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Returning Exploration to Kerala-Konkan Basin: Invoking Paradigm Shift in Exploration Model

Pratap V. Nair

Retired Exploration Petroleum Geologist, Devidarshan, Kawdiar, Thiruvananthapuram - 695003, Kerala, India
Email: *vpratapnair[at]gmail.com*

Abstract: ***Petroleum exploration in the Kerala-Konkan Basin has been ongoing for the last four decades through several waves of limited exploration, but success has eluded explorers. The exploration model in vogue perceived the basin to be an extension of the Mumbai offshore oil province, and fourteen exploration wells have been drilled to date. The thick Deccan basalts posed a serious challenge in imaging the sub-basalt stratigraphy. However, long-spaced seismic data acquired in 2008-09, when interpreted, integrating plate tectonic reconstruction and paleogeography linking with the hydrocarbon finds in Mannar Basin and leads obtained in Madagascar, has given a new lease of life to this vast expanse of offshore sedimentary tract. The lack of significant west-flowing rivers on India's west coast, in contrast to those on the east coast of India, accentuates the necessity of understanding the geological history of the basin and positioning it in the correct perspective. The amalgamation and break-up of the Gondwana landmass at different geological times resulted in sediment deposition within the basin, creating a favourable anoxic environment with a source rock proclivity for hydrocarbon generation, considering the heat flow. Analyzing the overall context of those geological periods and specifically applying it to the Kerala Basin while utilizing publicly available geoscientific data has revealed significant potential for oil and gas exploration in the region. Reviving exploration in the Kerala-Konkan Basin necessitates a diametric shift in the exploration model to target Mesozoic stratigraphy. Skepticism plays a critical role in oil and gas exploration, as one cannot establish a law of nature until the concept has withstood the scrutiny of exploration drilling. To achieve this, it is essential to commence drilling at promising locations as soon as possible to test the new exploration model conceived. Further, a time-bound initiative by the government involving the industry, regulators, and academicians must be swiftly pressed into action to work on an improved understanding of the subsurface and its evolution to fathom the hidden potential of the Kerala-Konkan Basin.***

Keywords: Kerala Konkan Basin, Long spaced seismic, Madagascar, Mannar Basin, Comorin Depression, Alleppey Trivandrum Terrace, Kerala Deepwater Basin

1. Introduction

The offshore Kerala-Konkan Basin constitutes a segment of a continuous series of elongated basins oriented in a northwest-southeast direction within the western offshore region of India. This basin occurs between two prominent basement arches: the Vengurla arch to the north and the Trivandrum arch to the south. Defined by a basin-ridge structure, this region comprises six interrelated tectonic features that extend from the northwest to the southeast. These tectonic elements include the Shelfal Horst-Graben complex, the Kori-Comorin depression, the Kori-Comorin ridge, the Laccadive depression, the Laccadive ridge, and the Arabian abyssal plain (see Figure 1). The regional line WC2K2-09 interpretation of Mullick (2015 illustrates the various tectonic features of the basin (Figure 2). The Kerala Basin is delineated from the Konkan Basin to the north by the elevated Tellicherry Arch basement. To the east, it is flanked by the steep escarpments of the Western Ghats, which rise to heights of 2,695 metres. To the west, the basin extends into the deep waters of the offshore Kerala–Konkan Basin, reaching the Chagos–Laccadive Ridges2.

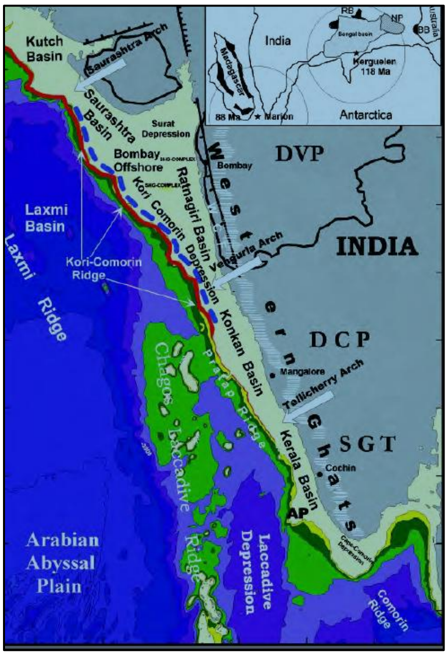

Figure 1: Tectonic map of the western coastal margin of India[3]

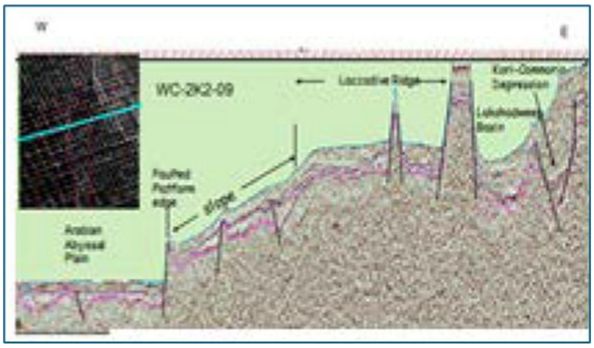

Figure 2: Regional line showing the tectonic elements[1]

2. Exploration Resume

Exploration in the Kerala-Konkan Basin has been ongoing for the last four decades, yet no breakthrough has been achieved. An area spanning 600,000 sq km has been sampled with 14 wells. The exploration strategy has been guided by the Mumbai Offshore productive oil occurrences, which led explorers to believe that the extension of this system could be present in the Kerala-Konkan offshore. Sedimentary basins located at passive continental margins typically hold significant promises for hydrocarbon exploration, as their development is linked to the thermal and tectonic processes that take place during lithospheric extension and rifting[4]. Furthermore, the vintage seismic data, which served as the foundation for previous exploratory drilling programs, failed to reveal the Mesozoic formations beneath the KT Flood Basalts. Further, no two prevailing maps concur, and there is an urgent need to unify the thought process to develop realistic geological maps for exploration. However, with the acquisition of long-spaced seismic in 2008-09, it has become apparent that the Kerala-Konkan Basin is one of the largest unexplored sub-basalt basins (Figure 3). Large-scale compressional features appear as large anticlinal folds beneath the Basalt cover. A significant anticline structure of relatively huge dimensions is identified beneath an erosion unconformity marked by the Cretaceous/Tertiary boundary. Multiple faults segment the sedimentary layers. The high-amplitude anomalies observed in the Mesozoic may indicate previous lava flow events associated with the Reunion events[5]. A study conducted by a national oil company has prematurely suggested the unlikely prospect of Mesozoic formations in the Kerala-Konkan (KK) Basin, a notion with which I disagree.

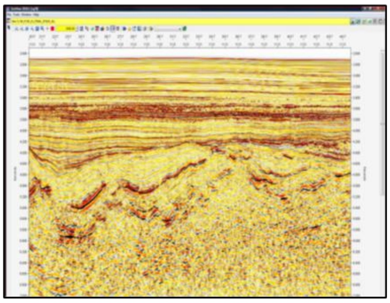

Figure 3: The remarkable imaging of Mesozoic stratigraphy beneath the basaltic cover[5]

3. Deciphering the Sedimentation

A tectonic change in the geologic thought process kick-started with the acquisition of long-spaced seismic data, which triggered groundbreaking truth. A private operator in their designated area on the southwest continental margin of India initiated this development, and their research team excelled by incorporating palaeogeographic reconstruction into a tailored exploration model. The peculiarity of the Kerala Basin is that there is no present-day river, large enough to transport sediments to the basin from the nearby landmass.

Mesozoic sediments that are covered by basalt layers have been identified as possible hydrocarbon prospects within the KK basin. The enhancement of imaging beneath the basalt primarily concentrates on the underlying Mesozoic sediment sequences associated with the India-Madagascar rifting event. This formation is constrained at its base and top by two volcanic events linked to the Marion hotspot (approximately 83 ± 6 million years ago) and the Reunion hotspot (65 million years ago), which have been recognized on a regional scale. The associated palaeogeographic counterparts through geological time of the Kerala Basin and their stratigraphic succession are illustrated in Figure 4a. Based on the finding that Mesozoic exists in the southwest continental margin of India, the stratigraphic succession expected is postulated based on correlation with Mannar Basin, and the East coast of Madagascar is shown in Figure 4b.

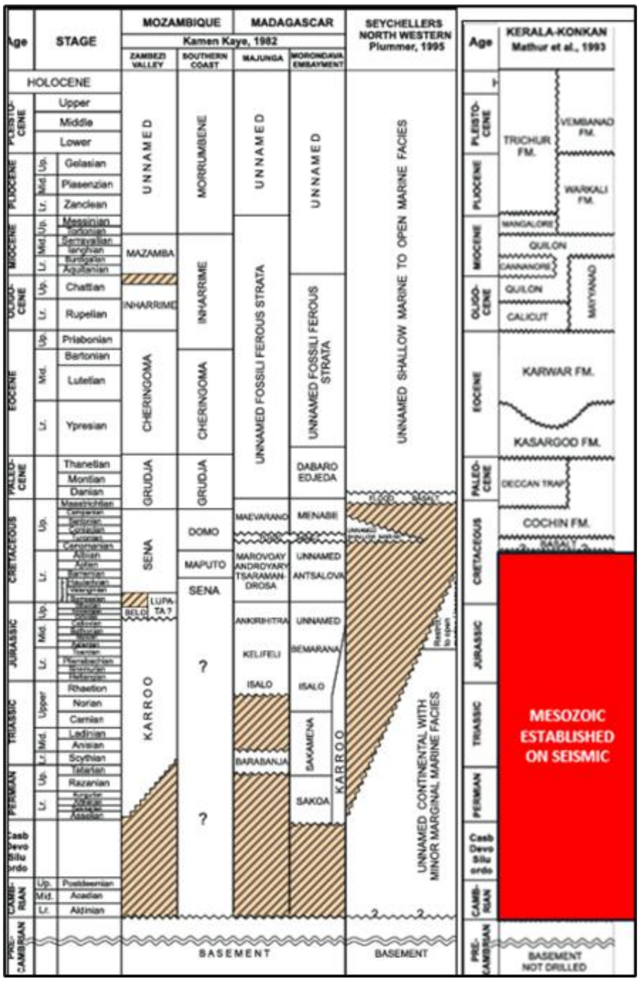

Figure 4a: Stratigraphy of palaeogeographic associates of Kerala Konkan Basin[6] and Figure 4b: Postulated Stratigraphy of Kerala Basin[7]

Kularatne (2020) studied the tectonostratigraphy of Mannar Basin, distinguishing pre-rift, rift, and post-rift sedimentary sections (Figure 5). There is no direct evidence from well data or rock outcrops to confirm the existence of this sequence within the Mannar Basin predating the rift in the Mannar Basin. The prominent packages with bursts of amplitude resting just above the basement horizon suggest the existence of the pre-rift sedimentary layer. The depositional environment is believed to be continental. Similar lithostratigraphy seems to be present in Madagascar. Rifting during the Jurassic period could have simultaneously occurred with a marine transgression, leading to the accumulation of organic-rich marine sediments within a confined embayment. Northerly transform faults would have acted as partial barriers to oceanic circulation. After the detachment of Africa from West Antarctica, the Seychelles and India separated from Madagascar, with India later drifting northward away from the Seychelles throughout the Late Cretaceous and Palaeogene periods. Hence, similar stratigraphy can be expected in the Kerala Basin, which formed in the intervening area between Madagascar and the Mannar Basin.

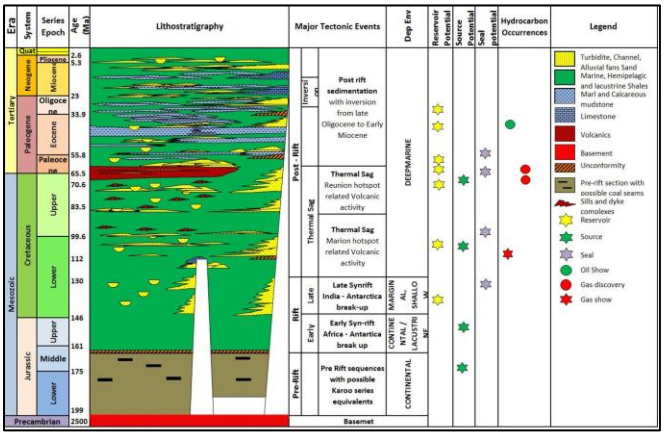

Figure 5: Stratigraphy of Mannar Basin[8]

4. Paleogeographic Reconstruction

India is generally regarded to have emerged from the slow fragmentation of the Gondwana supercontinent around 150 to 180 million years ago, during the Middle to Upper Jurassic era. This geological process of dismemberment led to the creation of West Gondwana, which comprises Africa, and East Gondwana, which encompassed Madagascar, Seychelles, India, Antarctica, and Australia. The breakup of East Gondwana commenced around 120 to 130 million years ago, leading to the rifting of Western India from Madagascar approximately 90 million years ago during the mid-Cretaceous period (Figure 6). This is supported by the identification of magnetic anomalies and the presence of basalt formations along Madagascar's eastern coastline. Data from the Mascarene Basin suggests that during the Campanian stage, India and Seychelles moved northeastward away from Madagascar. The plate tectonic reconstruction spanning from the Late Jurassic to the Early Cretaceous reveals that the basin was situated in the northeastern part of the Proto-Mozambique Ocean. Throughout this timeframe, Antarctica acted as the main provider of sediment, taking advantage of favourable oceanic and climatic conditions that enhanced organic productivity. During the Late Cretaceous period, the ridge axis that connected Madagascar and India migrated closer to India within the emerging Indian Ocean, thereby isolating the Seychelles platform from India. Following a significant increase in the spreading rate and rotation during the Late Cretaceous, the Indian plate advanced northeastward, resulting in a gentle collision with Tibet (Asia) in the Late Eocene, followed by a more pronounced collision at the end of the Mid-Miocene. This series of events initiated the formation of the Ganges-Brahmaputra and Indus fan systems. The development of the basin is associated with volcanic activity at the end of the Cretaceous period, as the Indian plate traversed the Reunion Hotspot, leading to the eruption of extensive effusive rocks known as the Deccan Traps, which constitute one of the largest volcanic provinces globally. This volcanic activity marked the initial structural differentiation and the emergence of various landforms. The eruption of Deccan flood basalts between 62 and 67 million years ago coincided with the rifting of the Seychelles microcontinent and was succeeded by rapid seafloor spreading, resulting in the formation of the present-day Arabian Sea.

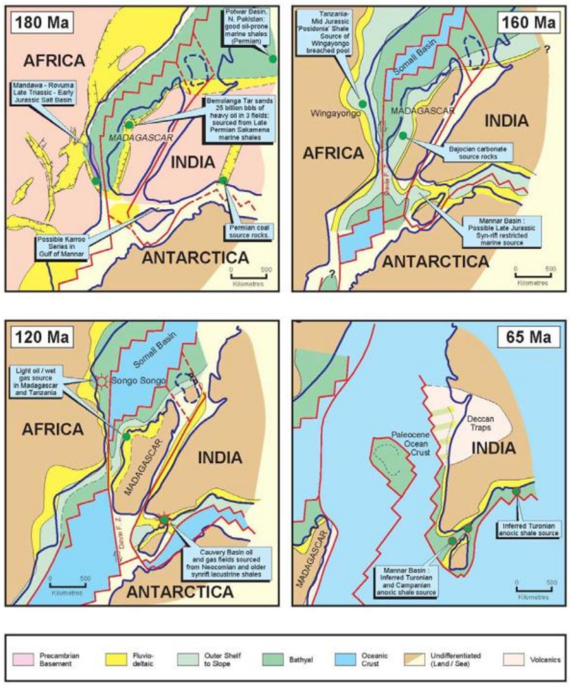

Figure 6: Distribution of regional source rocks; paleogeographic reconstructions for 180, 160, 120, and 65 mega annum[9].

The palaeogeographic reconstruction juxtaposes the western coast of India against the eastern coast of Madagascar and Sri Lanka all from 180 Ma to 120 Ma. Thus, during the Mesozoic period, the present-day Gulf of Mannar and Kerala Basin were connected. The Mannar Basin, located off the western coast of Sri Lanka, contains a sedimentary tract that exceeds 7 kilometers in thickness, with the stratigraphy ranging in age from the Jurassic period to the present day. This basin originated during the rifting and subsequent fragmentation of continents associated with the breakup of Gondwanaland in the Late Jurassic period. To the east, it is flanked by the Precambrian massif of Sri Lanka, while to the west, it is bordered by the southern Indian massif, which contains a diverse range of potential source and reservoir rocks (Figure

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7). A significant early Cretaceous source kitchen has been identified across extensive areas of the basin. A schematic plate reconstruction model illustrating the evolution of the Mannar basin from the Late Jurassic period (approximately 160 Ma) indicates the onset of rifting in the northern Mannar basin, as worked out by Singh in 2021. This model depicts the amalgamation of South India with Sri Lanka, resulting in the creation of the bay, which ultimately represents a failed rift that led to the formation of the Mannar Basin (Figure 7).

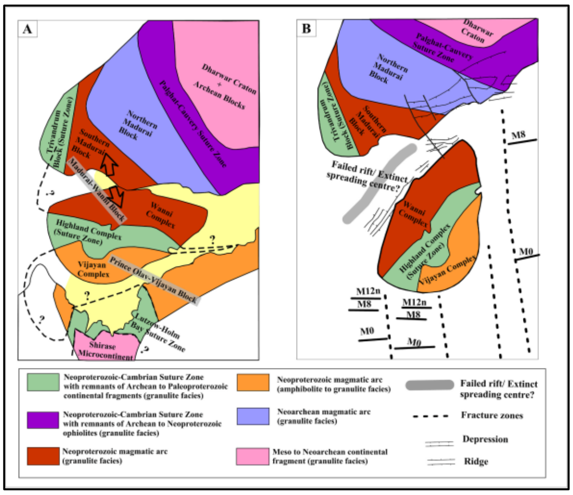

Figure 7: Schematic plate reconstruction models illustrating the evolution of the Mannar basin. (A) The Late Jurassic period, approximately 160 Ma, marks the beginning of rifting in the northern Mannar basin[10]

The pre-rift context of Sri Lanka, with southern India and East Antarctica, is established through the petrological and geochronological correlation of orogenic activities in the conjugate areas[11,12]. The Late Cretaceous period, approximately 65 Ma, marks the conclusion of the second phase of rifting.

The fragmentation of eastern Gondwanaland's continents through rifting and drifting has shaped the current layout of the Indian Ocean(e.g.,[13;14]). A significant rifting event during the Early Cretaceous period (ca. 130 Ma) marked the initial separation of Greater India ([15; 16; 17]). The landmass includes India, Sri Lanka, the Laxmi Ridge, the Seychelles, and Madagascar, split from the adjacent landmasses of Antarctica and Australia. The northward migration of Greater India followed this event. The Cauvery and Gulf of Mannar Basins are considered rift-related basins that formed due to crustal extension between the landmasses of India and Sri Lanka[13]. Research by Desa et al. (2018)[18]indicates that the initial rifting of Sri Lanka from India began south of Sri Lanka ca. 132 Ma. The anticlockwise rotation of Sri Lanka and the development of the Mannar Basin were constrained by the onset of seafloor spreading to the south and east of Sri Lanka by 128 Ma. Ultimately, rifting in the Mannar Basin ended by 120 Ma.

Deepwater Kerala represents a frontier region, making regional studies essential for establishing a geological foundation to comprehend the presence of the sub-basalt Mesozoic sedimentary basin, tectonic activities, potential petroleum systems, and the overall hydrocarbon potential. Investigations of the conjugate margins, including the Gulf of Mannar, Madagascar, Seychelles, and Mozambique basins, have contributed to a regional geological framework that aids in assessing the petroleum potential of the Mesozoic formations in the area.

5. Petroleum Geology

The Kerala Basin lacks documented source intervals in the Mesozoic era. However, facies indicative of restricted circulation may suggest the potential for anoxic source development at various intervals throughout the basin's history. It is pertinent to emphasize that the basin underwent three phases of rift tectonism: incipient rifting, the separation of Madagascar, and the separation of Seychelles. Each of these phases may be associated with restricted facies, both at the onset of sequences, characterized by restricted circulation, and during the later stages of development, where stagnating conditions prevail under the typical processes of basin fill (Figure 8). The tectonic synthesis through the integration of regional seismic data, well information, and studies on plate-tectonic reconstructions suggests the presence of multiple episodic rifts that align with global anoxic events. This finding significantly increases the likelihood of Mesozoic source rocks being present along the southwestern continental margin of India[19]

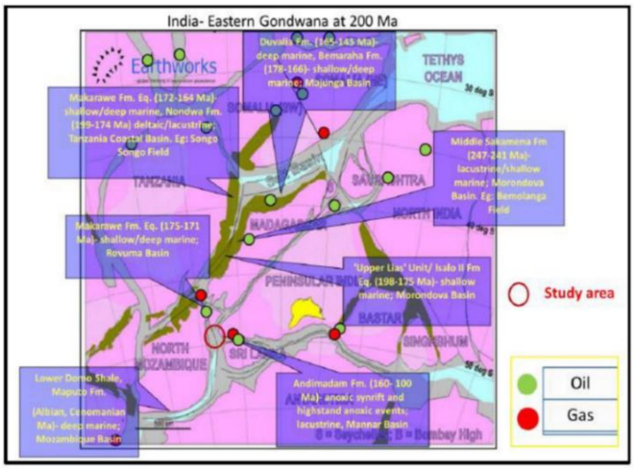

Figure 8: Source rocks of Eastern Gondwana with Oil and Gas fields[20]

Savostin and Kerusov (2001)[21] observed that the development of the Kerala Basin is marked by a relatively elevated heat flow, which has transitioned from an initial measurement of approximately 110 mW/m², characteristic of continental rifting environments—to its current range of about 60-70 mW/m² (Figure 9).

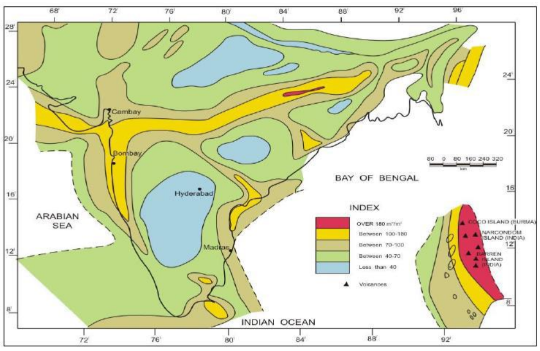

Figure 9: Heat flow map of India and adjoining areas[22]

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5.1 Eastern Madagascar Basins

The northeastern coastline of Madagascar features narrow, confined sedimentary basins that have formed along the shore. These basins are indicated as NW-SE oriented gravity low regions on the Bouguer gravity map (see inset in Figure 10). These slender basins have probably been filled with sediments ranging from the Late Cretaceous to the present. These were deposited during the early rifting of Madagascar and the Seychelles/India during the Santonian period (approximately 88 Ma)[23]. This geological activity is associated with the Marion mantle plume in southern Madagascar[24].

Only one exploration well has been drilled in the offshore area of Madagascar. The Ile Saint Marie-1 well was drilled in 1973 by Tenneco to probe a free-air gravity low located within a narrow half-graben structure (see Figure 10). This well reached a final depth of 1,770 metres and recorded oil shows from 1,725 metres to its final depth, found within a sequence of weathered sandstones and limestones of continental origin, which lie above slightly weathered and fractured gneiss and quartzite. The oil-bearing interval is recognized within a gently inclined syn-rift package. According to stratigraphic logs, the well encountered shallow marine sediments of indeterminate age in the initial 975 metres before transitioning to continental sediments of unknown age at the metamorphic basement. This wedged syn-rift section is likely a product of the transpressional rifting phase that occurred over eastern Madagascar and the Seychelles/India region.

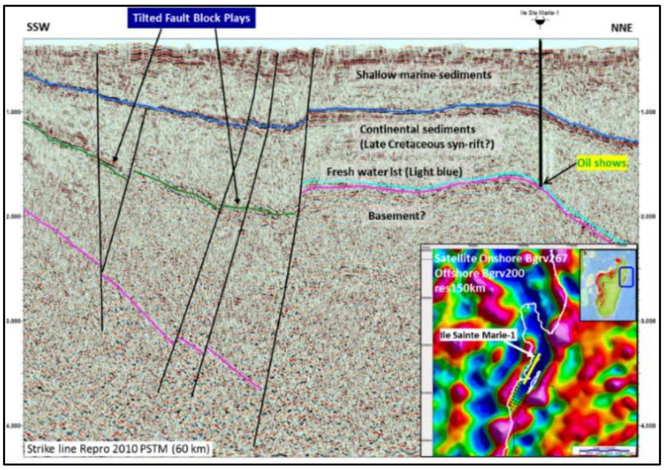

Figure 10: Illustrates the oil indications at Ile Saint Marie-1 on a strike line oriented from SSW to NNE, along the eastern margin of Madagascar. An accompanying inset highlights areas of low gravity, represented in blue on the Bouguer gravity map, with the 2D reprocessed seismic survey depicted in black[25].

The Marion thermal event represents a significant thermal episode, as revealed by an AFTA (Apatite Fission Track Analysis) study conducted in the Seychelles conjugate margin adjacent to eastern Madagascar[26]. Consequently, the Marion plume may significantly influence hydrocarbon generation in the eastern Madagascar basin, causing source rocks to reach temperatures that exceed the normal geothermal gradient, thereby enhancing their maturity and increasing the chances of hydrocarbon generation.

In Madagascar, a total of eighty-eight exploration wells have been drilled, primarily on land. Most of these wells have revealed oil shows or gas, albeit mostly in minor quantities. Two significant fields, Bemolanga (tar sands) and Tsimiroro (heavy oil), were identified in the 1930s, both located in western Madagascar (Figure 11). The reservoir rock in these fields is comprised of the Isalo I and II formations, which are part of the Permian and Triassic periods within the Karoo Supergroup. In 1987, OMNIS/Petro Canada International Assistance Corporation (PCIAC) identified wet gas at the West Manambolo-1 location, whereas Shell discovered light oil at the Manandaza-1 well.

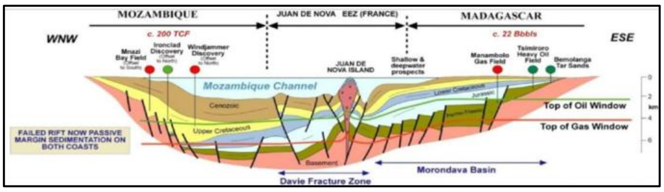

Figure 11: Geological cross-section illustrating the area from the Rovuma Basin in Mozambique to the coastal region of Madagascar, providing context for the recent findings in the Rovuma delta[27]

5.2 Mannar Basin

The Mannar basin is a rift basin promising in hydrocarbons, situated between the southeastern coast of India and the western margin of Sri Lanka. The deepwater Mesozoic hydrocarbon discovery in the adjoining Mannar Offshore Basin of Sri Lanka is a significant lead. The Mannar basin is a rift basin rich in hydrocarbons, situated between the southeastern coast of India and the western edge of Sri Lanka (Figure 12). Further, the basin also encountered intrusive and extrusive igneous activity related to the India-Madagascar rifting[28]. A high-quality Early Cretaceous source rock is probably present in the central region of the Mannar Basin, considering the subsidence history of the basin and the identification of a significant global anoxic event in the neighbouring Cauvery Basin. However, there has been no well penetration extending below the Upper Cretaceous in the Mannar Basin.

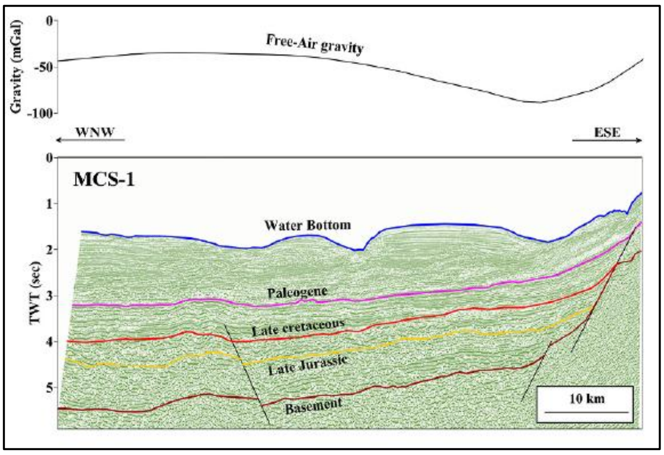

Figure 12: Multi-channel seismic profiles (MCS1) of the Mannar basin along with free-air gravity anomalies derived from the gravity grid along these profiles[9]

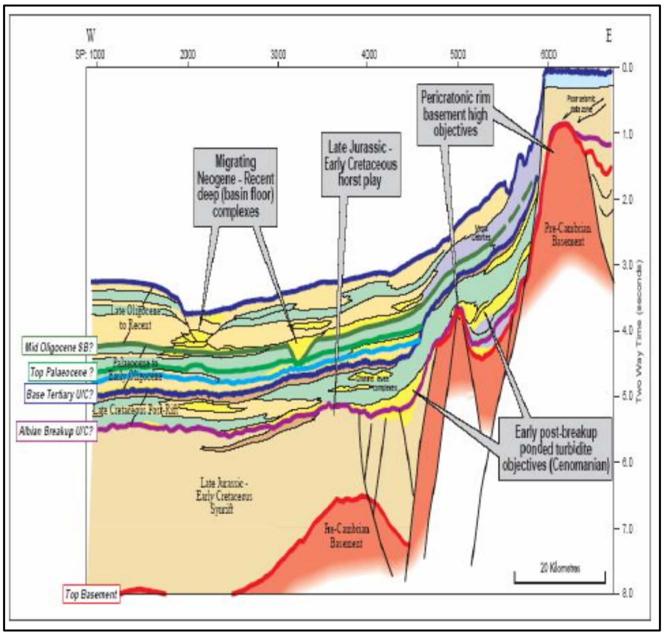

Figure 13: Cartoon illustrating play concepts in Mannar Basin[9]

The two continental margins of India and Sri Lanka are marked by patterns of low tectonic extension and a thinned crust, indicating that an anticlockwise rift, specifically an eastward rift, of Sri Lanka from India led to the formation of the Mannar Basin. Additionally, a subsequent north-south rifting process contributed to the development of the Cauvery Basin. In its current arrangement, Sri Lanka is positioned adjacent to the southeastern continental edge of India, with a narrow sea acting as a divider, which the Mannar, Palk Strait, and Cauvery Basins support from south to north.

A volcanic layer of extrusive flood origin, which spans over two-thirds of the region within the Sri Lankan jurisdiction of the Mannar basin and lies directly above the Cretaceous top horizon, can function as a regional seal over the upper Cretaceous horizon. The main potential source rock intervals in the Mesozoic section have generated significant volumes of oil and gas after 55 Ma[29]. Potential deep-water reservoirs are characterized by channel-levee complexes, slope fans, and basin floor fans identified within the Cretaceous and Tertiary sequences (Figure 13). Recent drilling in the basin has revealed substantial sand deposits from the Late Cretaceous and Tertiary periods, exhibiting log-based porosities reaching as high as 30%. Various play types, such as four-way structural closures, stratigraphic pinch-outs, rotated fault traps, and deep-water channel-fan systems, enhance hydrocarbon prospectivity in this emerging region. The deep seismic profile through the wells illustrates the lithostratigraphy along the wells and major structural elements in the basement with interpreted key horizons (Figure 14). Note that the quality of the seismic data is very poor below the flood volcanic layer (pre-flood volcanic sedimentary section)[29] .

A layer of volcanic origin, resulting from extrusive flood activity, covers more than two-thirds of the area within the Sri Lankan portion of the Mannar basin and is situated directly overlies the uppermost Cretaceous horizon. This layer can act as a regional seal for the upper Cretaceous strata. Significant quantities of oil and gas have been generated from the primary source rock intervals in the Mesozoic section since 55 Ma[29]. Potential deep-water reservoirs are identified by channel-levee complexes, slope fans, and basin floor fans found within the Cretaceous and Tertiary sequences (Figure 13). Recent drilling activities in the basin have uncovered considerable sand deposits from the Late Cretaceous and Tertiary epochs, with log-derived porosities reaching up to 30%. The mapping of various types of play, including four-way structural closures, stratigraphic pinch-outs, rotated fault traps, and deep-water channel-fan systems, significantly boosts the hydrocarbon potential in this developing area. The deep seismic profile through the wells provides insights into the lithostratigraphy and major structural features of the basement, along with interpreted key horizons (Figure 14). It is pertinent to note that the quality of the seismic data is notably poor beneath the flood volcanic layer (pre-flood volcanic sedimentary section)29.

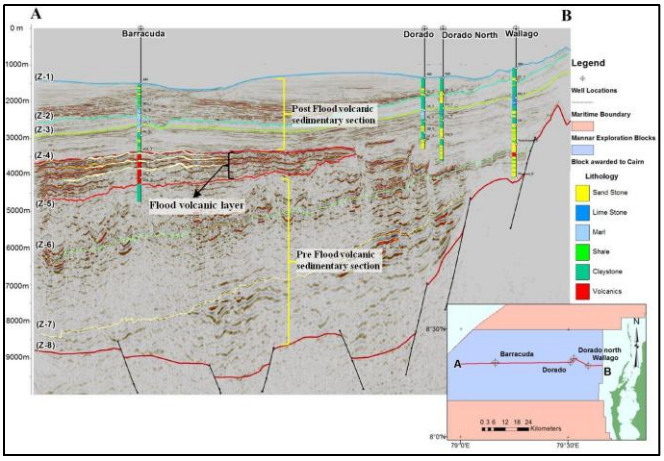

Figure 14: Seismic profile in depth through the recent wells (from A-B in the base map)[29]

Lending credence to the Mesozoic conjoined landmass connection between India-Madagascar-Sri Lanka, and Seychelles brings out the prospectivity of the Kerala Basin on the southwest continental margin of India, especially at the tri-junction of Cape Comorin, where the present-day seas meet.

6. Focus areas for Exploration

The Kerala Basin is enclosed by the Tellicherry Arch to the north, the Chagos-Laccadive Ridge to the west, the Central Indian Basin to the south, and the Gulf of Mannar to the east. It is generally inferred that the continental shelf of Kerala consists of continental crust, with Archean granitic basement up to the slope, modified and attenuated continental crust or transitional crust, and then oceanic crust, which underlies the abyssal plains of the Arabian Sea[30]. Kalra's 2014 map of crustal architecture enhances the understanding of tectonic regimes (Figure 15), highlighting the delineation of the Continent-Ocean Boundary (COB) along the western edge of Sri Lanka and the southernmost point of India.

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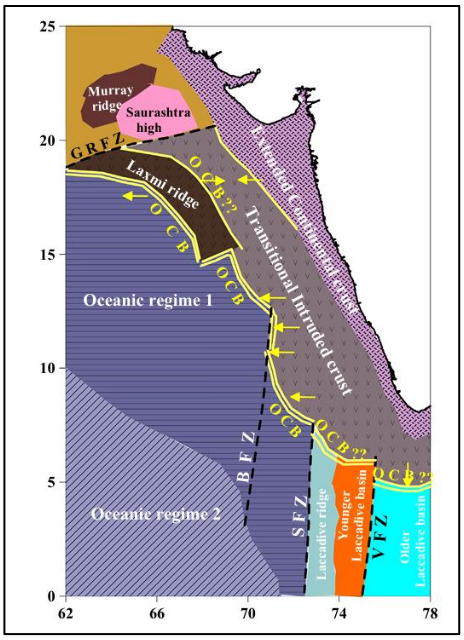

Figure 15: Illustrates the inferred crustal structure, the continental-oceanic boundary (COB), and various spreading regimes in the western offshore region[31].

Explanation of Figure 15: This is based on the analysis of crustal transects, the observed anomaly patterns, the clarity of magnetic anomaly features, established fracture zone trends, and seismic interpretations. The arrows indicate the orientation of Seaward Dipping Reflectors (SDR) identified in seismic data by previous researchers. The abbreviations used are as follows: GRFZ for Girnar Fracture Zone, BFZ for Brahma Fracture Zone, SFZ for Shiva Fracture Zone, and VFZ for Vishnu Fracture Zone[31].

The basic concerns highlighted by Nathaniel in 2008 include the following:

- The determination of the probable continental shelf break and the continental oceanic boundary (COB) at the southern tip of India, which encompasses the Gulf of Mannar and the Kerala Deepwater Basins.
- The identification of major strike-slip zones and the subsequent acknowledgment of a transform margin within the Kerala Deepwater Basin.
- The maiden establishment of a sub-basalt Mesozoic basin; the identification of significant structural plays from the Mesozoic era; and
- The development of a viable petroleum system through geological analogies, bolstered by supplementary evidence such as near-surface seismic characteristics and hydrocarbon slick analyses.

Nataniel in 2008 concluded the long-offset seismic characterization of the Vishnu Fracture Zone (VFZ), as illustrated in Figure 15 indicates that it functions as a transform fault, which has led to the structural inversion of the previously established rift-graben architecture. Significant geological structures resulting from inversion processes have been identified on the eastern flank of the VFZ, where sufficient heat flux and vertical migration pathways are anticipated to support the processes of hydrocarbon generation, migration, and entrapment. The Kerala Basin is encircled by three tectonic segments: the Konkan segment, which trends NNW-SSE to the north; the Chagos-Laccadive Ridge segment, oriented N-S to the west; and the Gulf of Mannar segment, which trends E-W to the southeast (Figure 16a and 16b).

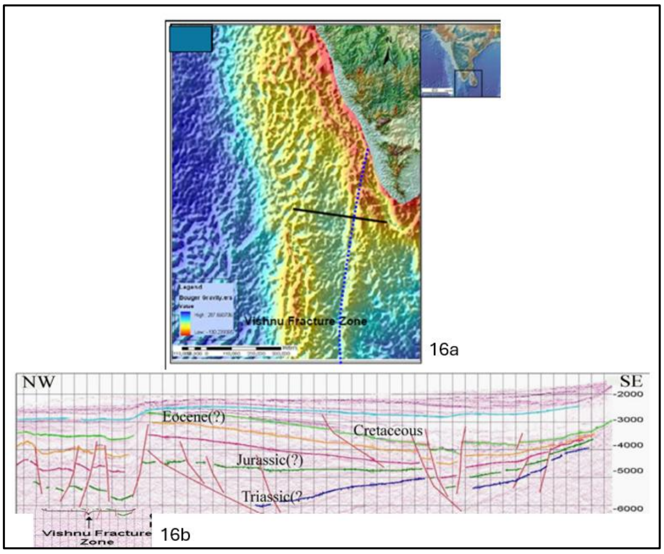

Figure 16a: Free-Air Gravity Anomaly Map above: the subsurface features of the Vishnu Fracture Zone, and 16b: below, the interpreted seismic depiction of the uplifted rift graben associated with the Vishnu Fracture Zone[32]

The areas that merit immediate attention leading to the drilling of parametric wells at present are the following are confined to the southwest continental margin (Figure 17). These areas also stand out in the Bouguer anomaly map of Balakrishnan, 1997.

1) Comorin Depression (within the continental crust)
2) Alleppey-Trivandrum Terrace complex
3) Kerala Deepwater Basin (Older Laccadive Basin)

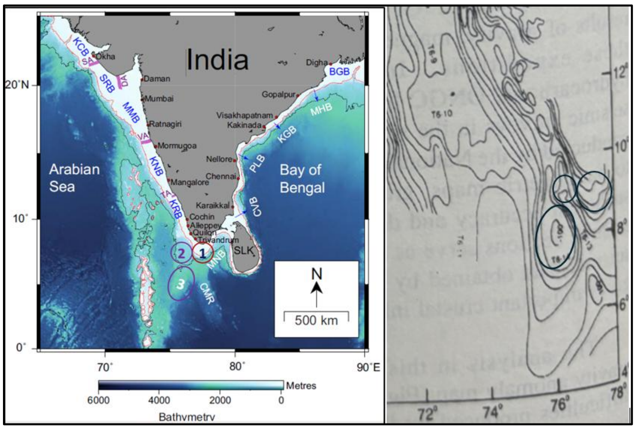

Figure 17: Bathymetry map[33] and Bouguer gravity anomaly map[34] with areas that merit attention by drilling

6.1 Comorin Depression

This depression lies directly off the Cape Comorin coast within the continental shelf. The Comorin depression occurs updip of the deep Mannar Basin. The seismic section in the adjoining shelf of Mannar Basin, very close to the Comorin Depression, shows the shelf-to-slope and abyssal deposits (Figure 18).

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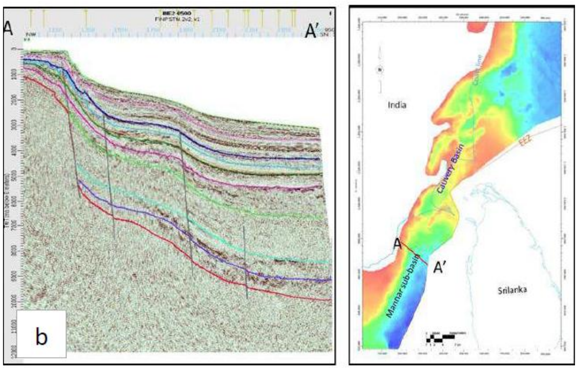

Figure 18: Seismic section across Mannar sub-basin depicting the Neogene compressional structures close to Comorin Depression[35]

The shelf is expected to be thicker in the Comorin Depression and there is a fair chance of the occurrence of Mesozoic. The shelf wells drilled in the northern area of the Kerala Basin revealed Mesozoic sediments in two of the wells. Baillie et al. (2003)[36] inferred the occurrence of sediments beyond the igneous rock encountered. This was later confirmed with the wells drilled in the Sri Lankan part of the Mannar Basin. Source rocks have been studied in Mozambique and Southeastern Madagascar. One widely accepted principle regarding the occurrence of petroleum is that significant hydrocarbon accumulations are predominantly found over continental crust. This assertion is generally valid, as sediment thickness tends to be greater over continental crust compared to oceanic crust. Additionally, the likelihood of source rock presence is higher before the transition of a rifted margin into an open marine environment. Furthermore, the heat flow from the Earth through continental crust can be up to twice as high as that through oceanic crust.

6.2 Alleppey-Trivandrum Terrace

The Kerala Basin represents the southernmost geological formation along the western continental margin of India, stretching from the Tellicherry Arch in the north to Cape Comorin in the south (refer to Figure 1). In the northern section, the western continental margin exhibits a consistent shelf-slope topography; however, the mid-continental slope area located south of Cochin displays an irregular topography due to the existence of two adjacent terraces, namely the Alleppey Terrace (AT) and the Trivandrum Terrace (TT) (Figure 18). Collectively, these are referred to as the Alleppey-Trivandrum Terrace Complex[37]. The seafloor depth of the Alleppey Terrace ranges from 300 m to 400 m, whereas the Trivandrum Terrace has water depths between 1500 m and 1900 m[37]. The southern boundary of the Alleppey Terrace is marked by an east-west trending scarp known as the Quilon Escarpment. Seismic reflection data from this area indicates that the Alleppey Terrace is linked to a basement high located to the west of its current configuration[38]. The Trivandrum Terrace is distinguished by a wide basement high trending from north-northwest to south-southeast in its central region, bordered by substantial sediment-filled grabens on both the eastern and western sides, referred to as the TT-Eastern Basin and the TT-Western Basin, respectively (Figure 19)[37]. Both basins exhibit NNW-SSE trending block-faulted basement characteristics that extend throughout the Trivandrum Terrace. The western edge of the Alleppey-Trivandrum Terrace Complex is marked by a steep, linear escarpment that stretches roughly 500 kilometers, referred to as the Chain-Kairali Escarpment.

It is understood that one of the national oil companies (NOCs) has a plan to drill an exploration wildcat in the terrace off Kollam Coast. This is the first opportunity to probe the Mesozoic. None of the wells had penetrated Mesozoic, hence drilling up to 6000m could gather crucial geological data.

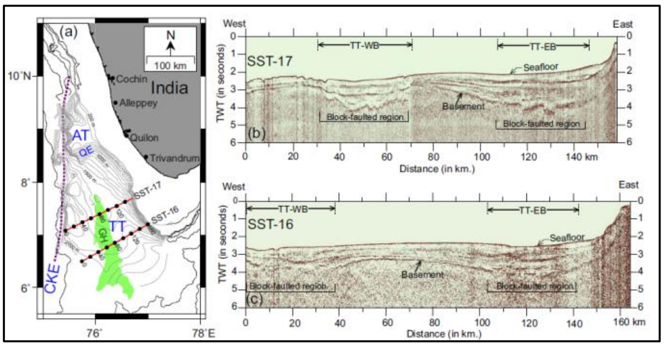

Figure 19: Illustrates the configurations of the seafloor and sub-seafloor within the Alleppey-Trivandrum Terrace Complex (ATTC) and surrounds, represented by (a) bathymetric contours, and (b) and (c) multichannel seismic reflection profiles along SST-17 and SST-16[37].

6.3 Kerala Deep Water Basin (East of Laccadive Ridge)

This deep-water basin is also called the Older Laccadive Basin by some explorers and is situated east of the Vishnu Fracture Zone (VFZ)(Figure 15). VFZ bisects the Kerala Basin into a younger crust basin on the west and an Older crust basin on the east. The deep-water basin in question is on the east. The seismic analysis enabled the identification, mapping, and assessment of three significant independent structural prospects from the Mesozoic era, along with various structural and stratigraphic prospects from both the Mesozoic and Tertiary periods[39]. A huge anticline is seen on the seismic profile and its origin is attributed to structural inversion (Figure 20).

Mesozoic deepwater deposits are likely associated with a shelf-margin deltaic origin within a ramp configuration in the Gulf of Mannar. Analysis of mega-sequences suggests that the source provenance is located to the east (encompassing India, Sri Lanka, and Antarctica), exhibiting a southerly lateral shift or avulsion[39]. Given that Deccan volcanic extrusives and flows rest over the Mesozoic, the conventional identification of reservoirs through seismic attributes is hindered. As a result, the initial emphasis for exploration shifts towards structural plays.

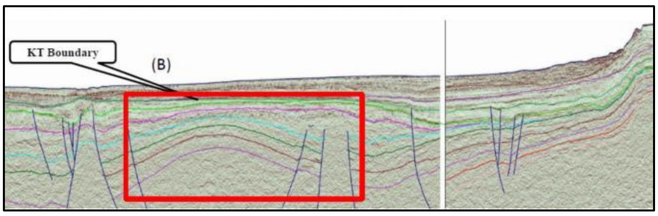

Figure 20: Seismic Profile across the Deep-water Basin (WNW to ESE) exhibiting Structural Inversion and Transpression within the Mesozoic[20]

7. Suggested Exploration Strategy

The perceived lack of potential in the basin has led to a declining enthusiasm among private entities for continued exploration efforts. During the NELP era, it was unlikely that any private investor would allocate funds for drilling through the substantial layers of basalt offshore to investigate the speculative Mesozoic petroleum system situated beneath the Tertiary with the uncertainty of its occurrence. Seismic imaging in the Kerala Konkan Basin faces challenges due to complex geology and episodic volcanic activity, limiting exploration. However, with the acquisition of long-spaced seismic and adopting a sound geological model incorporating palaeogeographic reconstructions involving plate tectonic concepts and analysis of associated basins over geologic time, the exploration model is robust now, and a breakthrough can only be obtained by drilling those prospects.

The responsibility now rests with the NOC to pick up the breathtaking findings of the private operator, which has a sound geologic basis, ascertain the thickness of the basalt, and determine what lies beneath it through fit-for-purpose fast screening, thereby positioning the Kerala-Konkan basin on India's hydrocarbon map.

One of the NOCs is slated to drill a deep well in the shallow offshore off the Kollam coast and target beyond the Tertiary. Furthermore, the Government of India should play a pivotal role by providing incentives and financial support for drilling research and development wells to penetrate the basalt's full thickness at the appropriate locale. The basin with 600,000 km^2 was probed with just 14 wells. It must be recalled that the Mesozoic is the biggest oil producer globally, and associated basins have given significant exploration leads. Alternatively, a consortium comprising various private entities and government companies should be established to undertake the challenge of exploring the Mesozoic basin in this region of the western offshore of India. The need to drill a few parametric wells is mandatory at this stage of exploration. The current faux pas of not drilling at all must not continue.

Exploration models were constrained by conventional, outdated notions of drilling into structural highs of the Tertiary period. However, the discovery of the sub-basalt Mesozoic potential has emerged from collaborative research efforts involving specialists from diverse disciplines. The importance of these studies indicates that it is now a question of when, not if, a commercial discovery will occur in the deepwater Kerala basin frontier. Skepticism is an essential part of hydrocarbon exploration as it is not possible to proclaim a law of nature until the idea has survived the exploration drill test[32]. Hence, it warrants immediate drilling, and it has been a while since the new geological model emerged and remains untested by the drill.

8. Concluding Remarks

The tectonic processes that have created hydrocarbon reservoirs within the Earth's crust have left a trail of scientific clues that explorers must try to unveil if they are to be successful in locating hydrocarbon accumulations. To achieve this, the depositional process caused by tectonics and sea-level changes for hundreds of millions of years must be reconstructed and understood.

1) It is imperative to approach this basin with an open mind to unravel the mysteries through novel data acquisition and processing methods, and fast screening is a must. The aim must be more plausible geology from geophysics.
2) The comprehension of the geology and petroleum system within the Kerala Konkan Basin is consistently evolving, but this should be supplemented with drill data to calibrate the geological interpretation to unlock value.
3) The vast publicly available information has been scanned, and these resources offer valuable opportunities for various stakeholders, including industry, regulators, and researchers, to analyse the system, identify knowledge and technological gaps, and reduce risks associated with the exploration of hydrocarbon resources.
4) The government must seriously think about setting a consortium within the framework of existing policies or even modify the policies to undertake meaningful exploration now that a robust geologic model is in place.
5) The assessment and incorporation of advanced concepts and technologies to obtain more geology from geophysics—such as long-offset seismic techniques, wide aperture reflection/refraction profiling (WARRP), controlled source electromagnetic (CSEM) technique, seabed logging, etc., for detection and delineation of hydrocarbon reservoirs**,** gravity measurements, and magnetic surveys—within the framework of plate tectonics facilitate the identification of deep and ultra-deepwater opportunities that have considerable potential to unearth new petroleum provinces.
6) Traditional processing technology may no longer be effective in addressing the intricate sub-surface conditions of volcanic basins, particularly where the targets are situated within and beneath traps. Conversely, modern processing techniques applied to existing data can partially investigate sub-basalt features. However, the combination of new broadband data and advanced technology holds greater promise for capturing low-frequency events located beneath basalt layers.

References

[1] Mullick, A.K, 2015. Exploration in Kerala-Konkan Basin, Western Offshore, India- Why &Why not? GeoIndia ID:2010635.
[2] Campanile D, Nambiar CG, Bishop P, Widdowson M & Brown R 2008. Sedimentation record in the Konkan–Kerala Basin: implications for the evolution of the Western Ghats and the Western Indian passive margin. Basin Research 20: 3–22.
[3] Biswas S.K, 2008a.Petroliferous basins of India- Fifty years' history and Perspective, Mem. Geol. Soc. India.v.66,p 159-202.
[4] Ju, K. Y., Zhang, B., 2020. Modeling of tectono-thermal evolution of Permo-Carboniferous source rocks in the southern Qinshui Basin, China: consequences for hydrocarbon generation. J. Petrol. Sci. Eng. 107343.
[5] Mishra,S et al, 2022. Modern Seismic Imaging and Basin Modeling Reveals Sub-Basalt Hydrocarbon Potential Offshore India, Conference: Association of Petroleum Geologists- AAPG ICE 2012 At: Singapore.

[6] Siawal, A. et al,2019. Evolution West Coast of India- A plate tectonic approach, ONGC Bulletin, Vol 54, No 1.
[7] Mathur, R.B et al, 1993. Lithostratigraphy of Indian petroliferous basins, Document VI, Kerala-Kokan Basin, Unpublished ONGC document.
[8] Kularathna E K C W, et al,2020, Play distribution and the hydrocarbon potential of the Mannar Basin, Sri Lanka, Journal of Petroleum Exploration and Production Technology (2020) 10:2225–2243 https://doi.org/10.1007/s13202-020-00902-8
[9] Baillie, P.W, et al, 2004.Petroleum Systems of the Deepwater Mannar Basin, Offshore Sri Lanka, Proceedings, Deepwater and Frontier Exploration in Asia & Australasia Symposium, December 2004, Indonesian Petroleum Association.
[10] Singh, A. et al, 2021. Crustal structure and subsidence history of the Mannar basin through potential field modelling and backstripping analysis: Implications on basin evolution and hydrocarbon exploration, Journal of Petroleum Science and Engineering, Volume 206,2021, ttps://doi.org/10.1016/j.petrol.2021.109000.
[11] Dharmapriya et al., 2016 New LA-ICPMS U-Pb ages of detrital zircons from the Highland Complex: insights into late Cryogenian to early Cambrian (ca. 665-535 Ma) linkage between Sri Lanka and India. Int. Geol. Rev. 58, 1856–1883.
[12] Takamura, Y., Tsunogae, T., Tsutsumi, Y., 2020. U-Pb geochronology and REE geochemistry of zircons in mafic granulites from the Lützow-Holm Complex, East Antarctica: implications for the timing and P–T path of post-peak exhumation and Antarctica–Sri Lanka correlation. Precambrian Res. 105850.
[13] Desa, M. A., Ramana, M. V., & Ramprasad, T. (2006). Seafloor spreading magnetic anomalies south off Sri Lanka. Marine Geology, 229, 227–240.
[14] Lawver, L. A., & Scotese, C. R. (1987). A revised reconstruction of Gondwanaland. In D. McKenzie (Ed.), Gondwana Six: Structure, Tectonics, and Geophysics, Monograph series (Vol. 40, pp. 17–23). Washington: American Geophysical Union.
[15] Ali, J. R., & Aitchison, C. J. (2008). Gondwana to Asia: Plate tectonics, paleogeography and the biological connectivity of the Indian sub-continent from the Middle Jurassic through latest Eocene (166–35 Ma). Earth-Science Reviews, 88, 145–166.
[16] Gibbons, A. D., Barckhausen, U., van den Bogaard, P., Hoernle, K., Werner, R., Whittaker, J. M., & Muller, R. D. (2012). Constraining the Jurassic extent of Greater India: Tectonic evolution of the West Australian margin. Geochemistry, Geophysics, Geosystems, 13, Q05W13. https://doi.org/10.1029/2011GC003919
[17] Seton, M., Müller, R. D., Zahirovic, S., Gaina, C., Torsvik, T., Shephard, G., et al. (2012). Global continental and ocean basin reconstructions since 200 ma. Earth-Science Reviews, 113, 212–270.
[18] Desa, M. A., Isamaiel, M., & Krishna, K. S. (2018). Oblique strike-slip motion off the southeastern Continental Margin of India: Implication for the separation of Sri Lanka from India. Journal of Asian Earth Sciences. https://doi.org/10.1016/j.jseaes.2018.01.015
[19] Mammo, T (2010): Delineation of sub-basalt sedimentary basins in hydrocarbon exploration in North Ethiopia, Marine and Petroleum Geology, doi: 10.1016/ j.marpetgeo.2009.12.009
[20] Nathaniel D.M. 2011. Elephant Prospects in the Sub-Basalt Sediments of the Deepwater Kerala Basin, India, GM workshop, SEG Annual Meeting, San Antonio, USA.
[21] Savostin L. A., Kerusov, I. N., 2001, Interpretation Report: Southern Tip of India, Laboratory of Regional Geodynamics Ltd.
[22] Heat flow atlas of India,1991.
[23] Storey M, Mahoney JJ, Saunders AD, Duncan RA, Kelley SP, Coffin MF. Timing of hot spot--related volcanism and the breakup of Madagascar and India. Science. 1995 Feb 10;267(5199):852-5. doi: 10.1126/science.267.5199.852. PMID: 17813912.
[24] Hammond, J.O.S., Collier, J.S., Kendall, J., Helffrich, G., and Rumpker, G., 2012. Plume scar in the mantle lithosphere beneath the Seychelles revealed by seismic imaging. Earth Planet. Sci. Lett., 355-356, 20-31.
[25] Intawong, A et al, 2015. Petroleum System and Play Type Identification, Western and Eastern Offshore Madagascar, Conference: First EAGE Eastern Africa Petroleum Geoscience Forum, DOI:10.3997/2214-4609.201414439
[26] Waples, D. W., and Hegarty, K., 1999. Seychelles thermal history, hydrocarbon generation traced. Oil & Gas Journal: International petroleum news and technology. 97(21), 78-81.
[27] Ayodele et al, 2017, High Impact Exploration Inventory in an Emerging Hydrocarbon Province, Morandava Basin, Offshore Madagascar Search and Discovery Article #10957 (2017) Posted June 19, 2017.
[28] Ratnayake et al 2018. Assessment of hydrocarbon generation potential and thermal maturity of the offshore Mannar Basin, Sri Lanka. J Pet Explor Prod Technol 8:641–654.
[29] Kularathna E K C W, et al,2015, Forced-Fold structures in the Mannar Basin, Sri Lanks: Modes of Occurrence, Development mechanism and contribution for the petroleum system, Journal of Geological Society of Sri Lanka Vol. 17 (2015), 53-63 J.W. Herath Felicitation Volume.
[30] Savostin and Kerusov, 2001. Interpretation Report: Southern Tip of India, Laboratory of Regional Geodynamics Ltd.
[31] Kalra, R. et al, Crustal architecture and tectono-magmatic history of the western offshore of India: Implications on deepwater sub-basalt hydrocarbon exploration, Journal of Petroleum Science and Engineering Volume 122, October 2014, Pages 149-158.
[32] Nathaniel, D.M, et al, 2008. Convolution of Technology and Concepts Entails Enticing Deepwater Opportunities, India, 7th Biennial International Conference & Exposition on Petroleum Geophysics, Hyderabad 2008.
[33] Yatheesh V. 2020, Structure and tectonics of the continental margins of India and the adjacent deep ocean basins: current status of knowledge and some unresolved problems. Episodes 43:586-608. https://doi.org/10.18814/epiiugs/2020/020039
[34] Balakrishnan, T.S, 1997. Major Tectonic elements of the Indian subcontinent and contiguous areas: A

Geophysical view, Memoir 38, Geological Society of India.
[35] Kiranmayi, K.B et al,2022, Mannar Sub-Basin, Cauvery Basin-Characteristics and Opportunities for hydrocarbon accumulations, Geo India 2022.
[36] Baillie, P.W., Shaw, R.D., Liyanaarachchi, D.T.P., Jayaratne, M.G., 2003. A new Mesozoic sedimentary basin, offshore Sri Lanka. In: Proceedings of E.A.G.A. 64th Conference & Exhibition, Florence, Italy.
[37] Yatheesh, V., et al 2013b.Morphotectonic architecture of an India-Madagascar breakup related anomalous submarine terrace complex on the southwest continental margin of India. Marine and Petroleum Geology, v.46, pp. 304-318.
[38] Unnikrishnan, P., Radhakrishna, M., Prasad, G.K., Crustal structure and sedimentation history over the Alleppey platform, southwest continental margin of India: Constraints from multichannel seismic and gravity data, *Geoscience Frontiers* (2017), doi: 10.1016/ j.gsf.2017.06.002.
[39] Nathaniel, 2013.Hydrocarbon Potential of Sub-Basalt Mesozoics of Deepwater Kerala Basin, India,10th Biennial International Conference & Exposition, Kochi.

Author Profile

Pratap Vikraman Nair received the B.Sc. Hons. and M.Sc. degrees in Applied Geology from the Indian School of |Mines in 1981 and 1983, respectively, with full honours. He was also conferred a Doctorate in Petroleum Geology. He worked at the National Oil Company, ONGC Ltd, from 1983 to 2007 in various positions as a petroleum geologist in most of the sedimentary basins of India before joining Royal Dutch Shell in 2007. In Shell, he worked on assignments in the Netherlands, Nigeria, India, and Malaysia before superannuating in 2021. As a Principal Technical Expert, he was part of several frontier basin campaigns across the globe. He continues to work as a Consultant Petroleum Geologist for Gujarat National Resources Ltd, Adani Welspun Ltd, and Oil India Ltd. Besides his interest in Petroleum Geology, he has specialized in Geomechanics, Geohazards, and Pore Pressure Prediction.