterized by intensified deltaic progradation, slope instability, chaotic seismic facies, submarine landslides, and canyon incision on the slope (Figs. 2 and 4), with widespread siliciclastic deposition completely smothering the residual carbonate platform and forming the regional cap rock over the carbonate reservoir system.

Seismic facies and thickness patterns across the shelf–basin transition exhibit a pronounced asymmetry (Figs. 5 and 6), driven by tectonic subsidence, eustatic sea-level fluctuations, and variable clastic input—all of which are encoded in the stratigraphic record and directly modulated carbonate platform morphology (Racey and Ridd, 2015c; Morley, 2017; Raveendrasinghe et al., 2024). Seismic reflections are parallel to subparallel and continuous across carbonate structural highs, reflecting stable shallow-marine conditions favorable for carbonate precipitation, while reflections become distorted, discontinuous, and thicken basinward, where shelf carbonates laterally pass into prograding deltaic and basin-fill siliciclastics (Figs. 5 and 6). Unconfirmed Late Oligocene strata beneath parts of the shelf and localized fan-shaped deposits east of the Mergui Ridge indicate a complex early depositional environment, with potential lacustrine or lacustrine-sourced facies analogs that may have influenced the initial paleotopography for carbonate nucleation (Raveendrasinghe et al., 2024).

Thus, the Tanintharyi Shelf's stratigraphic framework—defined by regional unconformities (PE-1 to PE-5), alternating carbonate and siliciclastic depositional environments, and sharp lateral facies changes (Figs. 2, 4 and 6)—not only provides the temporal and spatial context for carbonate platform evolution but also controls the distribution of diagenetic processes (e.g., potential dolomitization) and the quality of prospective Cenozoic carbonate reservoir units on the shelf and adjacent basinal depocenters.

Fig. 5. **(a)** Uninterpreted and **(b)** interpreted M1507_07 seismic profile showing the carbonate platform developed on the shelf adjacent to the East Sagaing Fault. **(c)** Uninterpreted and **(d)** interpreted N–S trending seismic profile derived from the 3D seismic volume, illustrating the morphology of the carbonate platform buried beneath the fluvio-deltaic shelf stratigraphic configuration (refer to Fig. 3 for detailed location information).

4.2. Tectono-sedimentary setting and depositional environment of the carbonate platform

The Tanintharyi Shelf carbonate platform was predominantly developed during the Early Miocene rifting phase, constrained by the regional tectonic framework and depositional dynamics of the Andaman Sea Basin. It is spatially associated with an asymmetric synclinal structure that dips westward (Fig. 4), with sediment thickness maximizing along the axial depression and gradually thinning toward the eastern truncation margin (Fig. 7). This structural configuration was directly shaped by syn-rift faulting, which created favorable accommodation space for carbonate accumulation while isolating the shelf from excessive clastic influx (Raveendrasinghe et al., 2024).

Collectively, seismic stratigraphy documents the complete morphological evolution of the Tanintharyi Shelf carbonate platform—from fault-controlled patch reef initiation, to the formation of a diamond platform, and ultimately to exposure, karstification, and burial. This evolution reflects the combined influence of syn-rift faulting, sea-level fluctuations, and huge sediment input from Himalaya, resulting in a laterally and vertically heterogeneous, westward-dipping carbonate platform. Key morphological features, including marginal reef complexes and central dolomitized highs, have critical implications for the preservation and reservoir potential of the Early Miocene succession.

4.4. Pockmark trains, gas chimneys, and their constraints on carbonate platform morphology and hydrocarbon migration

Seismic interpretation of the Tanintharyi Shelf reveals widespread signs of subsurface fluid migration features, such as gas chimneys and pockmarks, formed above the carbonate platform (Figs. 9 and 10). The gas chimneys appear as vertical to nearly vertical zones of chaotic or disrupted reflections, usually extending upward from the carbonate platform into the overlying layers. These chimneys range from a few hundred meters to over 1 km in height, with diameters of 200–300 m, and often end within the Pleistocene to Recent shale layers. Their vertical continuity and high-amplitude chaotic internal reflections suggest that they are focused fluid channels connecting deep reservoirs to shallower sedimentary layers. Most gas chimneys are capped by acoustic blanking zones and subtle pull-down effects beneath the current seafloor, indicating localized gas-charged sediments or shallow fluid build-ups (Figs. 9 and 10).

Above these fluid pathways, distinct pockmark depressions are identified both within buried strata and on the modern seabed (Figs. 9 and 10). Paleo-pockmarks are primarily found within the Pliocene units, characterized by downward-tapering, concave “U”- to “V”-shaped geometries that truncate the underlying reflectors. In contrast, the present-day seabed features a well-developed, crescent-shaped pockmark train situated along the eastern geomorphologic high of the shelf. This pockmark train extends over 12 km in length, and ~2 km in width, with individual depressions reaching a depth of around 50 m and exhibiting steep-sided morphologies. The pockmark train delineates a belt of focused seepage along the structural margin of the carbonate platform (Fig. 11).

The height of gas chimneys and the distribution of the pockmark clusters within the strata indicate a two-stage process of fluid expulsion. The aggregation of pockmarks at the paleo-surface of the Pliocene, indicates the first stage of gas migration. A subsequent phase of renewed overpressure within the Pleistocene to Recent marine shale layer prompted reactivation of fluid flow along existing conduits, leading to the formation of the current seafloor pockmark pattern (Fig. 11). Although large-scale fault control is absent, minor fractures around the chimneys and local structural highs seem to have directed upward fluid movement from the carbonate platform.

5. Discussion

5.1. Evolution of the carbonate platform

The Tanintharyi Shelf in the Andaman Sea shows a progression from the formation and eventual decline of a large Cenozoic carbonate platform to later siliciclastic deposits (Figs. 2 and 9). The underlying Mesozoic basement relief and syn-sedimentary faulting (Qiao et al., 2023; Raveendrasinghe et al., 2024) provided localized space during the Late Oligocene, allowing deltaic sandstones to fill in structural lows while isolated shallow-marine carbonates started to form on uplifted highs. By the middle of the Early Miocene, initial carbonate buildups had connected into a more continuous platform, with sea-level changes and tectonic activity playing key roles in creating space for growth (Jöhnck et al., 2020; Miller et al., 2020) (Fig. 9).

Seismic and well data indicate that this platform developed as an asymmetric, west-tilted syncline, with consistent reef growth along the flanks of the structure high balanced by moderate subsidence along a central sag axis (Figs. 4 and 6). The early stage of platform formation featured small, mound-like reef structures forming on fault-bounded structure highs (Fig. 8). Seismic geomorphology shows a basal carbonate layer with weak, low-frequency reflections, interpreted as fine-grained micritic carbonates interlayered with thin clastic layers above the basement. In this period, isolated reef mounds, about 100–300 m wide, often thickened basinward and onlapped onto basement highs. These features suggest the carbonate platform started as patch reefs on structural highs during early syn-rift subsidence, reflecting localized carbonate deposition influenced by fault-related paleotopography amid ongoing clastic input (Racey and Ridd, 2015c; Morley, 2017) (Figs. 8 and 9).

As the reef development advanced, the reefs merged into a large, carbonate platform characterized by a consistent internal depositional pattern (Fig. 8). Seismic sections show a thick composite unit with continuous, moderate-amplitude reflections, indicating substantial algal and skeletal carbonate buildup (Hendry et al., 2021). The platform’s western side developed a steep edge made of wave-resistant reefal facies (Wilson, 1974; Hendry et al., 2021), while the eastern flank had a gentler slope (Figs. 8 and 9). This asymmetry created a clear proximal–distal facies gradient, with coarse-grained bioclastic carbonates dominating at the platform area and finer outer-shelf deposits extending outward area (Wilson, 1974). Vertical aggradation proceeded in tandem with the formation of accommodation space, and limited reef-edge shifting indicated a stable, upward-building carbonate platform under relatively low-energy conditions (Wilson, 1974; Hendry et al., 2021) (Figs. 8 and 9).

The end of the platform’s development was marked by a shift to exposure, erosion, and eventual drowning. A prominent unconformity at the top of the carbonate sequence, seen as a high-amplitude reflector with relief in seismic profiles, indicates subaerial exposure and karstification of the platform top surface (Figs. 5, 6 and 8). Later, sedimentation became increasingly dominated by siliciclastic materials (Morley, 2017; Raveendrasinghe et al., 2024): parallel, onlapping seismic reflections show deltaic and fluvial deposits that covered the carbonate platform (Racey and Ridd, 2015c; Qiao et al., 2023; Jin et al., 2024). During this period, the carbonate layer thinned landward and showed reduced continuity, with facies patterns becoming heterogeneous as isolated carbonate formations were preserved among the invading clastics (Qiao et al., 2023; Raveendrasinghe et al., 2024). This progressive infill by overlying marine silts and sands records the drowning and final burial of the Tanintharyi carbonate platform during post-rift subsidence (Figs. 5, 6, 8 and 9) (Morley, 2017; Raveendrasinghe et al., 2024).

Together, these facies and geomorphic trends illustrate the full life cycle of the Tanintharyi carbonate platform, primarily shaped by tectonic activity and sea-level changes (Wilson, 1974; Hendry et al., 2021) (Fig. 2). The asymmetric, shelf structure and documented proximal–distal zonation indicate prolonged buildup on structural highs (Figs. 5 and 9), while the bounding unconformities and onlapping clastics highlight phases of erosion and siliciclastic resurgence (Qiao et al., 2023; Jin et al., 2024; Raveendrasinghe et al., 2024). These combined observations offer a foundational

Fig. 10. Intersecting time-slice at 1532 ms and vertical seismic profiles illustrating the characteristic morphologies of fluid escape structures, including gas chimneys and pockmarks, within the sedimentary succession overlying the carbonate platform. The seismic sections display the spatial relationship between fluid conduits and the carbonate platform, highlighting the pathways and surface expressions of subsurface fluid migration (refer to Fig. 3 for detailed location information).

context for the detailed discussion of platform initiation, development, facies architecture, and drowning.

5.1.1. Influence of tectonic process

The Cenozoic tectonic evolution of the Andaman Sea, situated at the complex Indo-Eurasian plate boundary (Fig. 1), played a key role in shaping the morphological development of the Tanintharyi Shelf carbonate platform. Its initiation, architecture, and eventual demise were fundamentally governed by a dynamic tectonic regime that created and altered accommodation space, influenced paleotopography, and controlled sediment supply (Figs. 2 and 4). A crucial structural feature was the Andaman Basin Central Fault Zone (ABCFZ), which, during the Early Miocene, established a significant paleo-bathymetric divide (Mahattanachai et al., 2021; Raveendrasinghe et al., 2024) (Figs. 1 and 3). Subsidence of the East Andaman Basin along the ABCFZ resulted in a relatively uplifted margin to the east (Mahattanachai et al., 2021; Raveendrasinghe et al., 2024). This tectonic division was vital, as it isolates the shelf from deep water environment, which serves as a sink for terrigenous sediments, thereby creating conditions conducive to extensive carbonate accumulation and avoiding interference from terrigenous clastics (Burgess et al., 2013) (Fig. 7). Simultaneously, movement along the East Sagaing Fault Zone added further structural complexity, generating a series of graben and half-graben structures to the east of the ABCFZ (Raveendrasinghe et al., 2024) (Figs. 4 and 7). The Tanintharyi platform developed mainly on the relatively stable horst blocks and gentle shelf areas near these structures (Figs. 4 and 7), providing sustained accommodation space and directing siliciclastic sediments into the rapidly subsiding grabens to the west (Jin et al., 2024).

The initial syn-rift subsidence phase generated a mosaic of fault-bounded horsts and grabens (Morley, 2017; Mahattanachai et al., 2021) that directly influenced early platform morphology (Figs. 8 and 9). Uplifted fault blocks remained within the photic zone, serving as nucleation sites for patch reefs and bioclastic carbonate mounds, while intervening lows accumulated thin clastic sediments (Figs. 7 and 8). As carbonate development

Fig. 11. Bathymetric of seafloor, TC surface, TE surface and seismic profiles depicting the backstepping of the carbonate platform edge and the pockmark fields surrounding the edge of the carbonate platform, as interpreted by Qiao et al. (2023) (refer to Fig. 3 for detailed location information).

continued, these isolated buildups merged into a continuous, carbonate platform occupying the whole horst. The NE–SW trending East Andaman Basin (Raveendrasinghe et al., 2024) further contributed to the platform's distinctive asymmetric, westward-dipping synclinal structure, with depocenters thickening basinward (e.g., westward) (Figs. 7 and 9). This structural framework established a clear proximal–distal facies gradient, as evidenced by seismic data. Coarse-grained reefal facies were present along the western margin, with finer outer-shelf deposits occurring distally to the west (Figs. 4 and 6). Intermittent transpressional pulses and uplift led to the development of key unconformities, some of which display karstification, indicating phases of platform exposure and subaerial erosion (Raveendrasinghe et al., 2024) (Fig. 8).

The platform's development was suddenly halted by a major tectonic reorganization after the Early Miocene, driven by intensified Indo-Eurasian collision (Fig. 2). The rifting and subsequent seafloor spreading in the Central Andaman Basin significantly restructured the regional physiography, constricting the Tanintharyi Shelf and increasing siliciclastic input from nearby uplifted terrains (Curray, 2005; Ramaswamy and Rao, 2014; Morley et al., 2022) (Figs. 1 and 2). This tectonic inversion, combined with the end of activity along the ABCFZ (Mahattanachai et al., 2021; Raveendrasinghe et al., 2024), stopped carbonate production and caused the platform to drown and become buried (Figs. 4 and 9). The following post-rift phase, marked by back-arc extension and strike-slip reorganization, enabled the progradation of deltaic systems that eventually smothered the carbonate factory (Curray, 2005; Morley, 2017; Morley et al., 2022). From a reservoir standpoint, these tectonic processes had two effects: first, they created the necessary structural framework for reservoir development, including paleo-highs, rimmed margins, and potential dolomitization zones in central highs; second, they established the stratigraphic pathways for its degradation and sealing through onlapping clastics and fault-related migration conduits (Fig. 9).

5.1.2. Influence of sea-level fluctuations

Sea-level change played a primary role in shaping the morphogenesis and stratigraphic architecture of the Tanintharyi Shelf carbonate platform (Fig. 2) by controlling the available space for carbonate buildup and pacing the cycles of aggradation, exposure, and backstepping recorded in seismic and well data. During the Late Oligocene–Early Miocene syn-rift period, rising sea levels, driven by regional subsidence and eustatic factors (Miller et al., 2020), created new accommodation on fault-bounded highs and enabled the formation of isolated patch reefs and mound-like structures (Figs. 8 and 9). When carbonate production locally met or surpassed accommodation, these nucleating structures merged into a rimmed shelf marked by continuous, parallel seismic reflections (Figs. 5, 8 and 9), indicating ongoing vertical accretion within the photic zone. Conversely, where accommodation exceeded production or where clastic supply increased, carbonate growth was limited, and facies became more diverse, resulting in the proximal–distal amplitude gradients observed across the platform (Figs. 4 and 6).

Intermittent relative sea-level drops during the early to middle part of the Early Miocene (Fig. 2) created clear sequence boundaries and a prominent high-amplitude capping reflector that indicates subaerial exposure and karst development on the platform top (Figs. 8 and 9). This exposed surface, with local relief of tens of meters, records meteoric dissolution, erosion, and the beginning of meteoric diagenesis that increased secondary porosity (Ott et al., 2023) and formed a regional sequence boundary. Later transgression restored shallow-marine conditions but typically limited renewed carbonate growth to the platform edges (Fig. 9), resulting in landward stepping and thinning of upper carbonate layers; in the seismic record, this behavior appears as backstepping geometries, chaotic high-amplitude reflections in stressed depositional areas, and onlap of fine-grained siliciclastics onto the eroded surface (Wilson, 1974; Burgess et al., 2013; Hendry et al., 2021) (Figs. 6 and 9). These stratigraphic patterns reflect how sensitive the carbonate factory is to minor sea-level changes when superimposed on a tectonically active shelf (Wilson, 1974; Hendry et al., 2021; Lunt, 2023).

The platform's final drowning and subsequent burial resulted from the combined effect of a major transgressive pulse and accelerated post-rift subsidence (Figs. 2 and 4), which together raised the relative sea level to rise faster than the carbonate factory could rebuild (Teillet et al., 2019, 2020; Lunt, 2023). As the photic zone was transgressed, onlapping clinoforms and prograding siliciclastic wedges gradually smothered carbonate production and created the thick post-platform siliciclastic cover documented in well M15-B-1 and seismic profiles (Racey and Ridd, 2015b, 2015c; Teillet et al., 2019, 2020). Importantly, the sea-level-driven cycle of aggradation, exposure, and drowning (Figs. 2 and 9) strongly imprinted reservoir heterogeneity: exposure and meteoric alteration locally increased secondary porosity and led to diagenetic facies formation (including dolomitized zones on central highs), while transgressive siliciclastic onlap and burial favored sealing and lateral isolation of reservoir bodies (Figs. 8 and 9). In sum, eustatic oscillations, working together with syn- and post-rift tectonics (Morley, 2017; Miller et al., 2020; Lunt, 2023), controlled the timing and spatial pattern of carbonate accumulation, the development of key sequence boundaries, and the preservation potential and connectivity of prospective reservoir facies on the Tanintharyi Shelf.

5.1.3. Sedimentary and diagenetic responses to Tibetan Plateau uplift

The progressive uplift of the Tibetan Plateau during the Neogene (Wang et al., 2014, 2017; Ding et al., 2022) significantly influenced the sedimentary dynamics and diagenetic evolution of the Tanintharyi Shelf carbonate platform. In response to the ongoing Indo-Eurasian collision (Fig. 1), this uplift not only restructured regional drainage systems but also changed

atmospheric circulation patterns, profoundly affecting sediment supply, seawater chemistry, and diagenetic processes throughout the Andaman Sea Basin (Najman et al., 2022; Zhang et al., 2023; Fathima et al., 2025). During the Middle Miocene, the increased uplift of the plateau (Fig. 2) heightened the gradients of major river systems like the Irrawaddy and Salween, leading to more siliciclastic material entering the Andaman Sea (Awasthi and Ray, 2019; Jonell et al., 2022; Ma et al., 2024). This rising influx gradually shifted depositional environments from predominantly carbonate to mixed clastic–carbonate systems (Teillet et al., 2019, 2020; Lunt, 2023) (Figs. 2 and 4), resulting in the drowning of the Tanintharyi platform. The greater detrital input decreased water clarity and limited light penetration in shallow marine areas (Fathima et al., 2025), reducing biogenic carbonate production and encouraging deltaic progradation over the previously steady carbonate factory (Paumard et al., 2017; Teillet et al., 2019, 2020; Lunt, 2023).

Simultaneously, the uplift-driven climatic changes strengthened the South Asian monsoon system, boosting seasonal rainfall and freshwater flow into the Andaman Sea (Ray and Radhakrishna, 2021; Zhang et al., 2023; Fathima et al., 2025). This led to lower salinity levels and higher nutrient input, altering the geochemical balance of the surface ocean (Fathima et al., 2025). These conditions favored heterozoan over photozoan carbonate production and encouraged early diagenetic changes (Westphal et al., 2010; Teillet et al., 2019). This aligns with seismic and stratigraphic data showing widespread stacking patterns from aggradation to progradation, along with a shift from high-energy reef margin facies to fine-grained bioclastic- and siliciclastic-rich carbonates during the platform's late stage (Figs. 6 and 9). The uplift-enhanced monsoon also increased continental weathering, raising the levels of dissolved ions like Mg^{2+} and Si^{4+} in the basin (Yang et al., 2021; Fathima et al., 2025), likely promoting dolomitization and silica cementation within the platform's interior.

In the late Neogene, the ongoing uplift of the Tibetan Plateau enhanced topographic relief and increased erosion in the hinterland, leading to more sediment being delivered to the Andaman Basin (Zhang et al., 2023; Fathima et al., 2025) (Fig. 2). This period also saw a regional shift toward a high-subsidence regime associated with back-arc extension and seafloor spreading (Curray, 2005; Morley, 2017), which sped up the burial of carbonate successions beneath prograding deltaic and turbiditic sediments (Figs. 4 and 9). Episodic release of diagenetic fluids through fault-controlled conduits, as shown by gas chimneys and pockmarks above the carbonate platform (Fig. 10), may also be indirectly linked to overpressure build-up (Qiao et al., 2023) driven by rapid sediment loading and tectonic compression, both effects of continued plateau uplift.

Thus, the uplift of the Tibetan Plateau acted as a distal yet dominant geodynamic force shaping the Tanintharyi Shelf carbonate platform through three interconnected mechanisms: increased siliciclastic input and decreased carbonate productivity caused by intensified monsoon-driven erosion; altered diagenetic pathways linked to changes in hydrology and seawater chemistry; and greater burial and compaction resulting from faster sedimentation and tectonic subsidence. These combined effects transformed the Tanintharyi platform from a lively Early Miocene carbonate system into a mixed carbonate–siliciclastic shelf and eventually into a buried reservoir complex with intricate diagenetic fabrics and diverse porosity. The stratigraphic and seismic records of this transformation thus record a sedimentary and diagenetic history of the far-reaching influence of Tibetan Plateau uplift on the evolving tectono-sedimentary framework of the Andaman Sea Basin (Zhang et al., 2023).

5.2. Implications for the prospective carbonate reservoir

The Early Miocene carbonate platform on the Tanintharyi Shelf is a highly promising yet naturally diverse reservoir system (Fig. 10). Seismic and well data show a rimmed-shelf structure mainly made up of wave-resistant reefal and algal grainstone facies along the western edge, which gradually transitions basinward into finer bioclastic- and siliciclastic-influenced carbonates (Figs. 7 and 9). This proximal–distal facies zoning creates predictable primary reservoir zones on structural highs but is characterized by rapid lateral and vertical facies changes that disrupt reservoir continuity (Joshi and Singh, 2019; Garland et al., 2025).

Diagenetic processes have greatly shaped this primary facies framework, creating a complex mosaic of preserved and destroyed porosity (Fig. 7). A pronounced high-amplitude unconformity at the top of the carbonate succession marks episodes of exposure and karstification, which locally produced secondary porosity (vuggy and moldic fabrics) within reef cores (Fig. 8). Additionally, intermittent early dolomitization in central highs and paleoreefs has resulted in the formation of dolomite bodies that are resistant to compaction and capable of maintaining favorable pore networks (Teillet et al., 2019, 2020) (Fig. 8). Conversely, ongoing burial under Late Miocene to Pliocene siliciclastics has possibly caused compaction and extensive carbonate cementation in deeper, basinward zones, leading to tightly cemented, low-quality rock. The overall result is a patchwork pore system where high-quality reefal and dolomitized cores are interspersed with cemented, mud-rich, and siliciclastic-influenced intervals, producing a porosity distribution that is highly discontinuous and closely linked to the timing and location of exposure, karstification, and subsequent burial (Jardine and Wilshart, 1987; Harris and Vlaswinkel, 2008; Hendry et al., 2021).

Seismic evidence shows widespread vertical fluid pathways, indicated by vertical gas chimneys and both buried and current seafloor pockmarks (Fig. 10). This suggests that the platform has served as both a transmission route for deeper hydrocarbons and a kitchen source. The two-stage fluid escape history observed, comprising an initial pulse in the Late Miocene and renewed activity in the Quaternary, indicates that the system has been in a saturated charge stage since at least the Late Miocene (Qiao et al., 2023) (Fig. 10). The extensive marine shales from the Middle Miocene to Pliocene act as an effective regional cap in many areas. However, local seal thinning and fault or fracture corridors have enabled leakage and focused seepage in certain locations, requiring an evaluation of chimney proximity and seal integrity on a case-by-case basis when assessing trap preservation.

From an exploration and appraisal perspective, the most promising targets are the reefal margin facies and potential dolomitized cores located on paleo-highs, where primary porosity has been enhanced by meteoric alteration and where dolomite has preserved pore networks from subsequent compaction (Jardine and Wilshart, 1987; Harris and Vlaswinkel, 2008; Hendry et al., 2021) (Fig. 7). Therefore, successful targeting requires high-resolution mapping of facies boundaries, sequence stratigraphic surfaces, and diagenetic bodies, all integrated with seismic-attribute analysis and correlated with available well control (as observed in M15-B-1) (Ghon et al., 2018) (Fig. 7). The main risks come from internal compartmentalization (such as intrabuild-up mudstones and sequence boundaries), variable cementation, and locally compromised seals related to chimneys and faulting (Harris and Vlaswinkel, 2008; Hendry et al., 2021). As a result, predictive models should incorporate fault architecture and subsidence history with sequence stratigraphy and diagenetic mapping to identify preserved porosity, evaluate both lateral and vertical connectivity, and assess seal integrity before development (Ghon et al., 2018). Once these factors are clarified, the Tanintharyi

carbonate complex shows significant hydrocarbon potential, but only through workflows capable of addressing its depositional complexity and diagenetic influences.

6. Conclusions

This study provides a detailed analysis of the morphological evolution of the Tanintharyi Shelf carbonate platform in the Andaman Sea, integrating high-resolution seismic geomorphology, well data, and regional stratigraphy to develop a comprehensive tectono-sedimentary model with direct implications for Cenozoic hydrocarbon exploration. The main conclusions are as follows:

1) The Tanintharyi Shelf carbonate platform initiated in the late Oligocene to Early Miocene as isolated patch reefs on fault-bounded structural highs. It evolved into a westward-dipping, asymmetric rimmed shelf with a steep western margin and a gentler eastern flank. Its decline happened due to subaerial exposure, karstification, and eventual burial under prograding siliciclastic sediments during the Middle to Late Miocene, driven by accelerated post-rift subsidence.
2) The platform's initiation and extinction were influenced by three main factors: (1) Syn-sedimentary faulting created paleotopography and controlled accommodation space, enabling carbonate production while preventing siliciclastic influx. However, post-Early Miocene tectonic activity halted this growth and caused burial. (2) Changes in relative sea level triggered cycles of aggradation, backstepping, and exposure, with a major transgressive pulse eventually submerging the carbonate-producing areas. (3) The Neogene uplift of the Tibetan Plateau increased siliciclastic sediment supply and changed basin hydrochemistry through the intensification of the Asian monsoon, which suppressed carbonate productivity and promoted dolomitization.
3) The Tanintharyi Shelf carbonate platform is a complex and heterogeneous reservoir system. Primary reservoir quality appears in wave-resistant reefal and algal grainstone facies at the platform margin. Diagenetic processes like karstification have enhanced secondary porosity in structural highs, possibly forming dolomite bodies. However, high-quality zones are interspersed with tightly cemented intervals and mud-rich facies, causing significant compartmentalization. Widespread gas chimneys and pockmarks indicate the platform functions as both a reservoir and a pathway for fluid migration. Paleo- and current seafloor pockmarks suggest hydrocarbon charging in the carbonate platform. Although the overlying Miocene–Pliocene marine shales serve as an effective seal, individual traps may be compromised by fault and fracture corridors associated with fluid escape.

Thus, this research establishes a predictive tectonostratigraphic framework for the Tanintharyi Shelf, focusing on high-resolution mapping of facies boundaries, sequence stratigraphic surfaces, and diagenetic features, especially reef margins and potential dolomitization on paleo-highs. Consequently, hydrocarbon exploration should incorporate seal integrity and fault architecture, while also considering tectonic history along with eustatic and diagenetic models to forecast the distribution and quality of complex carbonate reservoirs in tectonically active, rift-margin settings worldwide.

CRediT authorship contribution statement

Xi-Wu Luan: Writing – review & editing, Supervision, Software, Resources, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization, Formal analysis, Methodology, Validation, Visualization, Writing – original draft. **Thanuja D. Raveendrasinghe:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization, Data curation, Visualization. **Zi-Jie Wang:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation. **Li-Shuang Feng:** Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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