Cretaceous-Paleocene extension at the southwest continental margin of India and opening of the Laccadive Basin: Constraints from geophysical data

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Abstract. Previous geophysical investigations of the Western Continental Margin of India (WCMI) confirm the two-phase breakup history of the margin with the first breakup taking place between India and Madagascar in Late Cretaceous and the second breakup event in early Paleocene with Seychelles separating from India. Despite numerous geoscientific studies along the WCMI, the opening of the Laccadive Basin, lying along the southern part of the margin, remains poorly constrained. In this study, we evaluate the multi-channel seismic reflection and gravity anomalies at the margin to identify the early rift signatures in conjunction with the magnetic anomaly identifications in the Mascarene Basin. The analysis led to the identification of two extensional directions, a ENE-WSW oriented extension over the Laccadive Ridge north of Tellicherry Arch, and the NW-SE extension in the Laccadive Basin region towards the south. Previous plate reconstruction models of the Mascarene Basin using marine magnetic lineations suggest that the ENE-WSW extension observed over the Laccadive Ridge could be related to the India-Madagascar separation. We associate the pattern of sediment deposition and the presence of a Paleocene trap, associated with the NW-SE extensional grabens observed in the Laccadive Basin region, to the extension between the Laccadive Ridge and the West coast of India after the separation of Madagascar from India. We further propose that the anti-clockwise rotation of India and the passage of the Réunion plume have facilitated the opening of the Laccadive Basin.

1 Introduction

The breakup of Gondwanaland into the Eastern and Western Gondwana during the Early Jurassic period has initiated the formation of western Indian Ocean (fig. 1). The subsequent breakup of Madagascar and the Seychelles from India, and the seafloor spreading along the Carlsberg and Central Indian ridges culminated into the present northwest Indian Ocean. The Laccadive Ridge (LR), the Maldives ridge (MR), the Chagos Bank (CB) and the Saya-de-Malha Bank (SMB), the Nazreth Bank (NB), the Mauritius Island (MI), the Reunion Island (RI) are the major topographic features present in the northwest Indian Ocean (fig. 1A), and some of these are believed to be the micro-continents (Torsvik et al., 2013).

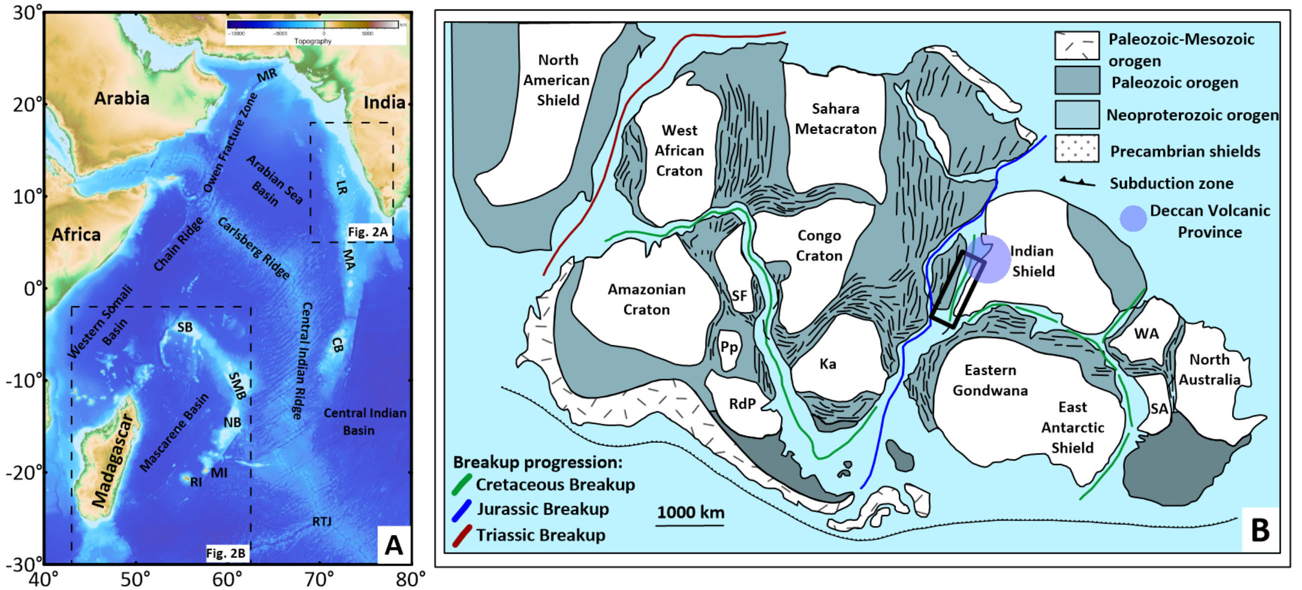

Figure 1. A) Regional tectonic map of the northwestern Indian Ocean with satellite-derived seafloor topography (Smith and Sandwell, 1997). The area shown in the dashed black rectangle is shown in figure 2A &2B. B) The map shows the position of India relative to Madagascar and Deccan Volcanic Province in late Paleozoic fit (Lovecchio et al., 2020, modified after). The area of interest is marked in black rectangle. SB: Seychelles Bank; SMB: Saya-de Malha Bank; NB: Nazarat Bank; MI; Mauritius Island; RI: Reunion Island; RTJ: Rodrigues Triple Junction;LR: Laccadive Ridge; MA; Maldives ;CB: Chagos Bank; MR: Murray Ridge.

The Western Continental Margin of India (WCMI) formed through the breakup and separation of India and Madagascar in the late-Cretaceous (Storey et al., 1995; Pande et al., 2001). This breakup event resulted in the formation the Mascarene Basin (fig. 1A & 2B), the details of which are recorded in the magnetic anomalies in the basin (fig. 2B). The northern part of the margin then experienced another breakup event when the Seychelles block separated from the combined Laxmi Ridge and India in the early Paleocene time. This second breakup event is well studied with the pre-drift juxtaposition of the continental blocks fairly well established from the magnetic anomaly identifications and geochronology (Collier et al., 2008; Chaubey et al., 2002; Ganerød et al., 2011; Shellnutt et al., 2015, 2017). The southern part of the margin is considered to be conjugate with the Madagascar (Katz and Premoli, 1979) based on the matching of the major shear zones and reconstructed to 2000 m isobath. However, recent close-fit reconstruction models have incorporated the continental fragments like Laccadive Ridge (Bhattacharya and Yatheesh, 2015) or Mauritia, comprising of Mauritius, the Southern Mascarene Plateau, the Laccadive Plateau and the Chagos Bank (Torsvik et al., 2013) between India and Madagascar in the India-Madagascar pre-drift scenario, and suggest a breakup timing of around 83 Ma.

Laccadive Ridge (Plateau) is the bathymetric high feature in the southwest offshore margin and lies parallel to the west coast of India. The Laccadive Basin lies between the Laccadive Ridge and the continental shelf (fig. 2A) south of Tellicherry Arch. It is known well that the southwest margin was affected by Réunion plume volcanism towards the end of Cretaceous (Singh and

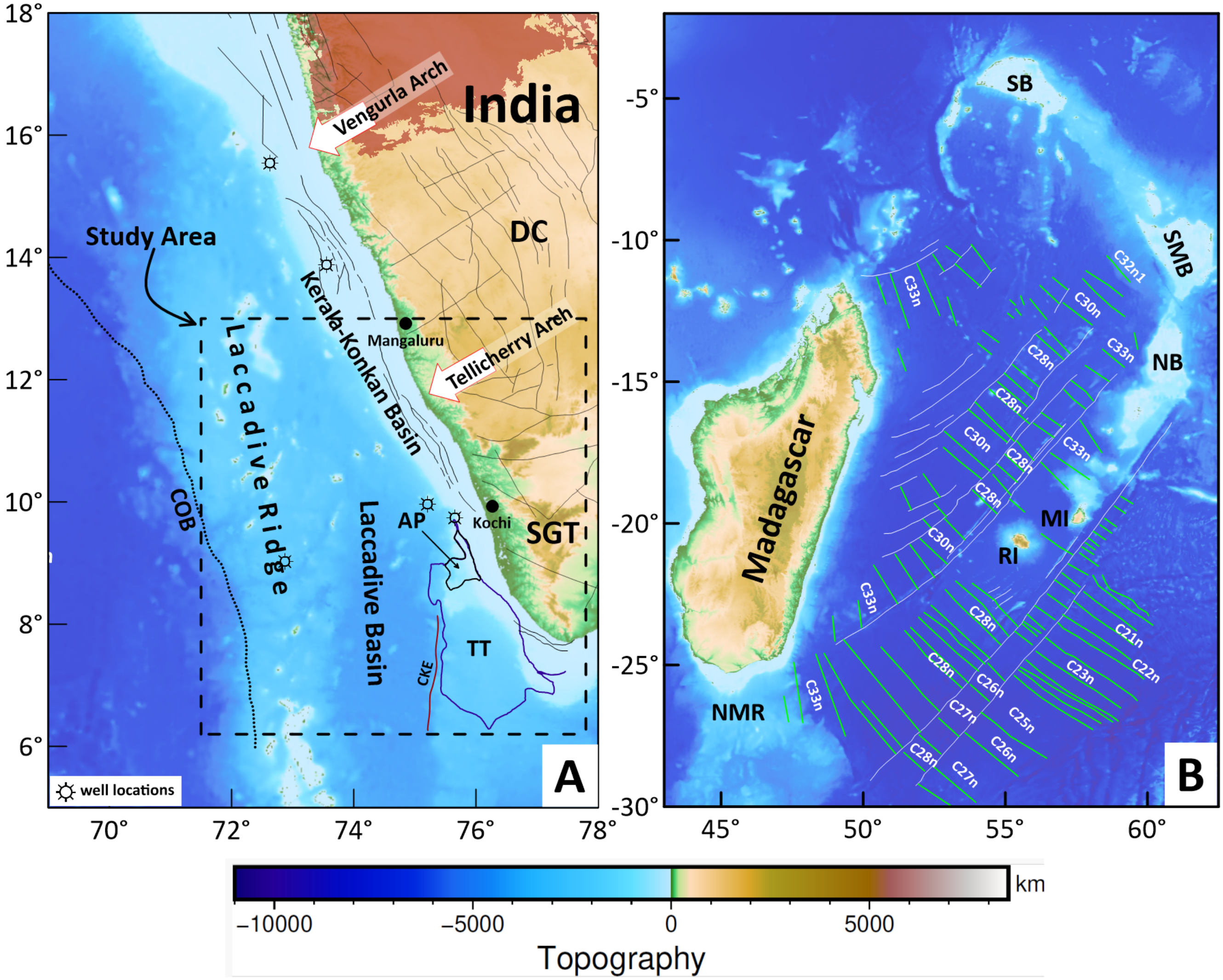

Figure 2. A) Regional tectonic map of the western continental margin of India (Smith and Sandwell, 1997). Black solid lines in the offshore region represent shear zones and faults. B) Tectonic map of Madagascar and Mascarene basin showing mapped seafloor spreading type magnetic lineations in solid green coloured lines (Bhattacharya and Yatheesh, 2015, and references therein). Solid white lines represent the mapped fracture zones or pseudo-faults. SB: Seychelles Bank; SMB: Saya-de Malha Bank; NB: Nazarat Bank; MI; Mauritius Island; RI: Reunion Island; NMR: Northern Madagascar Ridge; DC: Dharwar Craton; SGT: Southern Granulite Terrain; LB: Laccadive Basin; AP: Alleppey Platform; TT Trivandrum Terrace; CKE: Chain-Kairali Escarpment; COB: Continent-Ocean transition.

Lal, 1993) as revealed by the presence of wide-spread trap layer below the thin Tertiary sediment cover at the margin (Singh et al., 2007; Singh and Lal, 1993), as a result, the vintage seismic data was not of much help to decipher the basin architecture.

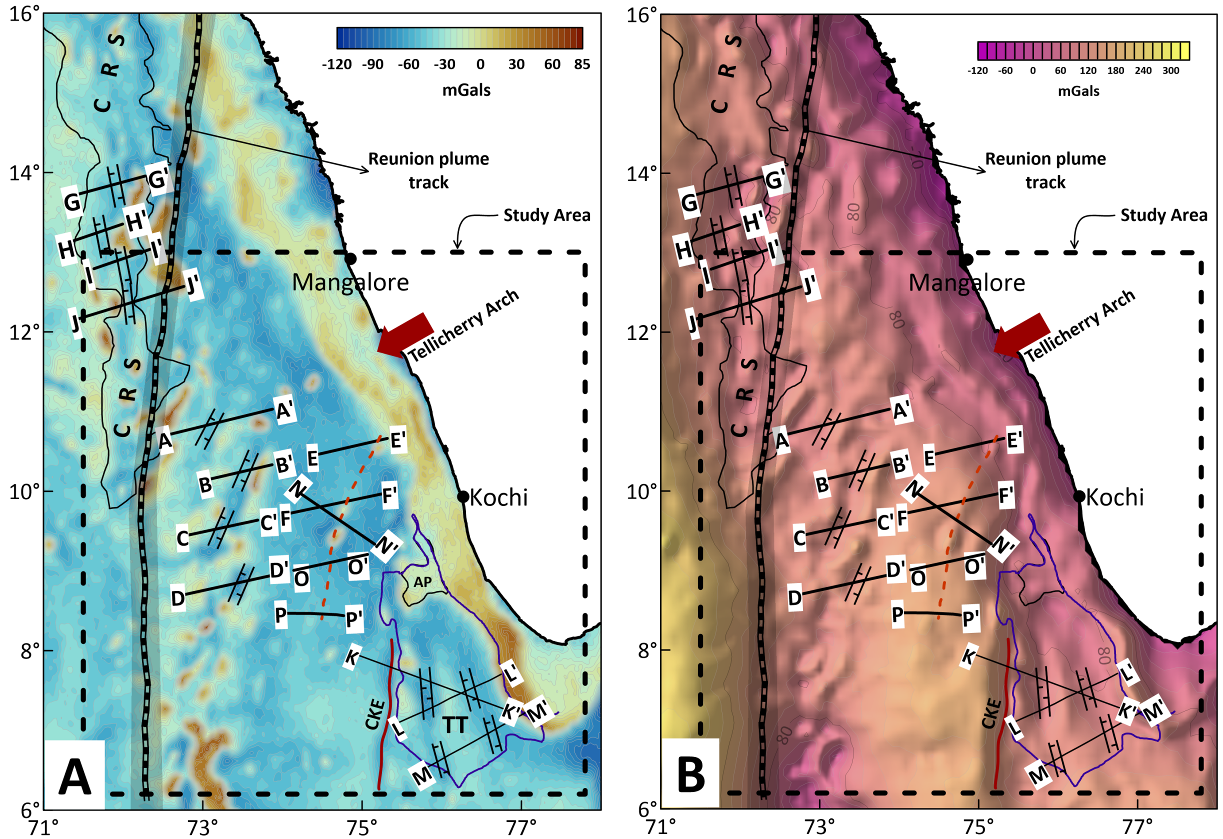

Figure 3. A) Satellite-derived free-air anomaly map B) Crustal Bouguer anomaly map. The location and orientation of identified extensional features, grabens and intrusives are marked. Black solid lines represent the location of the profiles. Interpreted seismic sections are shown in fig. 4.The thick broken reddish line in the centre of the basin represents the identified volcanic ridge. (refer to fig. 4 & S1 for seismic sections). CRS represents the Cannanore Rift System as identified by DGH. CKE: Chain-Kairali Escarpment; AP: Alleppey Platform; TT: Trivandrum Terrace.

Most of the drilled-wells along this margin neither penetrated the Paleocene trap layer nor encountered the crystalline basement, except the well CH-1-1 well located within the shelf, which penetrated through the trap and encountered Santonian formations (Singh and Lal, 1993). One of the key question that was not resolved is the absence of Late Cretaceous sediments in the Laccadive basin as a whole and the long time gap of more than 20 Ma between the India-Madagascar breakup at 83 Ma and the oldest sediments of Paleocene age. This long-time gap indicates either the presence of older sediments below the Paleocene trap layer or the opening of the Laccadive basin subsequent to the India-Madagascar separation. Further, the accommodation of the continental fragments between India and Madagascar (Bhattacharya and Yatheesh, 2015; Torsvik et al., 2013) makes a complex geodynamic setting, as how this separation took place, and therefore provides some insights into the pre-existing lithospheric inheritance. Hence, examining the development of the Laccadive Basin will provide important constraints on the

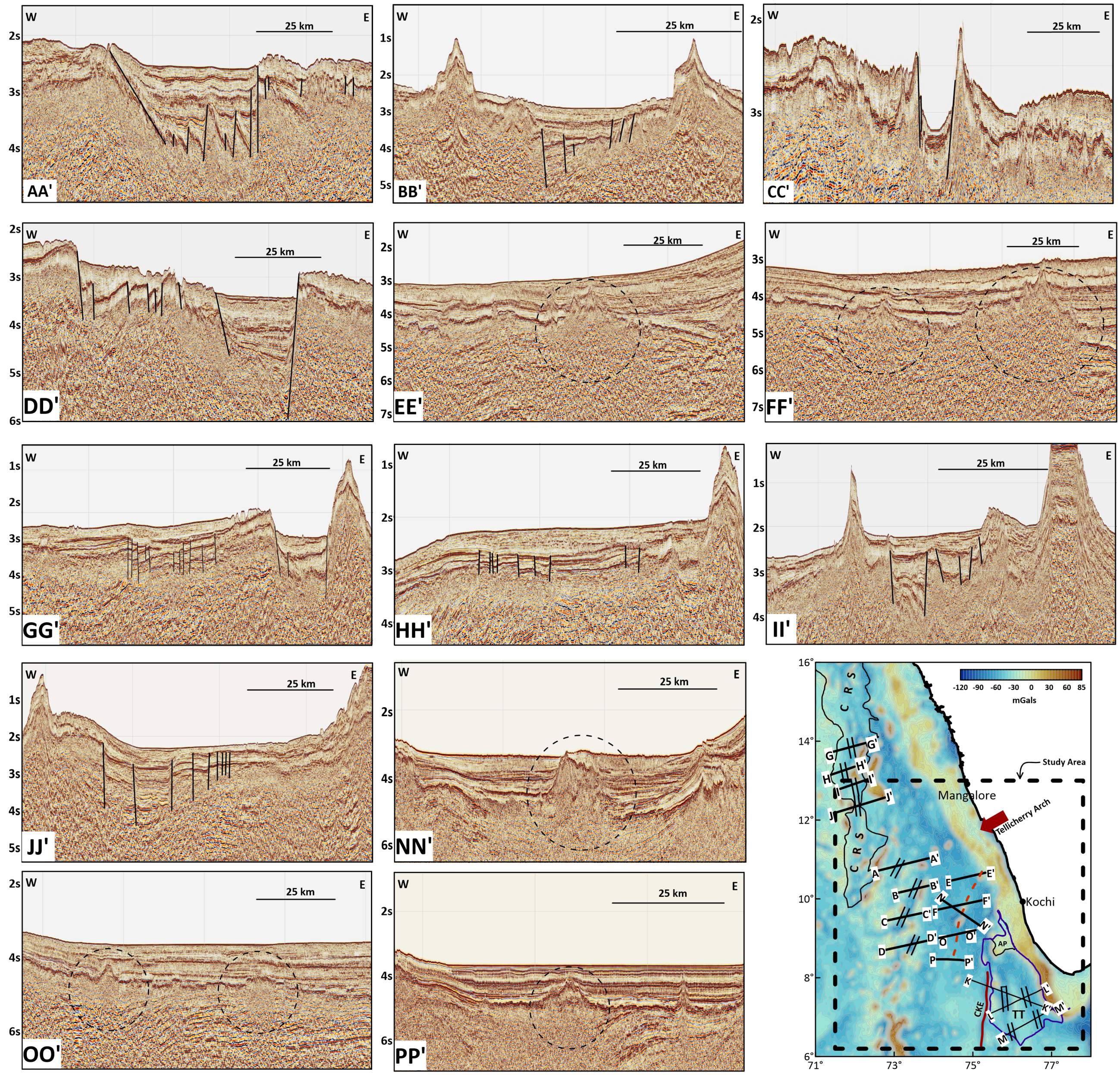

Figure 4. Figure showing interpreted seismic sections. The faults are marked and the intrusives are shown in dotted circles. The inset free-air anomaly map on the right bottom corner shows that location of seismic profiles. The time is given two-way travel times (TWT). TWT is the elapsed time for a seismic wave to travel from its source to a given reflector and return to a receiver at the Earth's surface.

early breakup evolution of the margin. In this study, we made a correlative analysis of the multi-channel seismic data with the residual gravity anomalies which provided evidence of a major extensional event that occurred at the southwest margin that is not related to the India-Madagascar breakup. The time-stamping of this major extensional event provides important constraints on the evolution of the WCMI and help to build improved tectonic reconstruction models.

2 Description of tectonic elements of the study area

The study area lies south of Tellicherry Arch and contains the southern part of the Laccadive Ridge and the Laccadive Basin (fig. 2A). The major geomorphic features present in the study area from west to east are the Laccadive Ridge, the Laccadive Basin, the Alleppey Platform and Trivandrum Terrace together called the Alleppey-Trivandrum Terrace Complex (ATTC) and the continental shelf (fig. 2A). The ATTC is characterized by horst-graben structures and bounded in the west by the Chain-Kairali Escarpment (CKE) feature (Yatheesh et al., 2006, 2013; Nathaniel, 2013) as revealed in the seismic sections (See fig. S1). Numerous seamounts/guyots/knolls are present in the region between the Laccadive Ridge and the continental shelf within the Laccadive Basin (See fig. S2) (Bijesh et al., 2018). In addition to this, the entire region is characterized by several intrusive structures within the Tertiary sediments (Unnikrishnan et al., 2023). The southern part of the Cannanore Rift system (CRS) identified over the Laccadive Ridge (fig. 3) by the Director General of Hydrocarbon (source: DGH) lies within the study area.

3 Data and Methods

In this study, we used the satellite-derived free-air gravity (Sandwell et al., 2014) and bathymetry from General Bathymetric Chart of the Oceans (GEBCO, 2020) for comparative analysis with multi-channel seismic reflection profiles. The large volume of industry seismic reflection data (see supplementary fig S3) at this margin provided information on the sediment thickness above the Paleocene trap layer and and various horizons within the post-Paleocene sediments (Unnikrishnan et al., 2023). We also gathered a few published seismic sections (Nathaniel, 2013; Yatheesh et al., 2013) within the study area (see supplementary fig S1).

The gravity effects of the water layer and the sediments are removed from the satellite-derived free-air anomaly data which gave rise to crustal Bouguer anomalies. High-resolution sediment thickness derived from two-way travel time (TWT) maps is used to calculate the gravity effect of the sediments. The TWT maps are available for three different times: the early Paleocene, early Eocene, early Miocene (Unnikrishnan et al., 2023). These maps were converted to depth with respective interval velocities (after Unnikrishnan et al., 2023) and the total sediment layer is used to calculate the gravity effect of sediments. The densities of 2.3 g/cc for sediments and 1.03 g/cc for the water column respectively are used. For the crustal rocks, an average density of 2.8 g/cc was considered as the study area lies within the extended continental crust (Unnikrishnan et al., 2023). A 10-200 km wavelength band-pass filter was applied to the crustal Bouguer anomaly map to highlight the crustal heterogeneities, and the first vertical derivative (FVD) as well as the total horizontal derivative (THD) of the band-pass filtered map was prepared to identify shallow structural features. The location of the identified features such as rifts and volcanic intrusives in the seismic sections are then transferred on to these gravity anomaly maps in order to understand their continuity. Scientifically derived colour maps are used to prepare maps(Crameri et al., 2020).

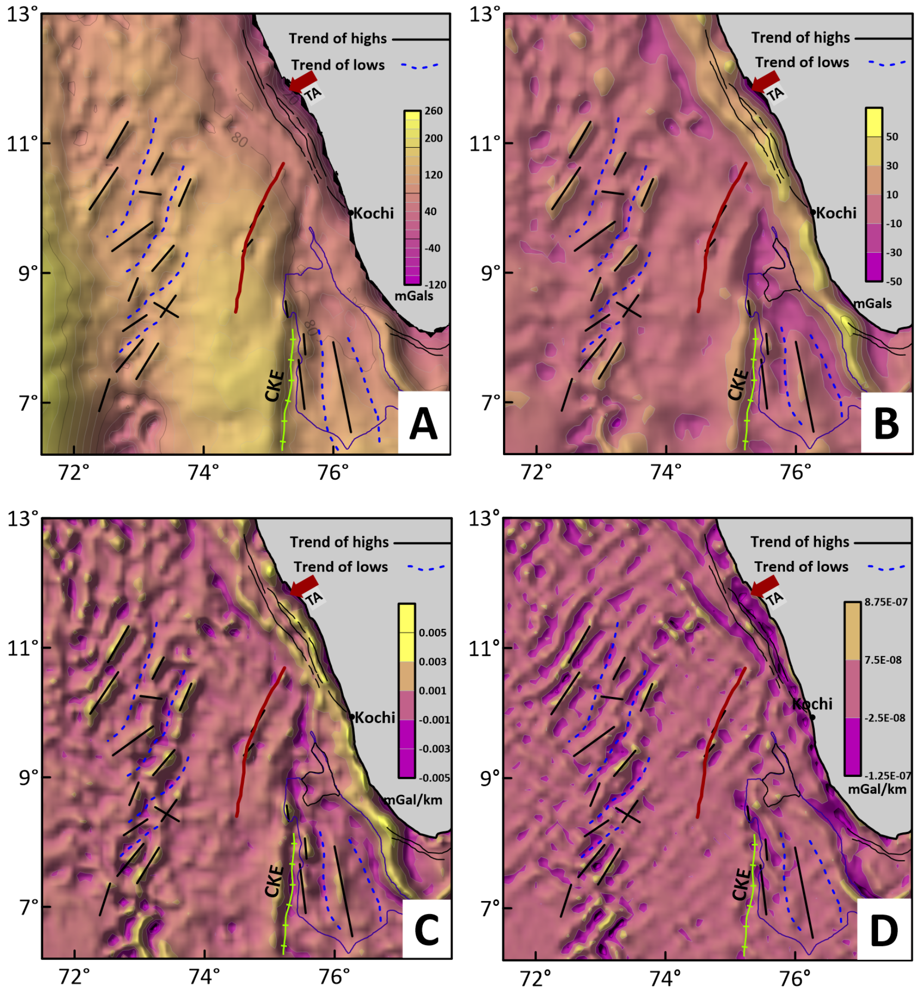

Figure 5. A) Crustal Bouguer anomaly, B) Band-pass filtered crustal Bouguer anomaly, C) First vertical derivative (FVD) of band-pass filtered crustal Bouguer anomaly, D) Total horizontal derivative (THD) of band-pass filtered crustal Bouguer anomaly. The black lines show the structural highs and the blue dotted lines show the continuity of rift basins identified. The chartreuse coloured solid ticked line represents the Chain-Kairali escarpment (CKE). The brown line represents the identified volcanic ridge. The thin black lines close to the coast represents major faults identified on the continental shelf Singh and Lal (1993). TA: Tellicherry Arch.

4 Results

We present thirteen interpreted seismic sections (fig. 4) which reveal several rift-related horst-graben structures (extensional features) at the margin. We correlated these structures with the gravity anomaly trends and noticed that the grabens are oriented in the NNW-SSE direction in the area north of the Tellicherry Arch, whereas, the grabens are oriented in NNE-SSW direction south of Tellicherry Arch (see fig. 3 & fig. 4). These identified extensional structures show low gravity anomalies and the

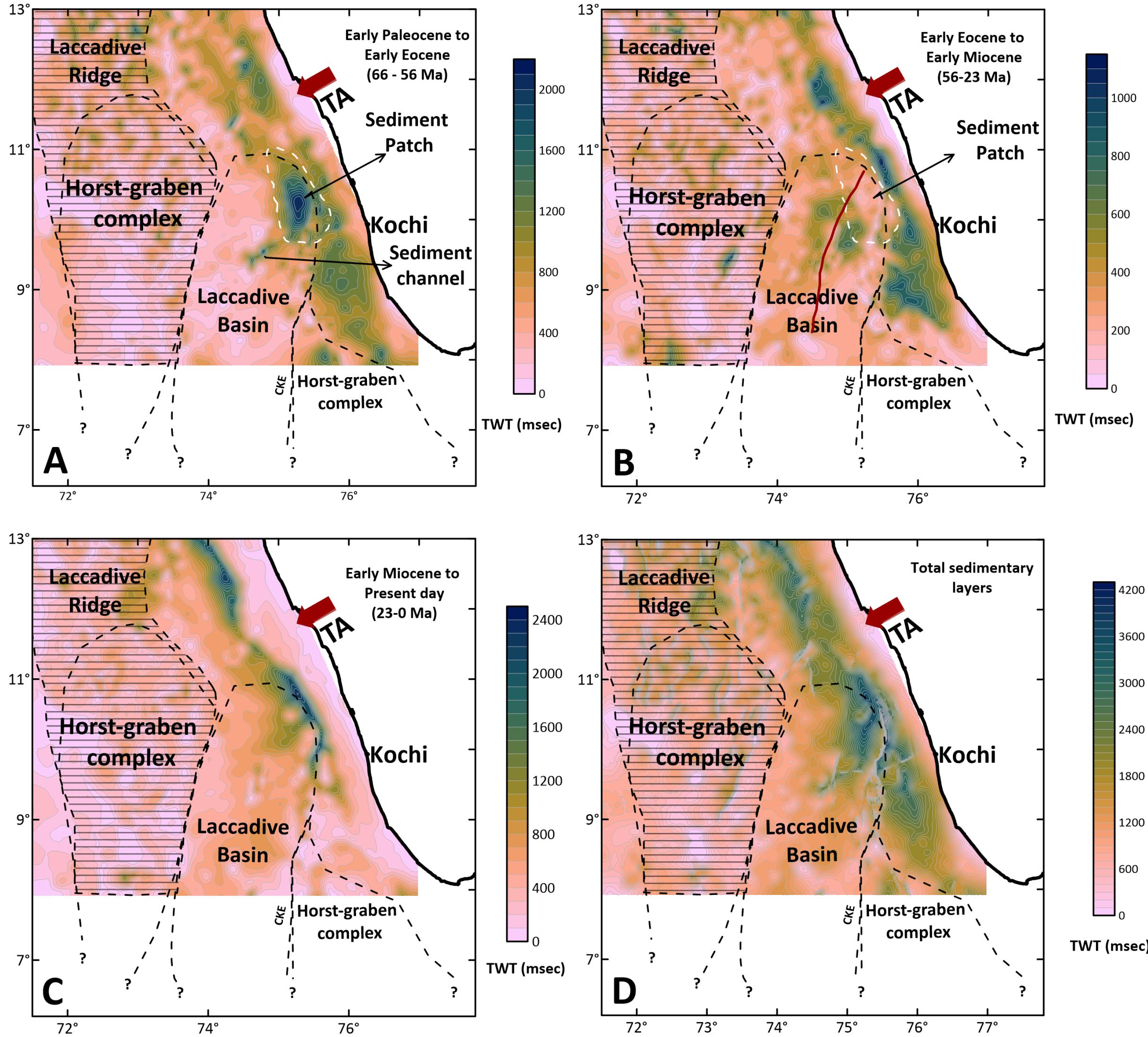

Figure 6. Isochron maps prepared from the TWT for selected time intervals: A) Early Paleocene to Early Eocene; B) Early Eocene to Early Miocene; C) Early Miocene to Present day; and D) Total sedimentary layers. The brown line in B represents trend of the identified volcanic Ridge. (Refer to text for detailed explanation and interpretation). TA: Tellicherry Arch; CKE: Chain-Kairali Escarpment.

continuity of which can be traced as gravity lows surrounded by highs in the anomaly maps (fig. 3A-B & fig. 5A-D). This is particularly prominent within the study area (south of Tellicherry Arch). The seismic sections also reveal series of volcanic intrusives in the centre of the Laccadive Basin which is seen in the gravity anomaly map also as a broken chain of highs (fig. 3, 4 & 5).

The isochron maps were prepared for three time periods in the study area (fig. 6). These maps show that for the early Paleocene to early Eocene time interval, significant sediment deposition occurred parallel to the coast with very less sedimentation in the Laccadive Basin. During this period, maximum deposition took place in the area between Tellicherry Arch and off Kochi (marked sediment patch in fig. 6A) with a minor sediment channel extending into the basin (marked sediment channel in fig. 6A). During the Early Eocene to Early Miocene time interval, the deposition within the sediment patch is almost absent, whereas, significant deposition is observed in the northern part of the Laccadive Basin on either side of the identified volcanic ridge (fig 6B). During Early Miocene to recent time, the sedimentation is uniform in the Laccadive Basin (fig. 6C). The sediment deposition along the coast remained high throughout the time intervals (fig 6A-C). The total sediment deposition pattern shows that most of the sediments were accommodated parallel to the coast and towards the south there is an axis of high sediment deposition into the Laccadive Basin (Figure 6D).

5 Discussion

This study identifies two major extensional events in the southern part of WCMI, one, the NNW-SSE oriented rift grabens over the Laccadive Ridge north of Tellicherry Arch, and the second, an NNE-SSW graben system in the Laccadive Basin area south of Tellicherry Arch (fig. 3). The NNW-SSE rifts conforms with the orientation of the onshore Dharwar structural trend which suggests that the pre-existing structural weakness have important influence on localization of deformation and thinning (Zwaan et al., 2021). Detailed analysis of multichannel seismic data in the southwest margin of India by the Directorate General of Hydrocarbons (DGH) helped to identify a complex block-like basement structures comprising of grabens, half-grabens and faults over the Laccadive Ridge (source: DGH) north of Tellicherry Arch, and named as the Cannanore Rift System (CRS). These rifts were mostly observed along the eastern flank of the Laccadive Ridge and extends between 17^0N-9.5^0N parallel to the west coast of India. The NNW-SSE rifts identified in this study are part of the CRS (fig. 3A-B). As mentioned earlier, India-Madagascar breakup took place at 83 Ma and resulted in the opening of the Mascarene Basin. The analysis of magnetic anomaly identifications together with plate-tectonic reconstruction studies (Shuhail et al., 2018) revealed that during the initial period (83-79 Ma), the spreading in the Mascarene Basin was E-W (fig. 2B). This spreading direction matches well with the NNW-SSE oriented rift system observed over the Laccadive Ridge which had resulted from the E-W extension during initial stages of India-Madagascar separation.

5.1 Opening of the Laccadive Basin

Since the entire Laccadive Ridge area was in extensional regime during India-Madagascar (as it was sandwiched between India and Madagascar), normally one would expect this trend to continue further southwards in the Laccadive basin area. However, the observed NNE-SSW orientation of the identified grabens in the study area south of Tellicherry Arch suggests that the Laccadive Basin had formed through a different evolutionary history that is not related to India-Madagascar separation. The sediment deposition in the basin is interpreted from the perspective of the creation of accommodation space and sediment supply. The available high-resolution time-structure maps (fig. 6A-D) provide insights on the timing of opening of the Laccadive

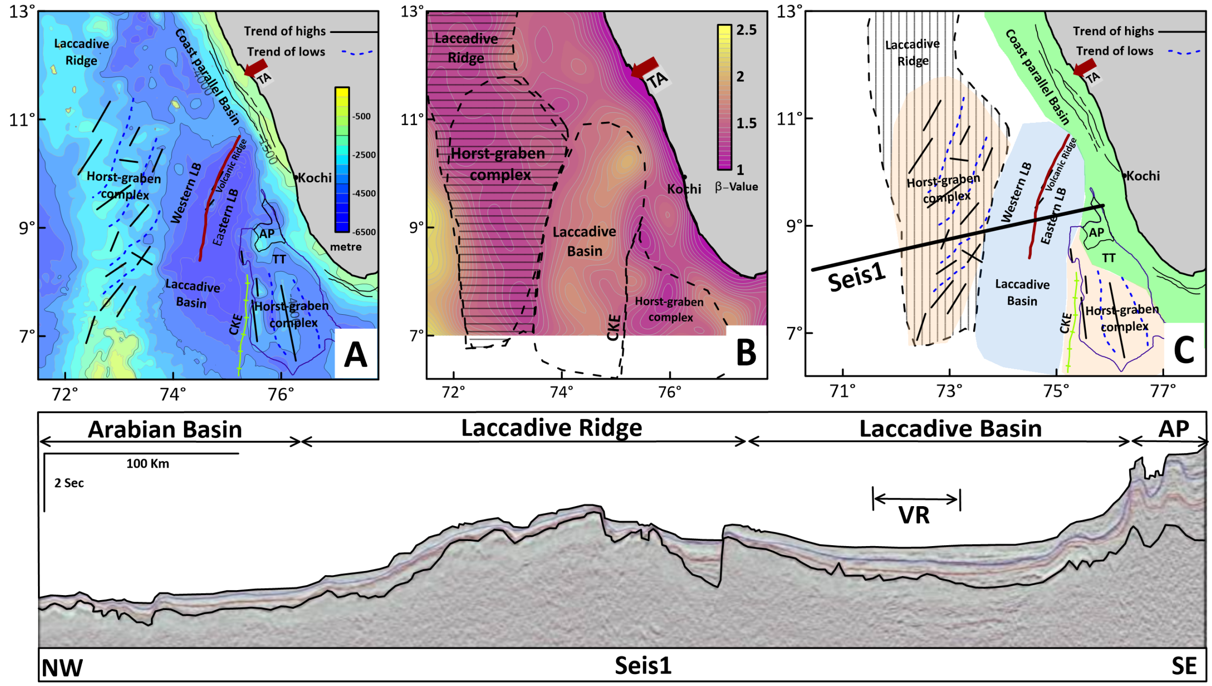

Figure 7. A) Depth to the basement map with all structures identified in the study, B) β-value map redrawn from Unnikrishnan et al. (2023), C) Proposed Tectonic map of the study area. Bottom panel shows a seismic section (Seis1), showing the general characteristic of the Laccadive Basin area. The seismic section is from Unnikrishnan (2018). The black lines show the structural highs and the blue dotted lines show the continuity of rift basins identified. The chartreuse coloured solid ticked line represents the Chain-Kairali escarpment (CKE). The solid brown line represents the identified volcanic ridge. The thin black lines close to the coast in A &B represents major faults identified on the continental shelf (Singh and Lal, 1993). TA: Tellicherry Arch; AP: Alleppy platform; TT: Trivandrum Terrace; CKE: Chain-Kairali Escarpment. AP: Alleppy platform; VR: Volcanic Ridge.

Basin. These maps clearly reveal significant sediment deposition along the coast parallel grabens within the shelfal part of the margin in all time periods. Further, during the Paleocene-Eocene period, sediment deposition was very significant on the northern fringe of the Laccadive Basin (sediment patch in fig. 6A) with negligible sediments elsewhere in the basin. During Eocene to Miocene the sediment deposition shifted further offshore into the Laccadive Basin (fig. 6B). The development of the volcanic ridge within the basin is also occurred during this time since it is observed that the sediments are deposited on either side of the location of the ridge. Further the seismic sections show sediments onlapping to the identified volcanic ridge (fig. 4 sections NN' & PP'). The comparative analysis of fig. 6A & 6B indicates that the basin opened some-time after the early Eocene as a result of which accommodation space was created and all the incoming sediments migrated southward into the basin. A small channel of sediment deposition into the Laccadive Basin towards the southwest of the sediment patch (marked as sediment channel in Fig. 6A) may represent the initial stage of opening of the basin. During the Miocene to recent period

(Fig. 6C), the sediment deposition is more or less uniform throughout the basin. The western edge of the western basin has relatively less deposition which may be due to the area's location far from any sediment supply.

Unnikrishnan et al. (2018) identified the Alleppy platform as a continental fragment and inferred its development during the Oligocene-Miocene period. Alleppy platform is located adjacent to the Laccadive Basin and hence the development of the basin and the platform is related. The timing of the development of the Alleppy platform given by Unnikrishnan et al. (2018) closely agrees with the inferred timing of the opening of the Laccadive Basin from this study.

5.2 Distribution of Bathymetry highs and intrusives

A striking feature along this margin is the presence of many intrusives and bathymetric highs (see fig. S2) observed in the seismic and bathymetry data, respectively (Unnikrishnan et al., 2023; Bijesh et al., 2018). These features have very clear expressions on the gravity image of the area (figs. 3 & 5A-D). The intrusives and bathymetric highs in the study area, south of Tellicherry Arch (fig. S2) appear to be elongated roughly parallel to the trend of the Laccadive Basin. In the centre of the Laccadive Basin, we noticed a series of volcanic mounds with a trend almost parallel to the CKE (fig. 3), which are clearly expressed in the seismic sections (fig. 4). The observed trend correlates well with the crustal Bouguer anomaly map (fig. 5A) as well as the depth to basement map prepared by removing the sediment thickness from sea bottom (fig. 7A). This trend divides the Laccadive Basin into eastern and western basins. The composite tectonic map of the study area is shown in fig. 7C.

Further, the β-value (crustal stretching factor) map (fig. 7B) calculated (Unnikrishnan et al., 2023) clearly reveals the extensional trend in the study area. The high β-values in the centre of the Laccadive Basin indicate maximum thinning, confirming our observation in this study.

5.3 Evolutionary model

Existing plate tectonic reconstruction models (Bhattacharya and Yatheesh, 2015; Shuhail et al., 2018), the pre-existing structural trends along WCMI, India and Madagascar (Subrahmanyam et al., 1994; Kolla and Coumes, 1990; Bhattacharya and Yatheesh, 2015), and the results from this study have been used to build a schematic evolutionary model for the opening of the Laccadive Basin at the southwest margin of India. Additionally, we also looked at analog and numerical modelling studies that explain extension along passive continental margin (Péron-Pinvidic and Manatschal, 2010; Zwaan et al., 2021; Bonini et al., 1997; Henza et al., 2010). The locations of India and Madagascar in various stages(I-IV) were adopted from the reconstruction model of Shuhail et al. (2018). The salient aspects of each stage is given below:

5.3.1 Stage I

Stage I (fig. 8-Stage I) shows India and Madagascar along with all the continental fragments in between them and a large number of suture zones onshore for both India and Madagascar (Bhattacharya and Yatheesh, 2015, and references therein) immediately after the spreading started at 83 Ma. These suture zones were earlier used as piercing points to find the relative position of India and Madagascar in the matching of coastlines (Katz and Premoli, 1979; Subrahmanyam and Chand, 2006).

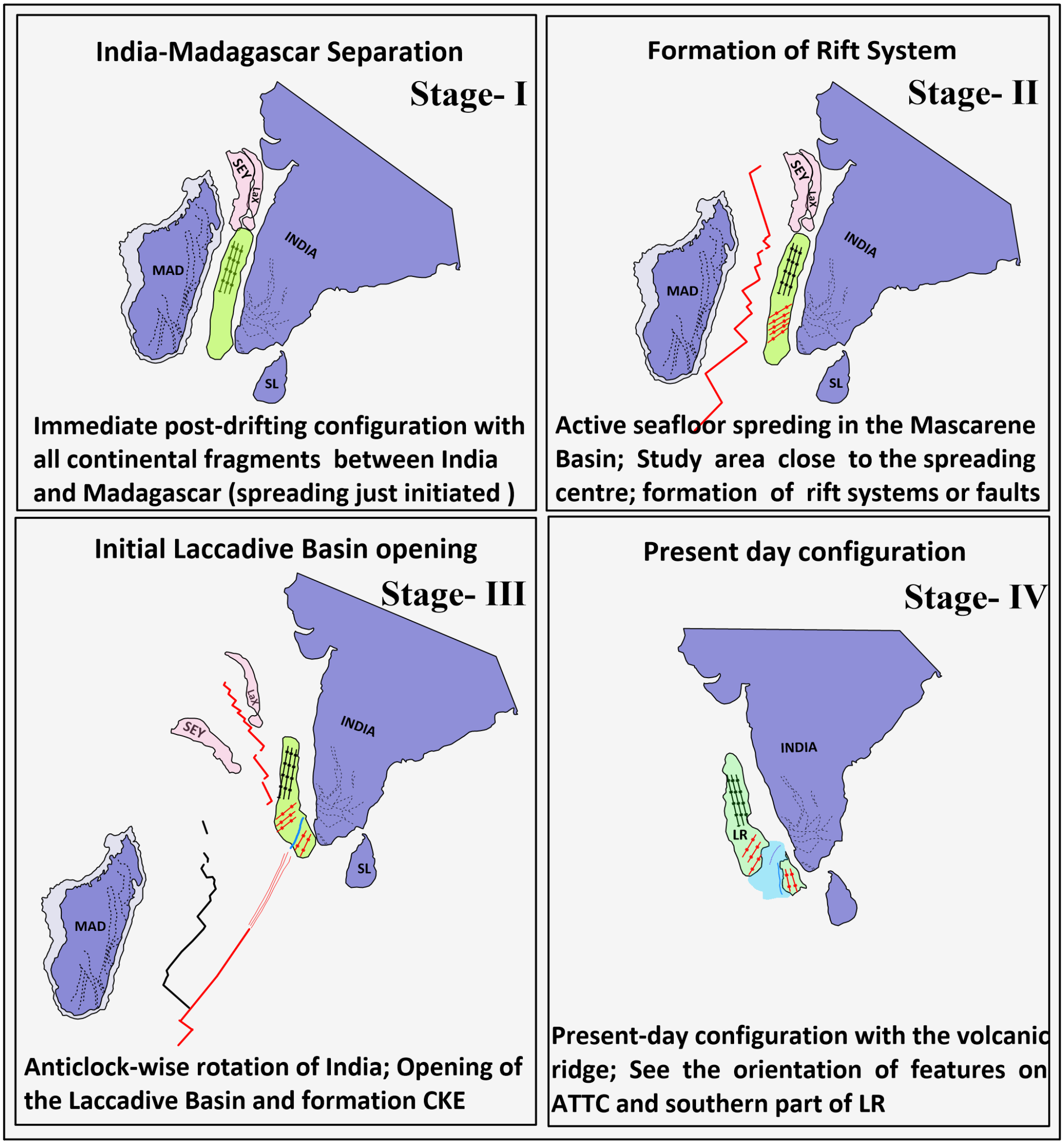

Figure 8. Map showing the evolution of the region in four stages. Stage I: The pre-rift juxtaposition of the continental fragments. Note that the Laccadive Ridge is larger since it incorporates all the fragments that are littered between India and Madagascar. Stage II: The formation of the faults system or the rifts system due to the influence of spreading in the Mascarene Basin. Stage III: The opening of the basin with CKE + ATTC and India moving away from the Laccadive Ridge. See how the orientation of the extensional feature's changes with the anticlockwise movement of India. Stage IV: The present-day configuration of the margin with all extensional features and the volcanic ridge. LaX: Laxmi Ridge; SEY: Seychelles; MAD: Madagascar; SL: Sri Lanka; LR: Laccadive Ridge; ATTC: Alleppey-Trivandrum Terrace Complex; CKE: Chain-Kairali Escarpment.

Besides, studies along the WCMI have shown the extension of onshore structural trends into the offshore region (Subrahmanyam et al., 1994; Kolla and Coumes, 1990) and studies (Péron-Pinvidic and Manatschal, 2010; Zwaan et al., 2021; Bonini et al., 1997; Henza et al., 2010) show that structural inheritance plays a role during rifting and breakup. Dating of volcanics in Madagascar yields an age of 88 Ma (Storey et al., 1995; Pande et al., 2001) and magnetic anomalies indicate spreading started around 83 Ma (Shuhail et al., 2018). Hence, we infer that during this extensional span, CRS formed on the Laccadive Ridge following the Precambrian Dharwarian trend which is dominant north of Tellicherry Arch.

5.3.2 Stage II

Stage II (fig. 8-Stage II) shows the proximity of Laccadive Ridge to the spreading centre. As discussed in stage I, the lithosphere between India and Madagascar was weak and as a result, when the area was proximal to the spreading centre, a number of parallel trans-tensional faults may have formed on the Laccadive Ridge south of Tellicherry Arch. Even though the spreading was happening along the entire basin, the spreading was very active in the southern part of the Mascarene basin, and also characterized by long transform faults (Shuhail et al., 2018). Also, Shuhail et al. (2018) proposed that the CKE was connected to the spreading in the Mascarene Basin through a long transform fault. As discussed in section 5.1 distribution of bathymetric highs and intrusives south of Tellicherry Arch provide some evidence for this. It is very likely that, later when the Reunion passed over the area, the magma may have migrated through the faults formed during this stage and hence intrusives show this orientation. Similar arguments can also explain the orientation of bathymetric features in this area.

5.3.3 Stage III

Stage III (fig. 8-Stage III) shows the initial stages of opening of the Laccadive basin. By this time, the entire region was flooded by Deccan volcanics during the passage of Réunion plume in the Paleocene time. Studies by Patriat and Achache (1984) andDewey (1989) showed that the Indian plate rotated anticlockwise about 40^0 since 84 Ma, out of which, it underwent about 25^0 after the soft collision at 50 Ma (Treloar and Coward, 1991). The passage of the Réunion plume over the area may have weakened the overlying lithosphere and together with India's anti-clockwise rotation and the presence of inherited structural weakness may have led to the reactivation and further extension in the Laccadive Basin. The sediment thickness data during the Paleocene-Eocene period shows a sediment channel (fig. 6A) extending into the Laccadive basin and an area of high sediment deposition (Sediment patch in fig. 6A) which indicate the initial stages of opening of the basin. Fig. 6B shows sediments being deposited on either side of the volcanic ridge in the Laccadive basin. By this time the basin opened and sediments were accommodated in the basin.

5.3.4 Stage IV

Stage IV (fig. 8-Stage IV) shows the present-day configuration of the Laccadive Basin. The ATTC remain attached to the Indian continent with CKE forming its western boundary. The centre of the Laccadive Basin experienced maximum crustal thinning and a series of intrusives got emplaced in the crust. The change in the orientation of horst-graben structures in the ATTC from that in the southern part of Laccadive Ridge can be noticed.

6 Conclusions

The seismic and gravity data analysis along southern part of WCMI revealed two significantly different orientations of the extensional graben system, one a NNW-SSE oriented rifts over the Laccadive Ridge, north of Tellicherry Arch, and the other NNE-SSW oriented rifts in the Laccadive Basin region south of Tellicherry Arch. The change in extensional direction in the Laccadive basin along with the isochron maps for different times provided evidence of opening of the Laccadive Basin. The Laccadive Basin opened within the post-Eocene period with maximum extension along the centre of the basin where the volcanic intrusives are emplaced. The lithosphere that existed had zones of weakness and this along with the plumeproximity to Réunion plume and anti-clockwise rotation of India led to complex rifting and evolutionary history for the southern part of the margin.

Data availability. The authors do not have permission to share data.

Author contributions. MGG – conceptualisation, methodology, validation, formal analysis, writing (original draft and editing), visualisation. MR – conceptualisation, validation, resources, writing (review and editing), supervision. PU – conceptualisation, writing (review and editing).

Competing interests. 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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