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Active intraplate deformation in south India

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Abstract

Two characteristics of the Indian plate are the intraplate deformation of the oceanic crust to the south of Bay of Bengal and the ongoing uplift of the continental crust in the southern Indian peninsula.

An irregular line connecting Mulki on the West Coast and Pulicat Lake on the East Coast (close to 13°N) constitutes a major drainage divide. Several large rivers of south India diverge from this line. This nearly east-west-trending ridge is characterised by gravity high, relatively thinner crust and microseismicity. The shoreline at either ends is convex towards sea. The coastal region particularly in the west is highly dissected. The coastal zone consists of series of beach ridges and swales indicating uplift of land.

A close scrutiny of the river channels indicates that the rivers south of the major water divide have successively shifted southward leaving behind paleochannels on the Quaternary terrain. There is similar migration of streams to the north shifting northward. Even in areas where the gradient is low, the rivers have elevated terraces, resulting from valley deepening.

The tide gauge records for Mangalore and Madras show a relative fall in sea-level. Occurrence of a dead oyster colony above the intertidal zone substantiates the tide gauge data.

These observations indicate that the continental crust close to Mulki-Pulicat Lake axis is undergoing compression and uplift, related to the north-south oriented regional stress field.

1. Introduction

The Karnataka coast of the West Coast of India has been intensively studied, because the area is prone to severe erosion during monsoon. The southern part of Karnataka Coast is categorised as "rocky coast with barriers" (Geological Survey of India, 1972) and is transitional in character from the cliffed Konkan coast to the north and alluvial plain coast of Malabar to the south. During the course of detailed beach profile studies, it became clear that though some pockets are undergoing erosion, taken as a whole, the south Karnataka beaches are accreting. This surprising result led to a detailed investigation of the possible causative factors. An analysis of the landforms indicated intensive dissection hinting at possible uplift of the region. This necessiated extension of the study to the plateau region and the east coast. Results of this exercise are outlined here.

2. The present study

Mulki-Pulicat Lake Axis: Although all the major rivers of the southern peninsula have their sources on the peaks of the Western Ghats, which is close to the

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West Coast, the rivers flow east to the Bay of Bengal. The causes for the dominant easterly drainage is ascribed to the nature of evolution of the western passive continental margin (Subrahmanya, 1994). An analysis of the easterly drainage reveals that it can be demarcated into northeasterly and southeasterly drainage. This demarcation line is close to 13°N. The coastal plains on the two extremities of this line have small streams which flow mainly on the Quaternary landforms. A careful scrutiny of the east–west-trending water divide, which separates northeast flowing rivers from the southeast ones, reveals that this major divide continues even on the coastal plain of West and East Coasts. The points where they meet West and East Coasts are near Mulki and Pulicat Lake respectively. A straight line connecting these two points (Fig. 1) has been named Mulki–Pulicat Lake Axis (MPA) (Subrahmanya, 1994). Obviously this axis is on an east–west-trending ridge. The slight deviation of the drainage divide from the MPA can be ascribed to differential headward erosion of the northeasterly and southeasterly flowing rivers. A detailed discussion of the nature and origin of the ridge and its tectonic implication follow. For the sake of convenience, the subject is dealt under three regions: West Coast, Mysore Plateau and the East Coast.

West Coast: Study of satellite images, has shown that there are a number of beach ridges alternating with swales, indicating progradation of land (Gangadhara Bhat and Subrahmanya, 1993) (Fig. 2).

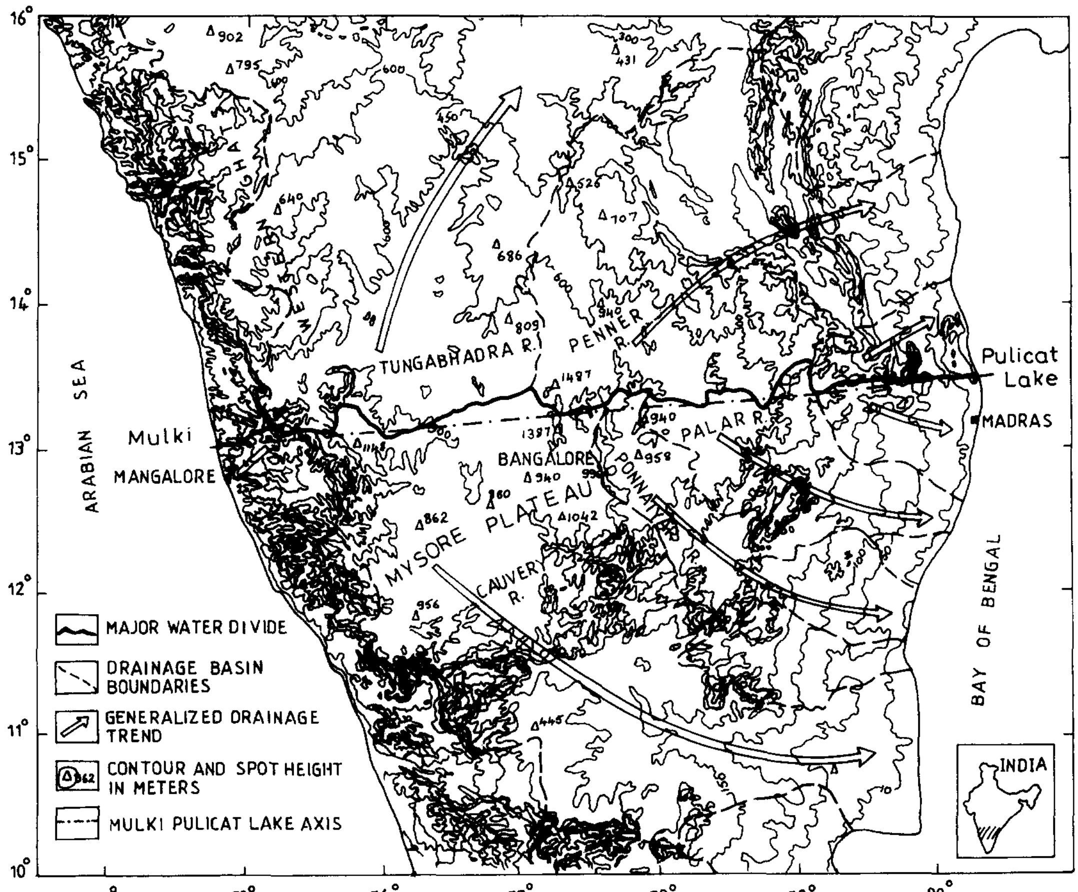

Fig. 1. A generalised drainage map of south India. A major water divide close to Mulki–Pulicat Lake Axis separates northeast flowing rivers from the south east flowing rivers.

The progradation of the land is also confirmed by the configuration of the shoreline which is convex towards the sea. The results of beach erosion/accretion studies undertaken by Jayappa and Subrahmanya (1989) indicate that erosion is dominant during monsoon (May to August) and accretion during the remaining months. When the entire stretch of 25 km is taken into consideration, there is a greater volume of sand accreted than eroded indicating widening of the beaches in most of the areas. A study conducted on the shoreline changes near Mulki shows that the northern barrier spit which is being

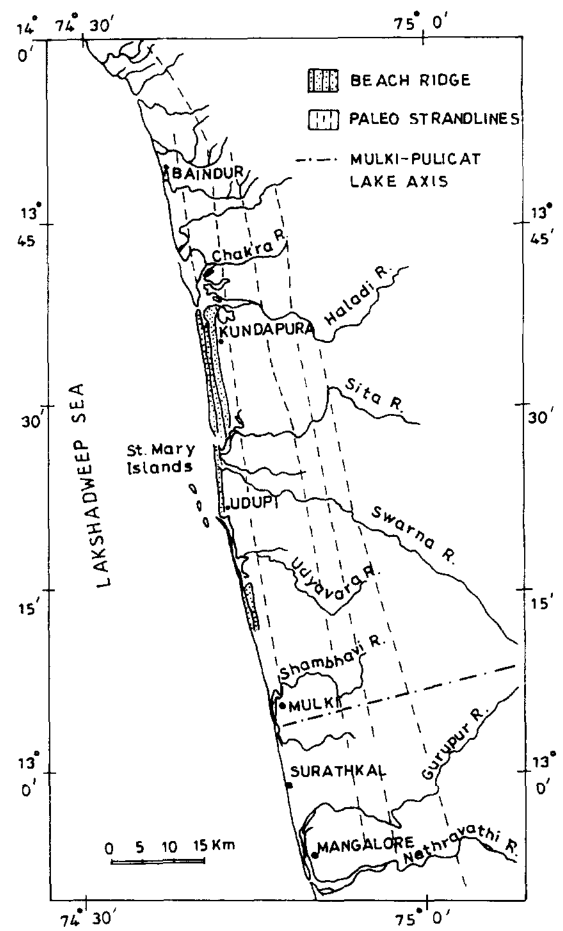

Fig. 2. Map of a part of the West Coast. Paleobeach ridges and swales indicate progradation of land. Two rivers Swarna and Gurupur which originate near a peak of the Western Ghats flow in a northwesterly and southwesterly directions. Position of the MPA is also shown.

eroded has lost 2.5 km^2 area, where as the southern spit which is growing has gained 3.0 km^2 resulting in a net increase of 0.5 km^2 (Gangadhara Bhat, 1995).

Investigation of the Netravati river channel reveals that even in areas where the gradient is low, river terraces with stratified sediments gently dipping in the down stream direction are present, indicating valley deepening (Gangadhara Bhat, 1992). The coastal region has a rugged topography as evidenced by flat topped lateritic mesas cut by deep valleys. Geological mapping of Mangalore area has shown two linear bands of pebble beds which are to the north of and nearly parallel to the present day channel of Netravati (Subrahmanya et al., 1991). These pebble beds indicate paleochannels of Netravati thus suggesting that the river course has migrated southwards. A similar southward migration of Gurupur river is revealed by the study of aerial photographs and satellite images (Fig. 3). Comparison of earlier offshore bathymetric records with the present day data indicates that there is a significant shift of contours seaward indicating uplift.

South of Mulki, near Surathkal, an oyster colony, which is now dead, is seen fringing a gneissic outcrop. This colony is above the inter-tidal zone indicating a relative fall in sea-level. The shells which have been dated by ^{14}C method at the University of Arizona (under the IGCP Project 274) give the age of the shells as post 1950 AD. The tide gauge data for Mangalore (obtained through Permanent Service for Mean Sea Level) indicates that during the past 25 years there is on the average, a relative fall in sea level of 1 mm yr^{-1} (Fig. 4A).

North of Mulki, there are a group of islands generally known as St. Mary Islands. The rocks here are rhyodacites and are known for their well developed columnar joints (Naganna, 1966; Valsangkar et al., 1981). These rocks have been considered to be products of rift stage volcanism, which took place at the time of separation of India from Madagascar around 93 Ma (Subrahmanya, 1994). The islands have wave cut platforms at different elevations, the highest being at 10 m. The other terraces are approximately at 6 m, 3.0 m and 1.5 m and 0 m indicating a relative fall in sea level/rise in land.

Mysore Plateau: Cauvery is a major east flowing river of the southern peninsula (Fig. 1). The various stages in the evolution of present day Cauvery have been discussed by Vaidyanadhan (1971) and Radhakrishna (1992). Vaidyanadhan (1971) has argued that the present day course of Palar river from Vaniambadi to the East Coast was the original course of the upper Cauvery. Radhakrishna (1992) considered that upper Cauvery, Ponniyar and Palar (Fig. 5) formed parts of a single drainage system. A segment of the upper Cauvery joined lower Cauvery because of the recent uplift of the land, which gave a youthful topography to the region, thus resulting in a rejuvenated course of Cauvery from Shivasamudram to Erode. Consequent to this, the original upper Cauvery dismembered into three streams namely upper Cauvery, Ponnaiyar and Palar. As can be seen from Fig. 1. Even the middle segment i.e., Ponnaiyar, moved southward and then eastward to join the Bay of Bengal.

East Coast (South of MPA): River Palar (Fig. 1) is the eastern segment of the original upper Cauvery. A detailed investigation of the Palar basin carried out by Narasimhan (1990) has shown that Palar had three paleochannels, all of which were to the north of the present day channel (Fig. 6). All the four chan-

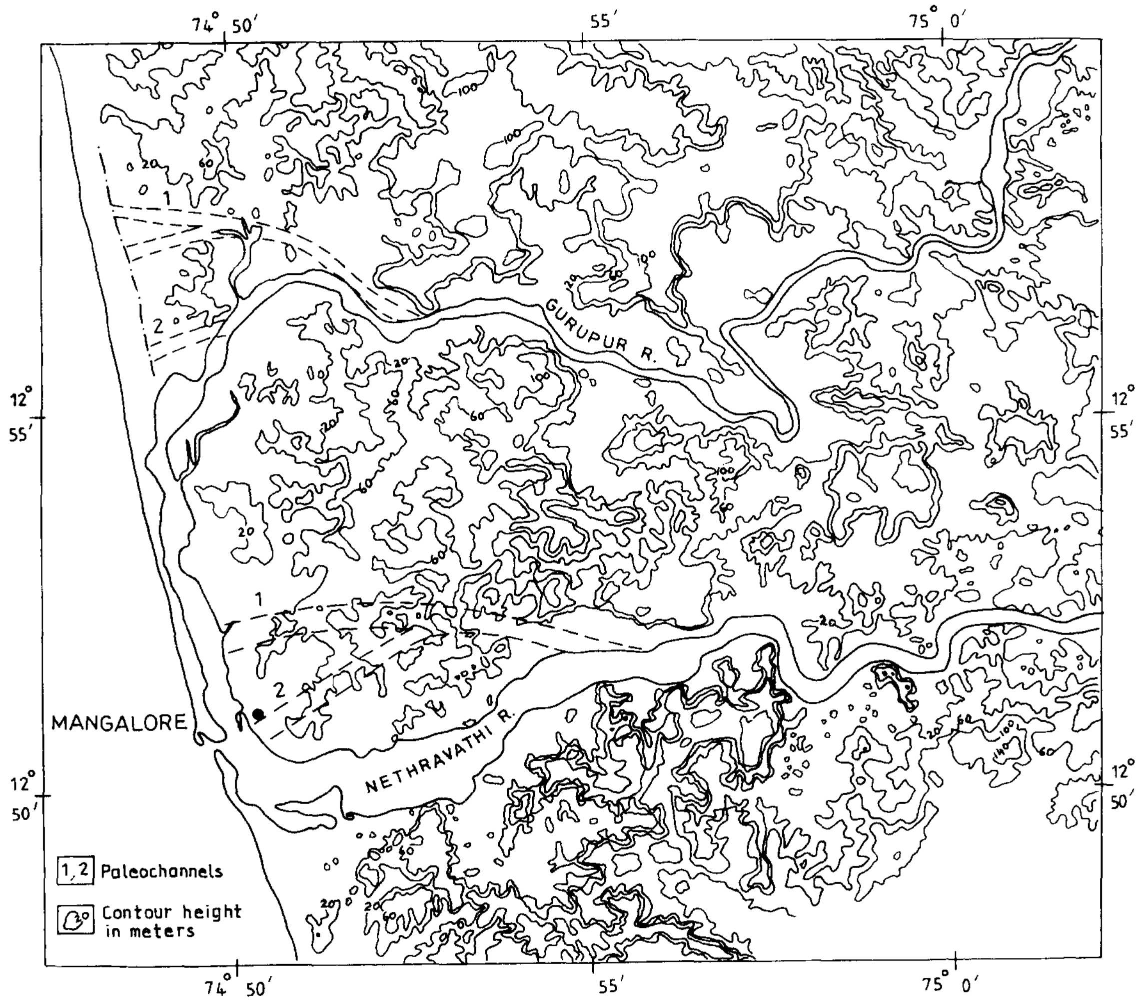

Fig. 3. Courses of river Netravati and Gurupur close to their confluence with sea. Both the rivers indicate a southerly migration of their channels. The area is to the south of MPA.

nels have been carved in late Tertiary sediments and even the interchannel areas are occupied by the late Tertiary sediments. On this basis, it has been concluded that all the channels are of Quaternary age. The northern-most channel is considered to be the oldest course, with two other paleochannels occurring successively to the south. The reason for the shift of the drainage from north to south has been ascribed to a "prolonged uplift of the northern parts of the region shown on the map. Considering the fact that all the channels cut through Late Tertiary sedimentary deposits, it can be concluded that the uplifts

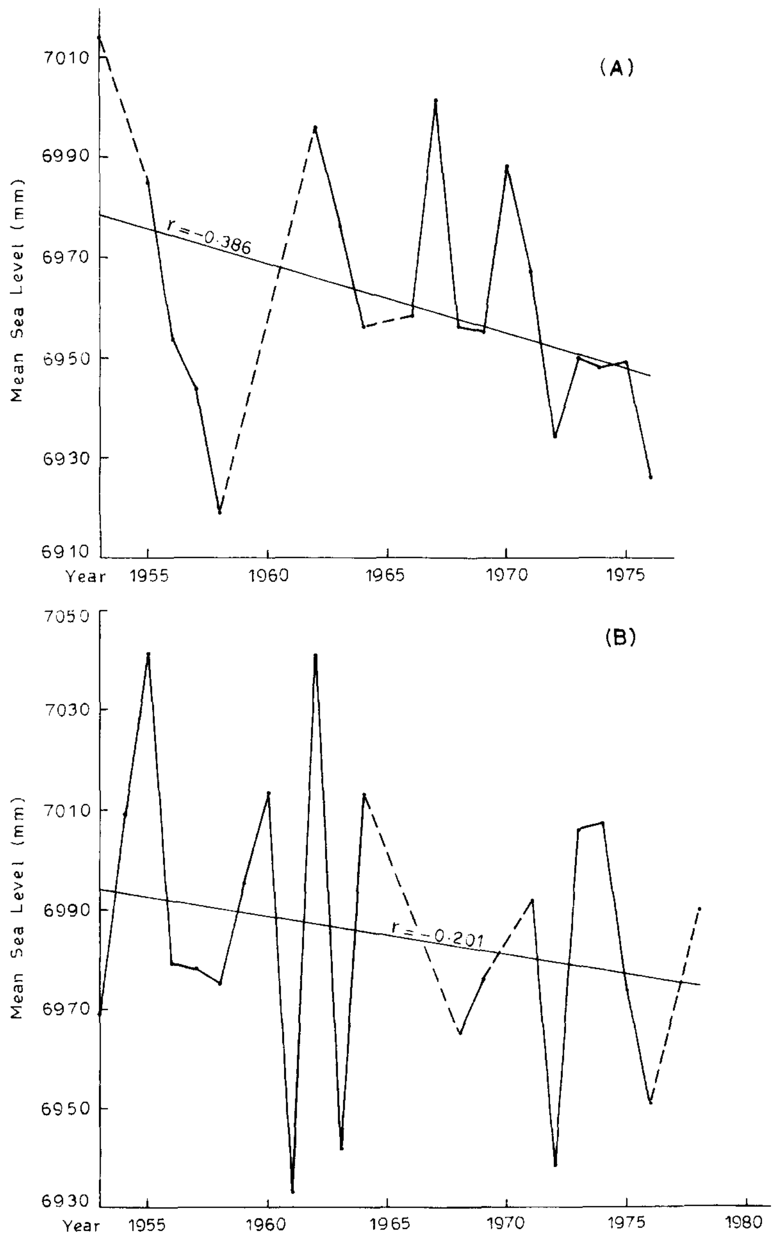

Fig. 4. A plot of the tide gauge data of Mangalore (A) and Madras (B) indicating an apparent fall in sea-level. The relative fall in sea-level for Madras is not as pronounced as that of Mangalore.

have occurred during Quaternary times'' (Narasimhan, 1990).

Detailed hydrogeological study of Madras city aquifers has been carried out by Ballukraya and Ravi (1995). Two ephemeral streams, Cooum to the north and Adyar to the south meander through Madras city. Referring to the geomorphology of the area, the authors comment ``That the ridge is higher than the erosion surface as well as the fact that bed rocks in the mouths of Cooum and Adyar are at much higher levels than the base levels during Pleistocene glaciation period suggests an isostatic uplift of the east Madras coast. This is also indicated by the narrowing of these river courses to the east. The slightly raised nature of the beach also points towards a coastal uplift. It is also possible that the Cooum joined the sea much to the north, than its present confluence, in the Pleistocene times as the depth to bed rock is much deeper there............ The slow uplift of the eastern coast is also indicated by the presence of marine sands, containing plenty of shells of marine organisms and highly saline waters at locations of 1–2 km away from the present coast''.

East Coast (North of MPA): River Penner is relatively small compared to other east flowing rivers. Ramesh and Deonath (1991) have carried out Quaternary studies of the Penner delta. They have noticed ``Anomalous northerly migration of the Penner

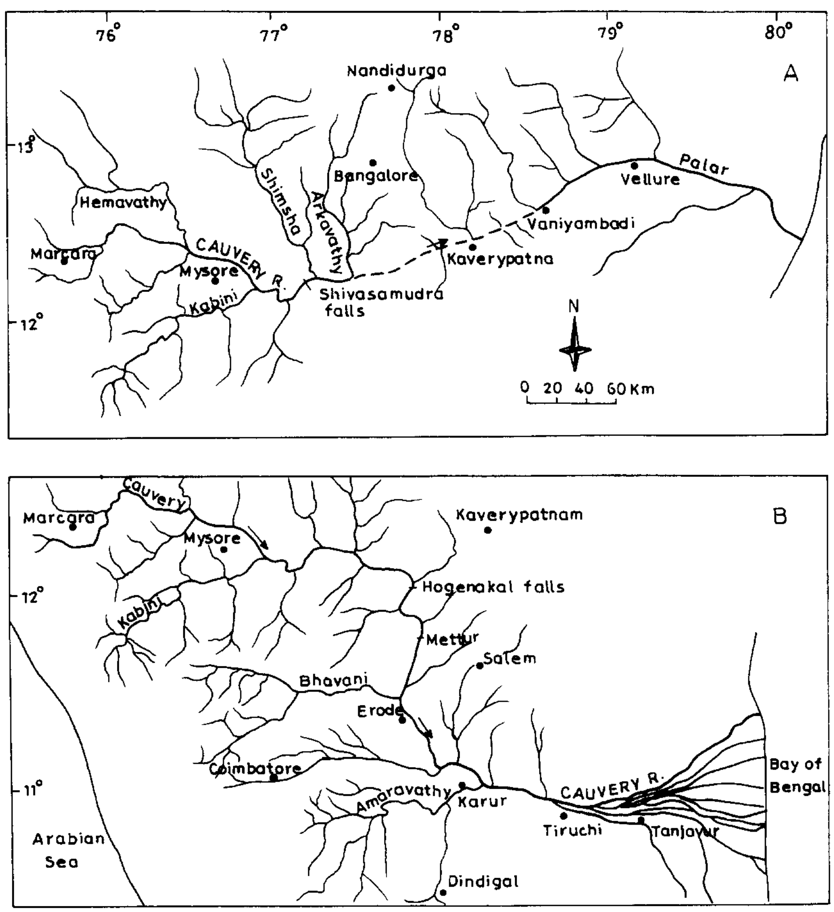

Fig. 5. (A) The original course of upper Cauvery, which included present day Ponnaiyar and Palar rivers (B) Dismemberment of the western-most segment of upper Cauvery and its southward migration to join lower Cauvery (Radhakrishna, 1992). The area is to the south of MPA.

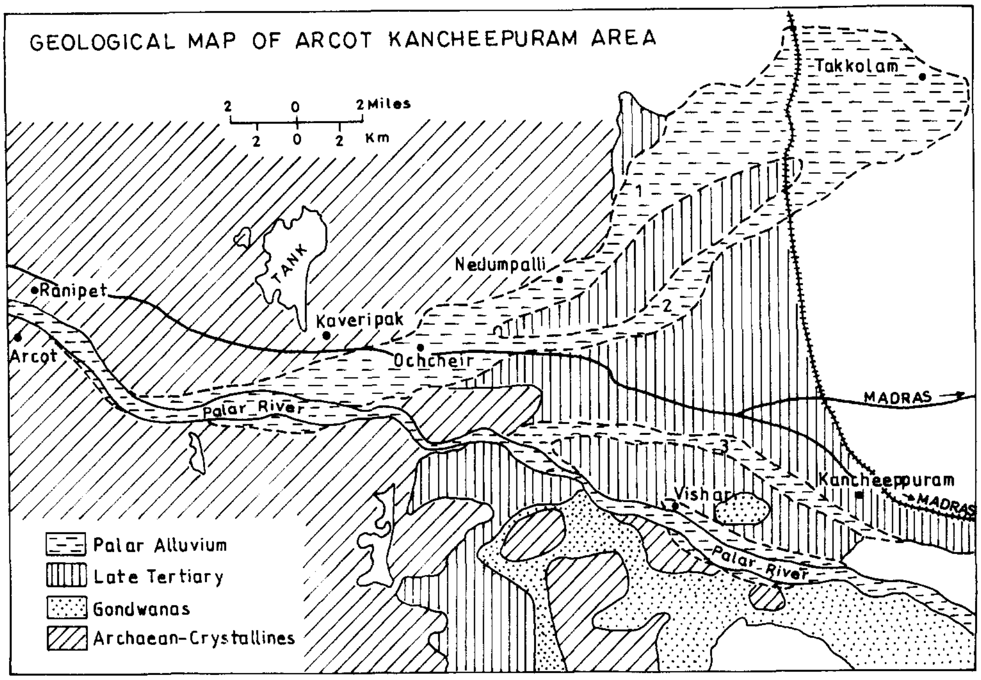

Fig. 6. Three paleochannels (*1*, *2*, *3* in the Figure) marking successive migration of river Palar southwards. The paleochannels are on Quaternary terrane indicating that the shifts have taken place in recent times (Narasimhan, 1990). The area is to the south of MPA.

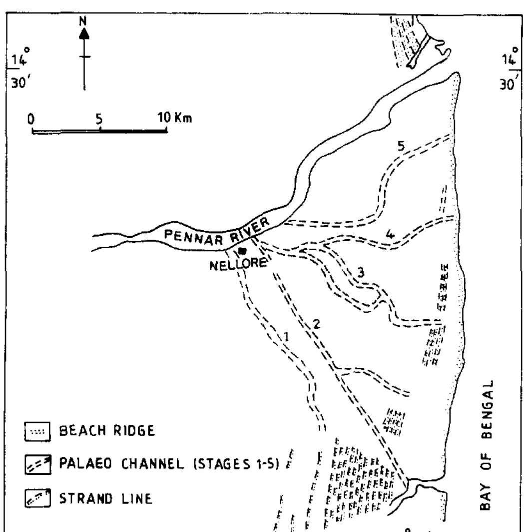

Fig. 7. Quaternary map of Penner river basin. Five paleochannels are marked *1*, *2*, *3*, *4*, *5*. Younger paleochannels occur to the north of older ones. Present channel is the northernmost (redrawn from Ramesh and Deonath, 1991). The area is to the north of MPA.

river leaving at least five paleochannels on the right bank indicating possible northerly tilting of the block'' (Fig. 7). Further, they have observed that the Penner river has transformed from a narrow and meandering channel into broad and braided channel indicating steepening of the river gradient.

Tide gauge data for Madras indicates a relative fall in sea-level which is not as pronounced as that of Mangalore (Fig. 4B). However, when seen in conjunction with other evidences, the data may point to a raise of land. The bulge or convexity of the land along with the presence of barrier beaches confirms progradation of land and regression of sea.

3. Discussion

The spreading of the sea-floor in the Indian Ocean which was responsible for the rapid migration of India northward and subsequent collision with the Asian mainland, resulting in the Himalayan mountain range, is still active. The newly created sea-floor is being accommodated in part at the collision boundary. The remaining part results in high compressive stress within the Indian plate. Manifestation of this is seen in the Central Indian Ocean Basin where the oceanic crust has undergone deformation. The lithosphere here, is a diffuse zone of compressional and strike-slip earthquakes. The deformation has resulted in long wavelength (100–300 km), large amplitude (1–2 km) undulations. Also associated are high angle reverse faults. This zone of deformation is considered to be a boundary between two plates i.e., Indian and Australian (Bull and Scrutton, 1990; Stein et al., 1990; Murthy et al., 1993 and references there-in). The region to the north of 10°S and east of 80°E is considered to be a zone of compression. The intraplate stresses here should result in relative sea-level changes along the continental margins (Cloetingh et al., 1985). Thus apparent sea-level changes should occur along the Indian continental margins given the high predicted stresses (Stein et al., 1989). As the stress required to cause significant apparent sea-level changes are much less than that required to deform Indian Ocean lithosphere, the continental margins may preserve records of stress changes prior to 7.5 Ma (Cochran, 1990 in Stein et al., 1990). The relative fall in sea-level at Madras and Mangalore can be interpreted as indicators of the present day stress regime which is resulting in deformation of the crust.

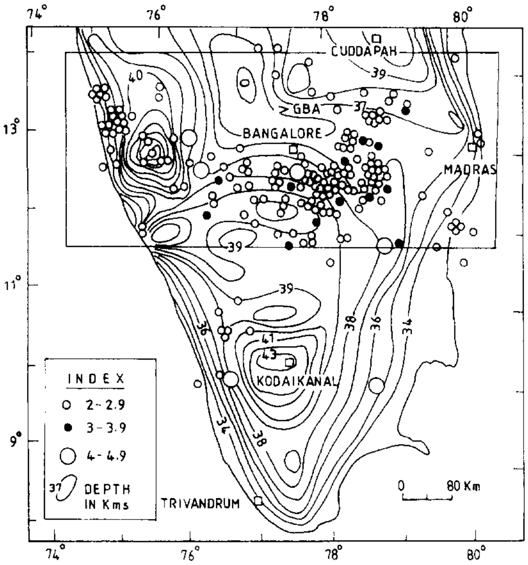

Fig. 9. Crustal thickness map (Subba Rao, 1987) on which the epicentral distribution of the earthquakes for the period 1968 to 1986 have been plotted (Ramalingeswara Rao, 1992). The data is from seismic array station at Gauribidanur (GBA). The accuracy of location of epicentres is within a few hundred meters (Ramalingeswara Rao, pers. commun.).

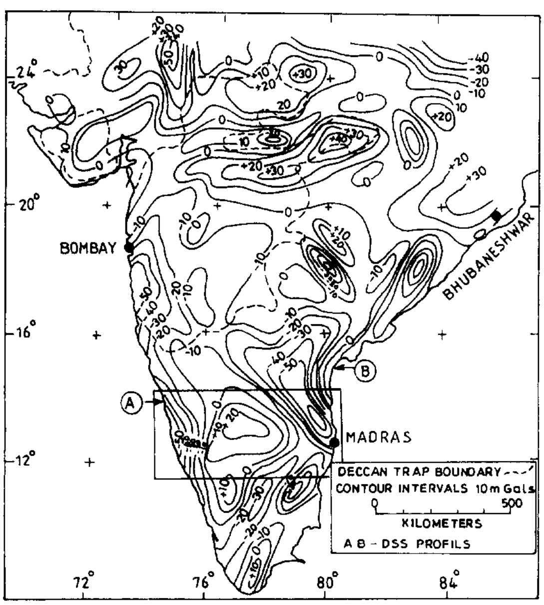

Fig. 8. "Regionalised residual isostatic anomaly" map of Indian peninsula (Qureshy, 1981) indicating a positive anomaly nearly paralleling MPA. The area of uplift lies within the rectangle.

The Free-Air Anomaly map indicates a positive anomaly in the Mysore Plateau region, which nearly coincides with the zone of upwarp. Likewise, the Bouguer anomaly, although not positive in absolute terms, is high compared to the region to the south and north (N.G.R.I., 1974). The gravity map prepared by Qureshy (1981) after taking into consideration, the effect of Indian Ocean Gravity low, indicates a positive anomaly in the region of upwarp (Fig. 8). A crustal thickness map (Fig. 9) prepared on the basis of regional gravity modelling (Subba Rao, 1987) brings out that the crust is relatively thinner in the upwarp zone by 2–3 km. Taking into consideration the fact that the upwarp zone is a ridge, the thinness of the crust becomes all the more striking. It points out that the Moho occurs at a shallower depth and hence it is possible that even the lithosphere is involved in the deformation. Ramalingeswara Rao (1992) has observed that a large number of micro- to moderate earthquakes ranging from M2 to M5 occur close to 13°N (Fig. 9). According to him, the seismicity occurs in the transition zone of low- to high-grade terranes which separates granulites from the greeenstone belts.

The occurrence of large numbers of small magni-

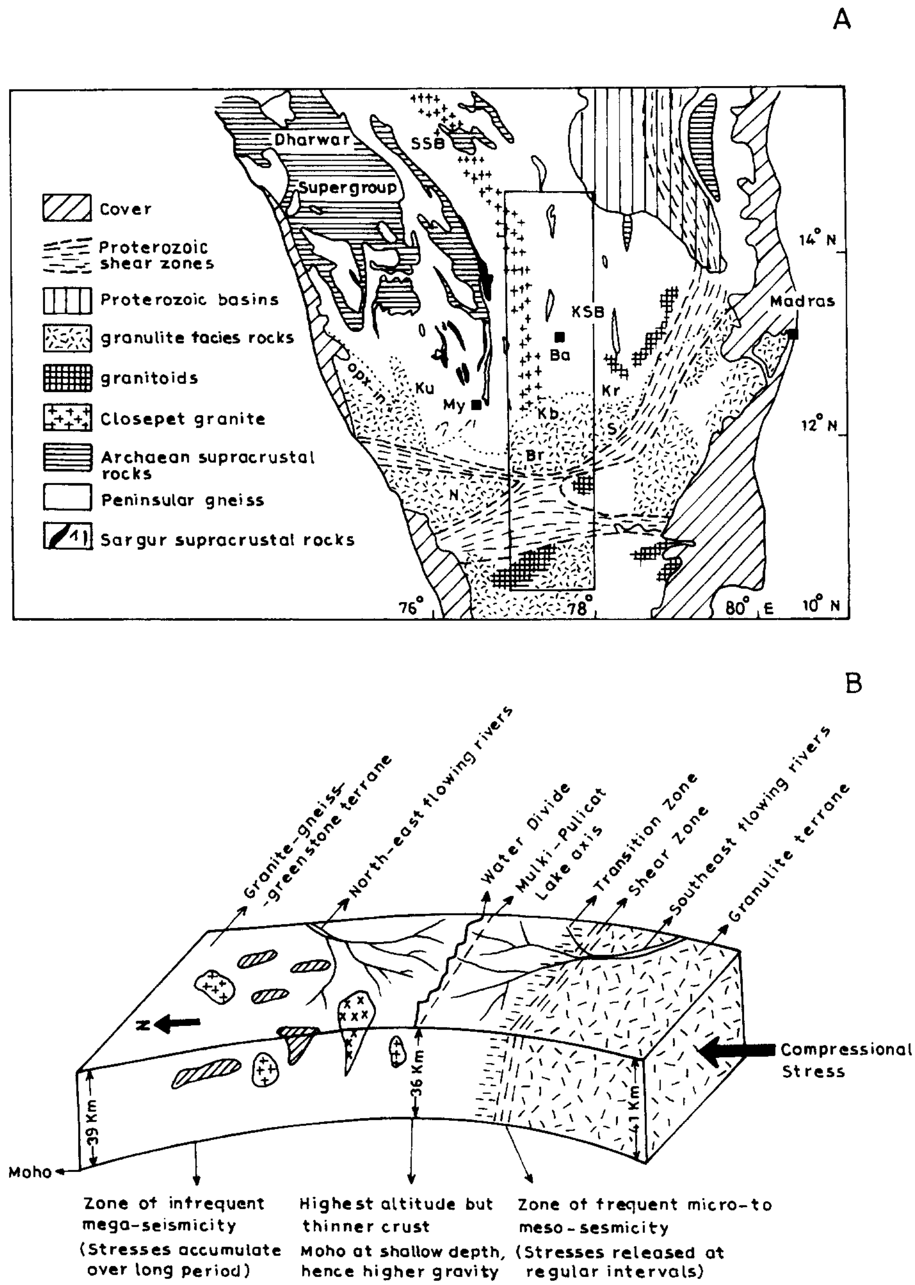

Fig. 10. (A) Geological map of a part of southern India (compiled by Friend, 1994). North–south trending rectangle is the area represented in (B). (B) Idealised block diagram of the area marked in (A). Compressional stress results in micro- and meso-seismicity to the south and mega-seismicity to the north of MPA.

tude earthquakes can be interpreted as being due to the compression the region is experiencing as a result of continued sea-floor spreading. Because the transition zone is close to a major shear zone, stress cannot accumulate and hence it is released in small amounts, resulting in micro- to moderate earthquakes. However, the region to the north of the MPA acts as a solid block and a considerable amount of stress accumulates. Earthquakes of large magnitudes are thus likely to occur here (Fig. 10A, B). The Killari (Latur) earthquake (M6.3) of Maharashtra (Ramakrishnan et al., 1994) is a pointer in that direction.

4. Conclusions

Data available from the offshore, continental margins and continental area offer indirect evidence to indicate buckling of the landmass along an east–west line close to 13°N. Ongoing uplift is suggested by seismicity and sea-level changes. The region is likely to experience further upwarp and result in micro- to meso-seismicity to the south and mega-seismicity to the north of MPA.

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