Status of Karur–Kambam–Painavu–Trichur shear zone, Southern Granulite Terrain in the context of Late Mesozoic dynamic evolution of Western Ghats: a geophysical–geological perspective

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Detailed magnetic and gravity surveys in the Periyar Plateau and adjoining coastal tract (central Kerala) have brought to light a family of four major geophysical lineaments. These include the NNW–SSE trending Idamalayar lineament (LM-1) and the Kerala lineament (LM-2); both housing gabbroic and doleritic dykes dated ~90 Ma and geochemically related to the Marion plume and the NW trending Periyar lineament (LM-3) and Todupuzha lineament (LM-4) housing in part dolerite dykes dated 65 Ma and chemically related to the Reunion plume. The lineaments largely cut across the litho-tectonic framework of the Precambrian basement. Integrating geological evolution of the region, these lineaments seem to have been formed by reactivation of the deep-seated distensional fractures, that facilitated magmatic emplacements during the episodic breakup of Gondwanaland under distinctive mantle thermal regimes of the Late Mesozoic. Possibly, later in the Cenozoic, these lineaments were enlarged to their present dimensions during the uplift of Western Ghats.

Keywords: Geophysical lineaments, gravity anomalies, KKPT shear zone, magnetic anomalies, Periyar Plateau.

A detailed geophysical study, utilizing gravity and magnetic methods, was carried out over the Periyar Plateau and the western coastal tract[1,2]. Considerable insights have been gained as a result of these surveys regarding the major tectonic lineaments in the region. Here, we discuss the status of the recently proposed Karur–Kambam–Painavu–Trichur (KKPT) shear zone[3,4] in the light of new geophysical data integrated with geological history. It is suggested that the existence of such a V-shaped lineament is inconsistent with the tectonic evolution of the two regions and the distinctive geological setting and age differences between the Periyar and the Kambam lineaments[5,6].

The study area covers about 15,000 sq. km between 9°30′N and 10°45′N lat. and 76°00′E and 77°30′E long. (Figure 1), and is bound by the E–W trending Palghat–Cauvery shear zone (PCSZ) in the north, and the WNW–ESE trending Achankovil–Thenmalai shear zone (ATSZ) in the south. The NE–SW trending Karur–Kambam rift zone (KKRZ) delimits the region to the SE. To the west, the area is bound by the West Coast Fault (WCF) which is related to episodic Late Mesozoic rifting, Deccan trap, with associated magmatism, and the episodic breakup of the Gondwanaland in the late mesozoic, around 145, 90 and 65 Ma and associated magmatism. It therefore seems that the Periyar Plateau at an elevation of over 500 m amsl, is an uplifted eastern collar of the West Coast distensional breakup of Gondwanaland[7,8] and has been a region of distensional fracturing and mafic dyke emplacements.

The major geological formations in the area comprise a Precambrian basement with members of charnockite suite and associated hornblende-biotite gneisses, mafic granulites, migmatitic gneisses and metadolerites. The charnockites and associated gneisses have undergone migmatization. They have been transformed through diaphthoretic metasomatic changes into gneisses falling in the amphibolite facies. This occurred because of a hot mantle along deformation zones, by the large scale influx of CO_2 and H_2O rich fluids of mantle origin[9,10]. Such a transformation is responsible for lowering the density and magnetic susceptibility properties rendering them more buoyant. The gneissic rocks in the area have been assigned Sm–Nd (T_{DM}) ages of 3.2 to 2.8 Ga (ref. 4) and 3.01 to 2.51 Ga (ref. 11) and U–Pb age of ~2.5 Ga (ref. 3). These dates imply a dominant Archaean age and date the transformation of the pristine charnockites into the decharnockitized and metasomatized gneisses

The Precambrian basement is intruded by three generations of Late Mesozoic mafic intrusives, around ~140, 90 and 65 Ma, along distensional fractures formed during the episodic rifting of the West Coast during the break up of Gondwanaland and drift of the Indian plate northwards. The earliest of these is confined to the southern tip of the shield[8,12]. Dykes of 90 Ma and 65 Ma ages are dominantly exposed in our study area. Among these, the most prominent is a leuco gabbro dyke dated at 90 Ma, striking NNW–SSE, traceable for ~100 km from south-east of Kottayam through Muvattupuzha and Angamaly to Peechi. This linear dyke trend is often referred to as Kerala Lineament[13]. The dykes of 65 Ma are more abundant and strikes NW–SE, some of these cut across 90 Ma dykes. Unlike 90 Ma dykes, these dykes are of small thickness and much shorter strike lengths of not more than a few kilometres (Figures 1 and 2). On the basis of chemical composition, 90 Ma dykes are related to the Marion plume and the 65 Ma dykes to the Reunion plume[8,12]. The change in the strike of these dyke systems is due to changes in stress fields experienced by the

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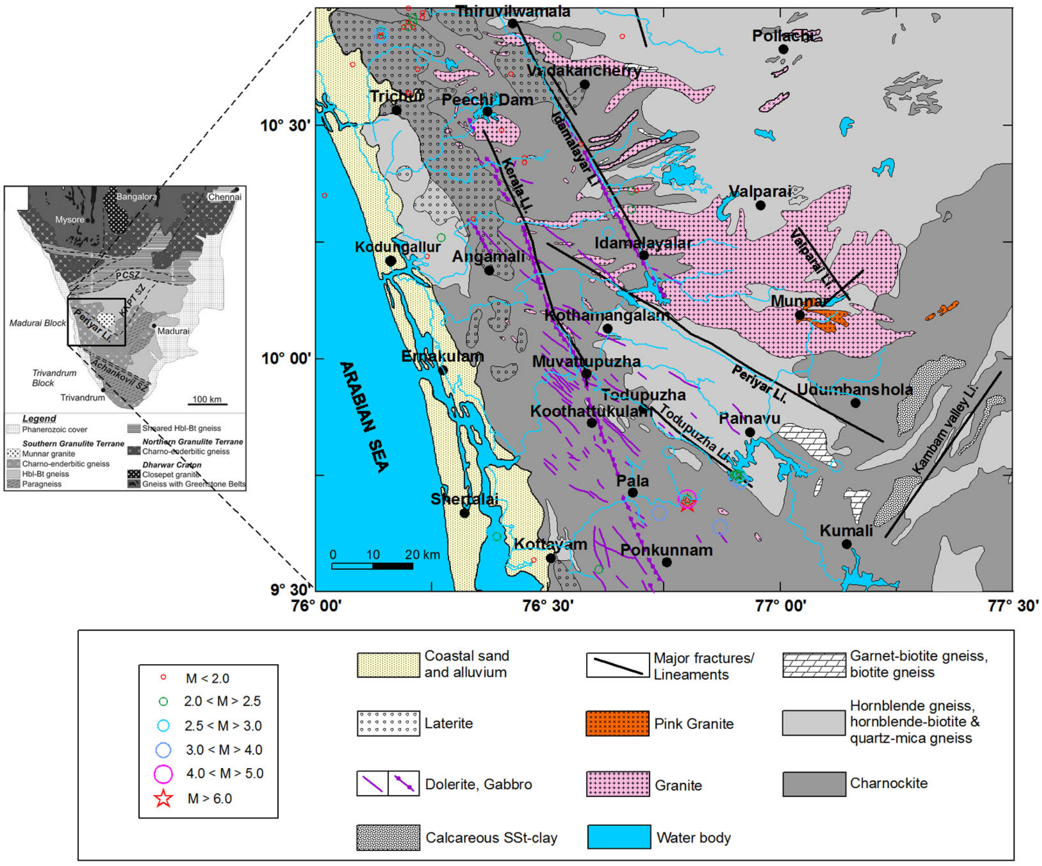

Figure 1. Geological map of the study area (modified after GSI)[13]. Inset: The south Indian geology map (modified after Brandt *et al.*[26]) present study area is marked by rectangle in the inset. Earthquake epicenters (Saikia *et al.*[24] and Rajendran *et al.*[25]) are plotted and the magnitude scale is shown as legend in the inset.

migrating Indian plate between two episodes of plume interaction. The area is fringed by a narrow coastal tract of Cenozoic sedimentary rocks comprising the Vaikom, Quilon and Warkalli beds, and Sub-Recent to Recent alluvial and laterite cover. The offshore region is characterized by Cochin-Konkan basins[14]. The loading of these supracrustals has contributed to flexuring of the basement of which the Periyar Plateau is a part[7].

The area is dissected by several faults[15,16] and the identified a number of geophysical lineaments, some of which coincide with these faults and are discussed here.

The ground magnetic data were collected over the area at 1–2 km intervals all along most of the accessible roads using a Proton Precession Magnetometer (EG&G, model G-856) with a sensitivity of 1 gamma. Measurements were taken over a thousand stations, covering 15,000 sq. km, along with gravity surveys. The magnetic map brings out the major lineaments tens of kilometers in length, inferred from zones of contrasting magnetic susceptibilities and steep gradients.

Apart from the ground magnetic and gravity map prepared from our data, the available aeromagnetic and analytic signal maps pertaining to the study region[17,18] have been considered as additional constraints.

The density and magnetic susceptibility of various rock types were determined by collecting a good number of rock samples and the data were used in constraining the interpretations.

A Lacoste–Romberg (Model G) gravimeter, with an accuracy of 0.01 m Gal, was used for gravity data acquisition at nearly 1200 stations, spaced at an average of 1–2 km. The measurements were made utilizing available base stations and by establishing additional secondary base stations. The elevation data have been considered from spot heights, benchmarks and Survey of India toposheets. The 1930 international gravity formula and the surface rock density of 2.67 g/cc, were used for the purpose of gravity data reduction. The error in the elevation could be ~3–5 m and considering other factors such as instrumental limitations, the maximum error in the gravity data may be ~1.5 mGal.

The total field anomaly map (Figure 2) shows positive (high) and negative (low) fields of large wavelength and these fields are numbered sequentially H1 to H11 and L1 to L9 respectively for convenience.

The total field anomaly map (Figure 2) of ground data represents a combination of short and long wavelength anomalies with a combination of NW–SE, NE–SW and

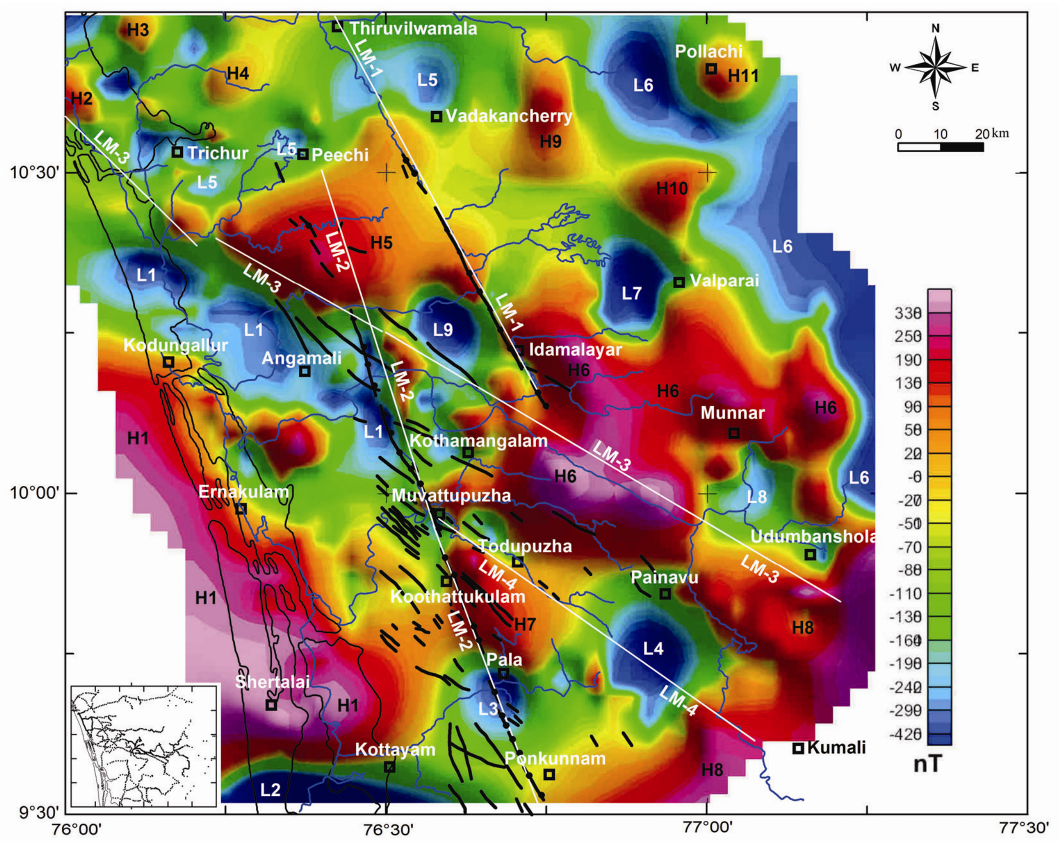

Figure 2. Total field magnetic anomaly map of the study area generated from Ground magnetic data collected with an average data spacing of 0.5 to 2 km. The magnetic highs are marked as H1 to H11, magnetic lows are marked as L1 to L9. The major magnetic lineaments are shown by solid white line and marked as LM-1 to LM-4. Solid black line shows the Dyke swarms. Only the lineaments of relevance to this paper are plotted here. A detailed separate paper on these and all other lineaments is under review.

E–W trends. The positive fields are termed here as highs and negative fields as lows. The total magnetic field anomaly map of the region may be divided into two major parallel belts of magnetic highs which send irregular arms into the intervening magnetic low fields. On the west, the magnetic high, H1, forms one major western high, which possibly extends to H2. In central part of the map, the Munnar and associated ranges extending from Kumali in the south to Trichur in the north, called the Kumali–Trichur belt, constitutes the other major magnetic high comprising H5, H6 and H8. These two major highs are linked by magnetic high H7 in the south. Two prominent magnetic peaks found in H6 zone, possibly represent relatively more basic composition within the charnockite massif, or relatively fresh charnockites that are not much retrograded.

The Bouguer anomaly map[2] at a contour interval of 5 m Gal is shown in Figure 3. It shows good correlation with the surface geology and minor geological structures of the area. The Bouguer anomaly values range from 0 to –155 m Gals. A series of negative closures of ≥ 120 m Gals (Periyar Plateau gravity low, PPGL-1, PPGL-2 and PPGL-3) coincide with the Munnar granitic region, though, it is suspected that a good share of the negative field is possibly due to the thick lateritic cover. Two isolated anomalies –85 m Gal closures in the southernmost central part of the map are correlated with the small granite bodies. Gravity modelling[2] has shown that the positive gravity gradient is due to progressive crustal thinning of 41 km on the east (Periyar Plateau), to 36 km close to the coast in the west. Such thinning may be related to the large emplacement of dykes of 65 Ma age in this zone, and is testimony to the accompanying crust–mantle interaction.

A number of tectonic lineaments have been identified from the geophysical anomaly maps based on the change in magnetic and gravity trends, amplitudes and gradients separating distinctive fields. The more important among these include the lineament that accommodates the two generations of dyke systems of 90 Ma and 65 Ma referred to earlier, associated with distensional tectonics during the evolution of the West Coast by break up of Gondwanaland. The 90 Ma old gabbroic and doleritic dykes include the Idamalayar (LM-1) and the Kerala (LM-2) lineaments. The 65 million year old dolerite dykes cover the NW part of the Periyar lineament (LM-3) and the whole of the Todupuzha lineament (LM-4) (Figures 1 and

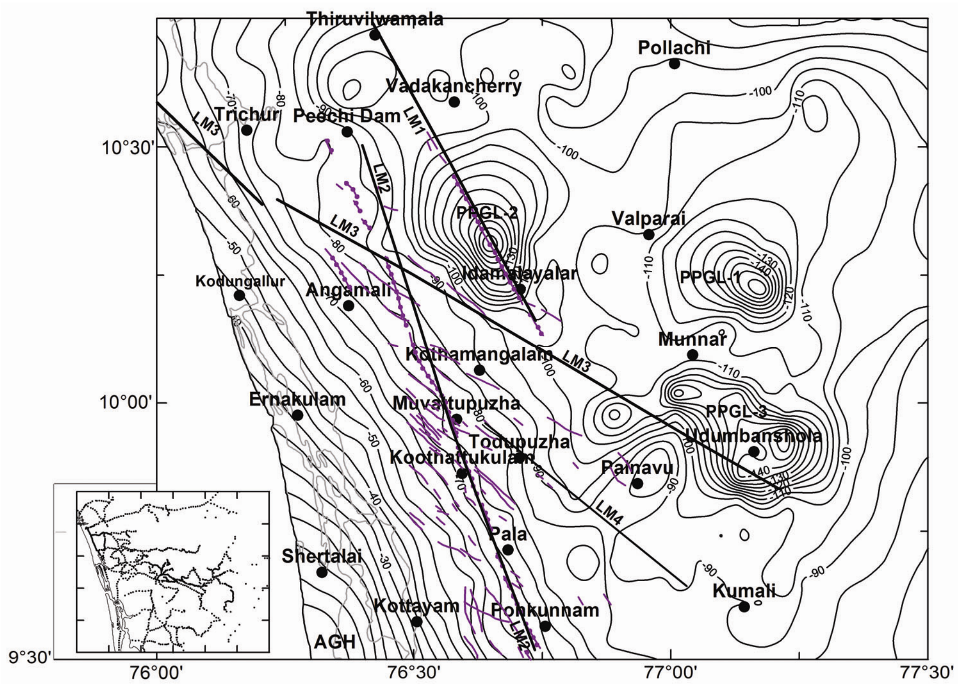

Figure 3. Map shows the Bouguer anomaly map of the Periyar plateau and the adjoining areas. Contour interval 5 m Gal. PPGL1, 2 and 3: Periyar plateau gravity lows; LM1, Idamalayar Lineament; LM2, Kerala Lineament; LM3, Periyar Lineament; LM4, Todupuzha Lineament, Solid magenta line shows the Dyke swarms. Light Gray colour line show the alluvial boundary. The gravity data distribution is shown as in the inset. Only the lineaments of relevance to this paper are plotted here. A detailed separate paper on these and all other lineaments is under review.

3). These lineaments are closely associated with dyke emplacements, and as in the case of LM-3, LM-4 and LM-1 extend beyond. It is concluded that these are deep fracture zones that nucleated in the distensional dyke emplacement belts, associated with Late Mesozoic evolution of the West Coast and were possibly reactivated to their present dimensions, presumably during the uplift of the Western Ghats in the Cenozoic. Their physical dimensions are explained below.

(i) Idamalayar lineament (LM-1) trending NNW–SSE, extends from the south of Idamalayar to Thiruvilwamala in the north and almost meets the Periyar lineament (LM-3) in the south. The lineament is defined by the sharp eastern boundary of magnetic high H5, sharp western boundary of magnetic high H6 and also the respective gravity gradients. The lineament cuts across the major litho units such as charnockites, gneisses and granites that contribute to the H5 and the lows L9 and L5.

(ii) Kerala lineament (LM-2) trending NNW–SSE is traceable over a length of over 100 km from near Koothattukulam through Movattupuzha, east of Kothamangalam to Peechi. This lineament may be the eastern boundary of a distinct gravity field increasing from –35 to 0 m Gals at Alleppey gravity high (AGH), which falls just outside the study area in the south-western portion of the map. It cuts across the charnockitic masses (Figure 1) and is defined by gradients associated with magnetic anomalies H7 and H6 and H5.

(iii) Periyar lineament (LM-3) trending NW–SE, is traceable over a length of 90 km, extends from Udumbanshola in the south (NE of Kumali) through Kothamangalam and beyond to southwest of Trichur. It separates a strong gravity gradient tending to be positive, towards the SW all the way up to the coast, from the significant gravity lows and highs in the NE ranging from –85 to as low as –150 m Gal, covering a large part in the Periyar Plateau. The high positive gradient is related to the thinning of the crust consequent on the Deccan magmatism of 65 Ma period. The Periyar lineament is oblique to the other two 90 Ma lineaments, LM-1 and LM-2. It marks the northern boundaries of magnetic fields H6 and H8 and southern boundary of H5. Although marked as a single lineament in this map, it is possible that this lineament is made up of *en echelon* segments, one constituting the northern boundary of magnetic anomalies H6 and H8 and the other extending from the southern boundaries of magnetic fields H2 and H5. The Periyar lineament cuts across major litho units such as charnockites, gneisses and granites.

(iv) Todupuzha lineament (LM-4) trending NW–SE, extends from SW of Kumali to the NW of Todupuzha and almost meets the Kerala lineament (LM-2) in the northwest at Muvattupuzha. The lineament may be recognized through the sharp eastern boundary of magnetic high H7 and cuts across the magnetic low L4, with the respective gravity gradients.

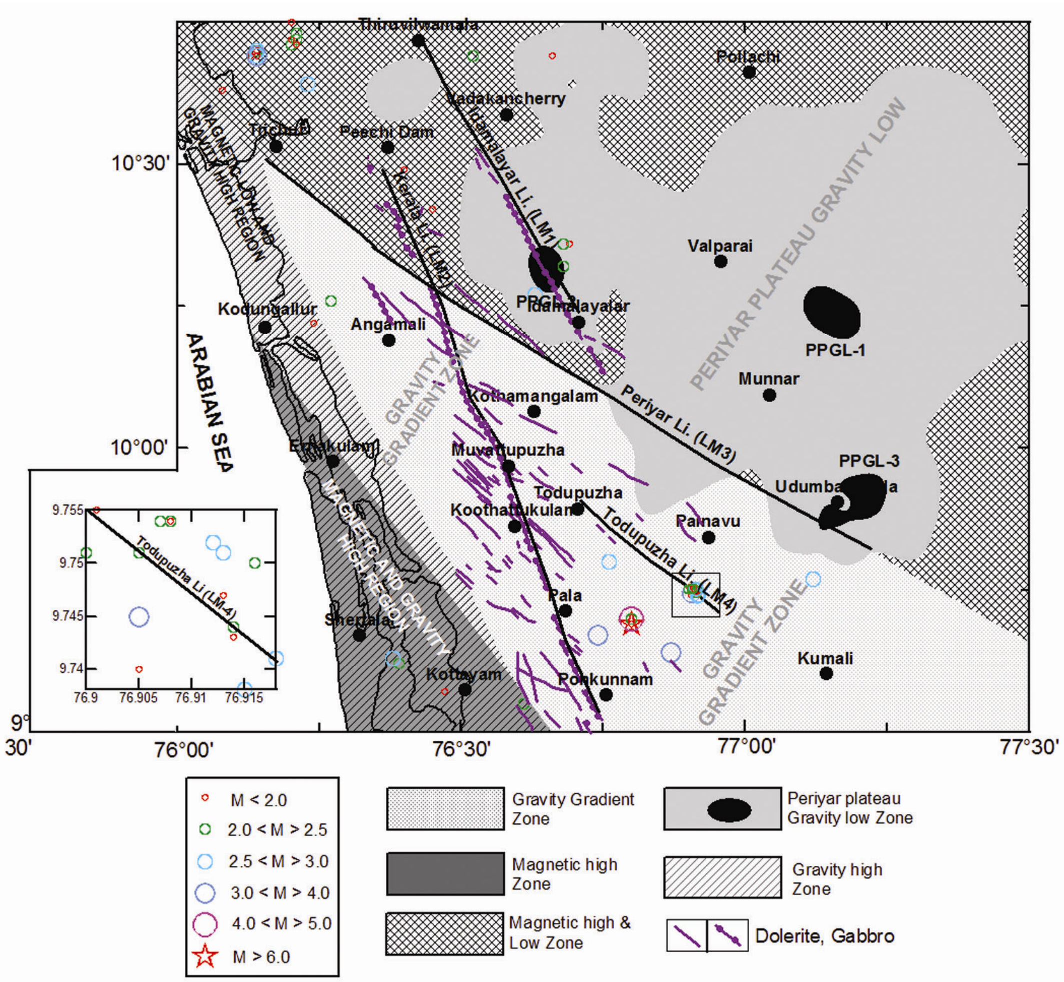

Figure 4. A generalized map depicting gravity and magnetic anomaly trends and patterns in the study area (modified after Ajayakumar *et al.*[2]). Periyar plateau gravity low shown as PPGL1, 2 and 3. Earthquake epicenters (Saikia *et al.*[24] and Rajendran *et al.*[25]) are plotted and the magnitude scale is shown as in legend, Small rectangular area is enlarged is shown in the inset.

The four lineaments are expressed in a map integrating gravity, ground magnetic, aero-magnetic and analytical signals (Figure 4). In this map, two distinct sub-provinces of magnetic highs may be distinguished: (i) Trichur–Udumbanshola province in the NE and (ii) the Trichur–Ernakulam–Kottayam province in the SW. A prominent NW–SE trending belt of magnetic lows separates the two magnetic high provinces.

2-D gravity modelling of the Periyar Plateau[2] reveals that there is thinning of crust from 41 km to 36 km towards the coast. Such thinning of crust viewed in the context of large number of 65 Ma age dyke swarms, is related to Deccan magmatism and is therefore a Mesozoic event. The Periyar lineament limits the region of crustal thinning during the great Mesozoic rifting episode on the east. The coastal gravity high has been assigned to magmatic underplating[19].

The Karur–Kambam–Painavu–Trichur (KKPT)[3] shear zone is proposed as a continental collision boundary, based on satellite imagery interpretation and limited U–Pb zircon geochronology[3]. It links the NE trending Karur–Kambam lineament with the NW trending Painavu–Trichur lineament, resulting in a V-shaped structural element called KKPT. The NW–SE Painavu–Trichur arm coincides with the Periyar lineament described here. The claim KKPT constitutes the Archaean–Proterozoic terrain boundary[3], a palaeotectonic lineament (collision zone) dividing the Archean Dharwar craton and the Pan-African southern Indian granulite terrain. The V-shaped KKPT is 'inconsistent with the lithological association and regional structure'[5,6]. The Karur–Oddanchathram shear zone (NE wing of the KKPT) could mark the Archaean–Neoproterozoic terrain boundary[20]. Based on additional geochemical and geochronological data, KKPT may be separating two isotopic provinces[3]. The NE arm of the structure, namely the Kambam–Karur segment, coincides with the proposed Suruli shear zone[21]. This arm has now been extended from south Kambam towards the Achankovil shear zone, thus delinking the eastern arm from the Painavu–Trichur arm. This view is consistent with the fact that no linkage is seen between these lineaments in the magnetic or gravity maps presented here. On the basis of new U–Pb dates, the Archaean–Proterozoic isotopic boundary has been shifted further to the south of the KKPT[11], placing the KKPT as part of the Archaean province.

The tectonic status of the proposed KKPT shear zone has to be viewed from the inferred age of the lineament in the Periyar plateau and their relation to the Late Mesozoic geodynamic evolution.

Among the family of the four geophysical lineaments described above, the Idamalyar (LM-1) and Kerala (LM-2) lineaments striking NNW–SSE host gabbroic dykes dated 90 Ma. The NW–SE trending Periyar (LM-3) and Todupuzha (LM-4) lineaments trend oblique to the other two lineaments and are closely associated with the NW–SE trending dolerite dykes dated Ca 65 Ma (ref. 22). The Periyar lineament (LM-3) limits a zone of coastal thinning during the Mesozoic rifting on the east and is discordant to the Precambrian fabric. These two generations of lineaments therefore are classed as a family of distensional fractures associated with the episodic breakup of India from Gondwanaland. They were possibly reactivated to their present dimensions during the uplift of the Western Ghats.

The Kambam–Karur part of the lineament is a distensional fracture striking NE–SW as it houses a few syenites and carbonatite bodies of Late Neoproterozoic age. The monazite grains in the Kambam carbonatite band are dated 715 ± 42 Ma and the monazite filling cracks within the apatite in the carbonatite are dated 405 ± 5 Ma (ref. 23). The Kambam lineament may be assigned a Neoproterozoic age. Therefore linking of the Periyar (Painavu–Trichur) lineament with the Kambam–Karur lineament would span across a wide time-range. It is suggested that the Painavu–Trichur (Periyar) lineament is a Late Mesozoic distensional feature, unrelated to the Late Neoproterozoic Kambam–Karur lineament. No linkage between these two lineaments is seen in the geophysical anomaly maps.

Linking Painavu–Trichur (P–T) arm and the Kambam–Karur (K–K) segment into a collision boundary is based on geochrons spanning a time band of 3.1 to 2.5 Ga, reported on some samples taken across the Periyar lineament (LM-3). These geochrons in fact date the Late Archean transformations of the massive charnockites and granulites of lower crustal rocks, as a result of major impact of tectono thermal event in Late Archaean. The transformations recorded across the Periyar lineament are widespread in the Western Ghats (Sahyadri). Therefore, we may expect the dates to be replicated in several areas of the Western Ghats. These transformations are not unique to the Periyar lineament and so it may not define an Archean–Proterozoic time boundary.

The only Proterozoic event in the region is the emplacement of granitic plutons dated ~750–550 Ma and related to the Pan-African tectono-thermal event. These plutons have not led to any major regional transformations in mineralogy except along their contact zones. The geological setting of the region does not provide any evidences of a collision zone and the petrotectonic evidences for a collision zone are lacking.

KKPT, as a terrain boundary, seems geologically debatable and is based largely on geochronology and isotope chemistry, which challenges the known aspects of geological evolution and, as presented here, the geophysical lineaments in the region. Generalization in assigning tectonic boundaries, based on very limited geochronology across a poly-orogenic terrain such as south Indian shield, seems fraught with severe limitations.

Micro earthquakes in the Idukki and Peechi reservoir area (over the Periyar Plateau) are confined to a NW–SE trending fault close to Painavu–Trichur segment that constitutes the Todupuzha and Periyar lineaments[24,25]. A cluster of epicenters fall very near to the Todupuzha lineament (LM-4) (Figure 4). It would therefore seem that the Periyar and Todupuzha lineaments, and perhaps the family of Mesozoic faults, are getting reactivated in the strike–slip mode leading to local seismicity.

To conclude, the proposed V-shaped KKPT lineament comprises two arms, of which the NW segment Painavu-Trichur (P–T) coincides with the Periyar lineament that is a part of major distensional lineaments, from major geophysical anomalies. These lineaments seem related to distensional fractures that house basic dykes dated 90 Ma and 65 Ma, and seem to have been subsequently activated possibly during the isostatic uplift of the Western Ghats in the Cenozoic. The Kambam–Karur (K–K) segment of KKPT is assigned a Neoproterozoic age, based on the ages of syenites and carbonatites. It has a distinctive Precambrian evolution, different from the Mesozoic distensional fractures of the Periyar Plateau. It is suggested that clubbing the two arms of KKPT into a V-shaped tectonic feature would be inconsistent with the differences in the age of the two arms and ignores the distinctive dynamic evolution of the lineaments in the Periyar Plateau. The geochrons of 3.1 to 2.5 Ga across the Periyar lineament, date the widespread transformation of the charnockitic lower crustal rocks, as part of Archaean crustal growth under thermal influence of the mantle. They may not be unique to the Periyar lineament, which appears to be a Late Mesozoic overprinting on an Archean crust.

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Iron oxide–copper–gold-type mineralization in Machanur area, Eastern Dharwar Craton, India

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Parallel to the Krishna river course, a set of ENE to WSW trending brittle–ductile shear zones affecting the Neoarchaean pink porphyritic granite remains athwart to the NW–SE tectonic fabric of the Eastern Dharwar Craton (EDC) in Raichur and Gulbarga districts, Karnataka, India. These zones are not only manifested by intense mylonitization, brecciation and fracturing, but also witness several episodes of mafic and felsic intrusions. At Machanur, Raichur district a 5 km long and 400 m wide shear zone hosts copper,

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