

Land-Ocean Tectonics (LOTs) and the associated seismic hazard over the Eastern Continental Margin of India (ECMI)

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Abstract: The South Indian (Peninsular) Shield which includes both the Eastern and Western Continental Margins of India is not as stable as it was originally thought of. The importance of intraplate seismicity within this Shield has recently been realized with some devastating earthquakes that occurred during the last few decades. It is also significant to note that most of the Precambrian tectonic lineaments in this Shield are oriented in either a NW-SE or W-E direction, joining the eastern offshore. In contrast, the western margin has an elevated coast, associated with a linear coast parallel escarpment, particularly on the southern side, superimposed by Deccan Trap volcanics on the northern side. The fault reactivation and the associated seismicity are hence more predominant on the east coast. Recent geophysical studies delineated Land-Ocean Tectonics (LOTs) over the eastern margin, in some cases associated with moderate seismicity as a result of the compressional stress acting on the Indian Plate. Though the Eastern Continental margin of India (ECMI) is considered as a passive margin, coastal seismicity due to the reactivation of the pre-existing tectonic lineaments extending offshore represents a potential natural hazard. In this context, the ECMI appears to be much more vulnerable compared to its counterpart on the west.

Keywords: ECMI, Passive margin, intraplate seismicity, Land-Ocean Tectonics (LOTs)

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1. Introduction

Passive margins, also called as Atlantic type of margins, by definition are generally the sites of negligible tectonic activity like earthquakes, volcanoes, mountain building, etc. The Eastern Continental Margin of India (ECMI) is considered as a passive margin, though the geodynamic processes and the resultant seismotectonics prevalent in the vicinity of the ECMI are quite different compared to other passive margins. The ECMI has evolved due to the break-up of India from East Antarctica around Late Jurassic to mid-Cretaceous (140-120 Ma) (Curry et.al 1982; Gopala Rao et.al 1997). The initial break-up seems to have occurred at the bight of the present day Krishna-Godavari (K-G) basin (Ramana et.al 2003), in two major stages along two different segments; the northern (K-G) rifted segment and the southern (Cauvery) sheared or transform segment (Subrahmanyam et.al 1999). The Indian Plate has undergone an eastward tilt due to this initial break-up and for this reason we find that most of the South Indian rivers along the Gondwana Grabens have an eastward trend, though most of these major rivers have originated far west. The tectonic fabric in the south Indian shield (**Fig.1**), south of Son-Narmada Lineament has a predominantly NW-SE or W-E trend (Vita-Finzi 2004; Roy 2006) The Western Continental Margin of India (WCMI) on the other hand was formed at a later stage and in a much different way. The break-up occurred in two stages; first the separation of Madagascar from western India around mid-Cretaceous (85 Ma) followed by the separation of Seychelles micro-continent from the present northern part of the west coast of India at the end of Cretaceous (Subrahmanyam et.al 1995; Bhattacharya and Chaubey 2001; Krishna et.al 2006). The resultant morphology of the west coast is also different compared to the east coast. The origin of WCMI is associated with a nearly 1500 km –long, coast parallel escarpment (WESP, **Fig.1**) with a similar counterpart on the east coast of Madagascar (Gunnell and Harbor 2008). The conspicuous Palghat Gap is the only break in this escarpment (John and Rajendran 2008), which continues as the Ranotsara Gap on the eastern Madagascar. This Gap coincides with the W-E trending Palghat–Cauvery Shear Zone. On the northern part of the west coast, the Deccan trap Volcanism that erupted during 65 to 62 Ma has further added to an already elevated coast. Most of the tectonic lineaments within the south Indian Shield have a clear expression eastward of this escarpment. However, some geophysical studies indicate offshore extension of Pre-Cambrian mega lineaments both into the Arabian Sea and Bay of Bengal (Mishra 1977, 1984; Bhattacharya and Subrahmanyam 1986; Subrahmanyam 1996; Subrahmanyam et al 2006).

2. Recent seismicity within the South Indian (Peninsular) Shield

Seismicity of the Indian sub-continent is predominantly confined to four major tectonic settings (marked as I, II, III and IV in **Fig.2**). They are: I) Extra-Peninsular (Himalayan region), associated with plate-collision seismicity, II) Peninsular or Stable Continental Region (SCR), associated with intra-plate seismicity. III) Equatorial region of Central Indian Ocean basin, associated with Late Miocene lithospheric deformation and IV) the Andaman-Sumatra subduction arc, associated with convergent margin seismicity.

The South Indian (Peninsular) Shield has been experiencing moderate seismicity ($M_w < 5.0$), which indicates the ongoing neotectonic activity or reactivation of existing Pre-Cambrian faults in this region (**Fig.1**). However, some of the earthquakes that occurred in this Stable Continental Region (SCR) are quite devastating, for example the Latur, (1993; M_w 6.3), Jabalpur (1997; M_w 6.0) and Bhuj (2001; M_w 7.7) events (Mandal et.al 2000). New data has been added during the last two decades to understand the process of crustal deformation and fault reactivation taking place in the South Indian Shield (Ramasamy, 1989; Banerjee et al 2001; Rajaram and Anand 2003; Vita-Finzi, 2004). Subrahmanya (1996) reported active intraplate deformation along a W-E axis following the 130N from Mulki on the west coast to Pulicat on the east. Ramasamy (1989) and Ramasamy and Balaji (1995) on the basis of morpho tectonics of the Tamil Nadu shelf suggest that the Indian sub-continent is buckling with the formation of a series of E-W arches and deeps right from Cape Comorin to the foothills of Himalayas. In a recent study Subrahmanyam et al (2006) reported offshore extension of two major Pre-Cambrian mega- lineaments; the Palghat-Cauvery Lineament (PCL) and Moyar-Bhavani-Attur Shear zone (MBA) following approximately 110N and 120N respectively. Ramasamy et al (2001) reported the existence of two NE-SW trending sub-parallel faults along which the Pondicherry coast is undergoing land subsidence due to differential tectonic movements.

Major tectonic lineaments extending from the coast to the offshore in a predominantly NW-SE direction were also delineated off the Krishna, Godavari basin (Ongole, Chintalapudi, Avanigadda, Pithapuram cross trends) and Mahanadi basin, which represent the rift related tectonics of these Gondwana grabens (**Fig.3**) (Venkatarangan and Ray 1993; Murthy et. al 1995, Subrahmanyam et. al 2008).

3. Land-Ocean Tectonics (LOT) and the seismic hazard

Geophysical studies carried out by the Regional Centre of National Institute of Oceanography (C.S.I.R.), Visakhapatnam for the last 8 years (Murthy et al 2002; Subrahmanyam et al 2007, Sarma, et al 2009) indicate at least three locations on the east coast, where moderate seismicity was reported, associated with the Land-Ocean Tectonic lineaments (LOTs), mostly oriented in NW-SE direction (shown as Blocks I, II and III at Visakhapatnam, Ongole and Pondicherry respectively in **Fig.3 and Table I**).

I - Visakhapatnam Block:

Coastal geology of this block mainly comprises of the Eastern Ghat belt of Pre-Cambrian age. It constitutes the oldest metamorphic rocks (Radhakrishna Murthy, et.al., 1991). Charnockite is the predominant member of the Eastern Ghat Complex. It is magnetic in character and contributes mainly to the magnetic anomalies recorded from geophysical surveys. The Charnockite basement is faulted and exhibits horst and graben like structure. It broadly maintains conformable relation with the anticlinal and synclinal structure of the overlying Khondalite suite of rocks. Earlier studies (Narayanaswamy, 1975 and Halden et.al. 1982) attribute the development of these faults to the earlier folding of the Eastern Ghats and their change in direction from

predominant NE-SW direction to NW-SE direction. Some minor river channels like Gosthani, Kandilavasa, Nagavali and Nellimarla follow the NW-SE structural trend in this area and extend offshore. Subrahmanyam et al (2007) correlated the minor tremor of 1995 (M3.3) reported off Vizianagaram shelf with the reactivation of Kandivalasa lineament extending from coast to the offshore. The seismicity record of this Block is given in Table I

II - Ongole Block:

This Block forms a part of the Eastern Ghat Granulite Belt. The structural lineament map of this area indicates the presence of all the three types of regional fault pattern, namely NW-SE, NE-SW and W-E. This block had been subjected structural deformation for the last 3000 Ma in the Plate tectonic history (Reddy and Chandrakala, 2004). This region is drained by minor rivers like Gundlakamma, Musi, Paleru and Manneru. Seismicity is however reported mainly along the NW-SE trending Gundlakamma river fault, which runs nearly for 100 Km from inland to Ongole on the east coast. Sarma et al, 2009 delineated the offshore extension of the Gundalkamma Fault from marine magnetic data. Seismicity record of the Ongole area is given in table I

III - Pondicherry Block:

This Block forms part of the Cauvery Basins, which is one of the three Gondwana grabens of the east coast of India, the other two being the Krishna-Godavari and Mahanadi basins on the northern part. Detailed geophysical studies (magnetic and free-air gravity data) by Subrahmanyam et. al (1995) and Murty et al, (2001) indicate that the Cauvery Offshore basin is a fault controlled basin. Gravity and magnetic data indicate offshore extension of two major Pre-Cambrian lineaments, namely the Moyar - Bhavani Attur (MBA) Lineament in the northern part and the Palghat-Cauvey Lineament (PCL) in the southern part of the Cauvery basin. Murty et .al (2002) were of the opinion that the Pondicherry earthquake of 25th Sept., 2001 (Mw 5.5) represents the reactivation of MBA lineament with its epicenter located on the continental slope off Pondicherry. (TableI) .

It is likely that in all these cases, the observed moderate seismicity is mainly due to the reactivation of pre-existing structural lineaments, which are also associated with major and minor river channels, like the Kandivalasa (Vizianagaram,), Gundlakamma (Ongole) and Cauvery (Pondicherry), The Bhadrachalam earthquake (1969) was one of the strongest earthquakes (Mw 5.7) in Southern Peninsular and was also located on the NW-SE trending Pranhita Godavai-Gondwana Graben (Wai-Ying Chung 1993).

4. Conclusions

The moderate to high seismicity observed in the South Indian Shield is mainly due to the fault reactivation under a SW-NE oriented compressional stress acting on the Indian Plate (Roy, 2006). Even within a short

geological period of nearly four decades, some devastating earthquakes have occurred near Bhuj, Latur, Jabalpur, Koyna, etc. Marine geophysical studies indicate moderate seismicity associated with the Land-Ocean Tectonics (LOTs) over the Eastern Continental Margin of India (ECMI). The coastal/offshore regions of Visakhapatnam, Ongole and Pondicherry have been identified as zones of weakness where neotectonic activity has been established.. While Earthquake data over the coastal and offshore areas of Visakhapatnam (including the Vizianagaram part) indicate moderate seismicity (with magnitude of tremors of the order of 3 to 4.5), the Pondicherry off shore experienced an earthquake of magnitude 5.5, in 2001, which was a fairly larger event for the South Indian shield. A continuous monitoring of coastal seismicity, through geophysical studies is essential. The rapid industrial scenario currently taking place along the east coast of India must contemplate this aspect of natural hazards for a sustainable development. The tectonic setting with predominantly W-E, NW-SE lineaments extending from the coast to offshore resulting in a basinal to non-basinal mosaic suggest that the ECMI is more vulnerable to the neotectonic activity, compared to the WCMI

Seismicity associated with fault reactivation was also reported on the western part of the south Indian Shield (Rajendran and Rajendran 1996; John and Rajendran 2008). However, these are mostly located at the western end of the Palghat Gap, a conspicuous geomorphic gap in the western Ghat escarpment. Reports of fault reactivation and associated seismicity are relatively sparse in case of the WCMI.

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Figures:

1. Major tectonic lineaments and earthquake locations in the South Indian Shield. Red circles indicate earthquake epicenters.

Source for the Generalized Bathymetry of Indian Ocean: GEBCO. MN: Mahanadi Trend; GD: Godavari Trend; C; MPL: Mulki-Pulicat Lineament; MBA: Moyar-Bhavani-Attur Lineament; PCL: Palghat – Cauvery Lineament; AKS: Achankovi Shear Zone; EGB: Eastern Ghat Belt; WESP: West Coast Escarpment.

2. Seimotectonic set-up in the Indian sub-continent.

I) Himalayan Block of Extra-Peninsular seismicity
II) Stable Continental Region (SCR) seismicity
III) Zone of lithospheric Deformation in CIOB
IV) Andaman-Sumatra Subduction Zone seismicity

Red circles indicate earthquake epicenters. Source for Generalized Bathymetry of Indian Ocean: GEBCO

3. Moderate seismicity associated with the Land Ocean Tectonics (LOTs) over the ECMI. Stars indicate epicenters of moderate seismicity. Blocks I, II and III described in the text.

CCT - Chintalapudi Cross Trend ; ACT – Avanigadda Cross Trend; PKL – Pudimadaka Lineament; VZL - Vizianagaram Lineament; COL - Chilka Offshore Lineament; DOL – Dhamra Offshore Lineament; PCL and MBA as defined in **Fig.1**

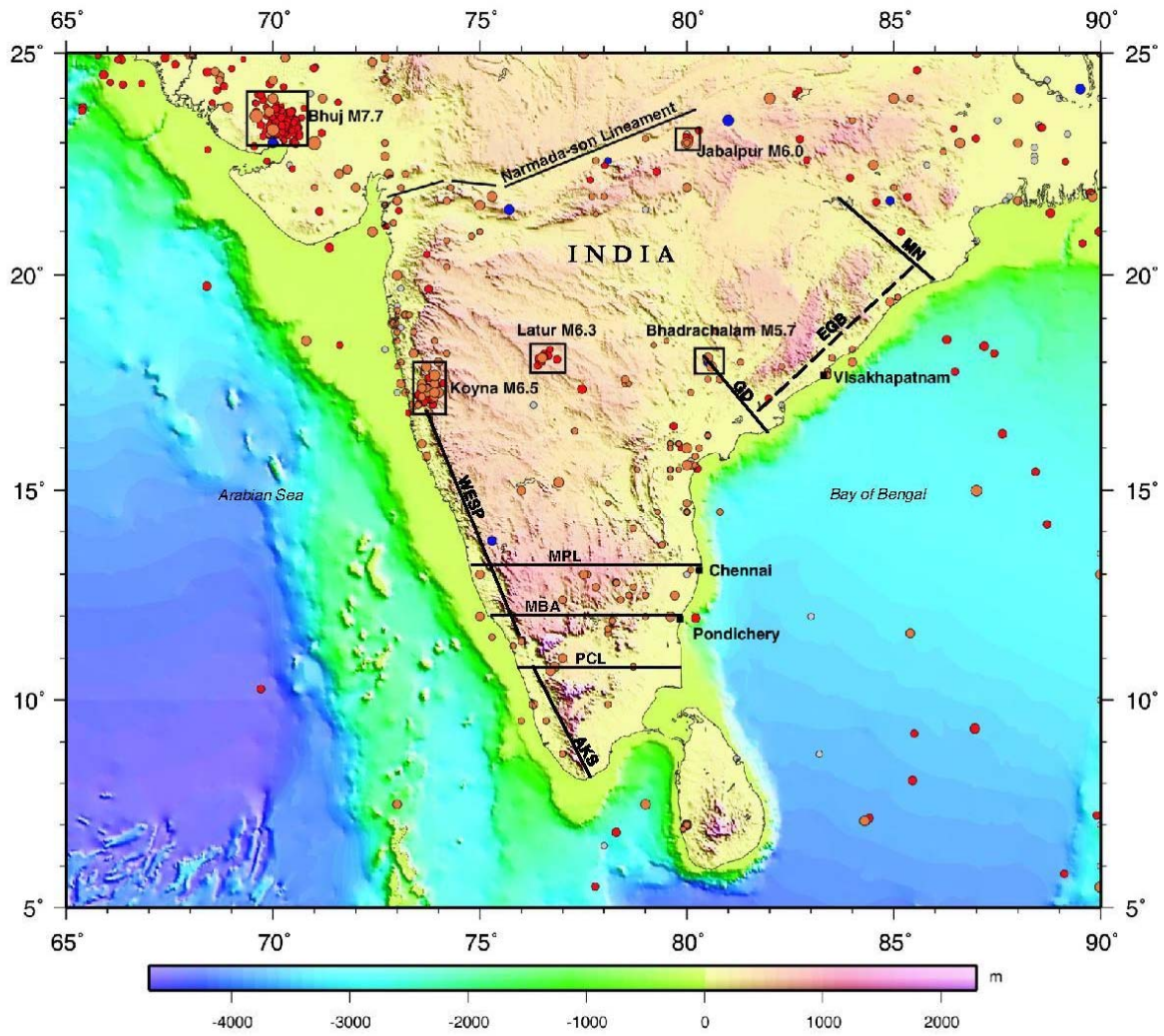


FIG.1

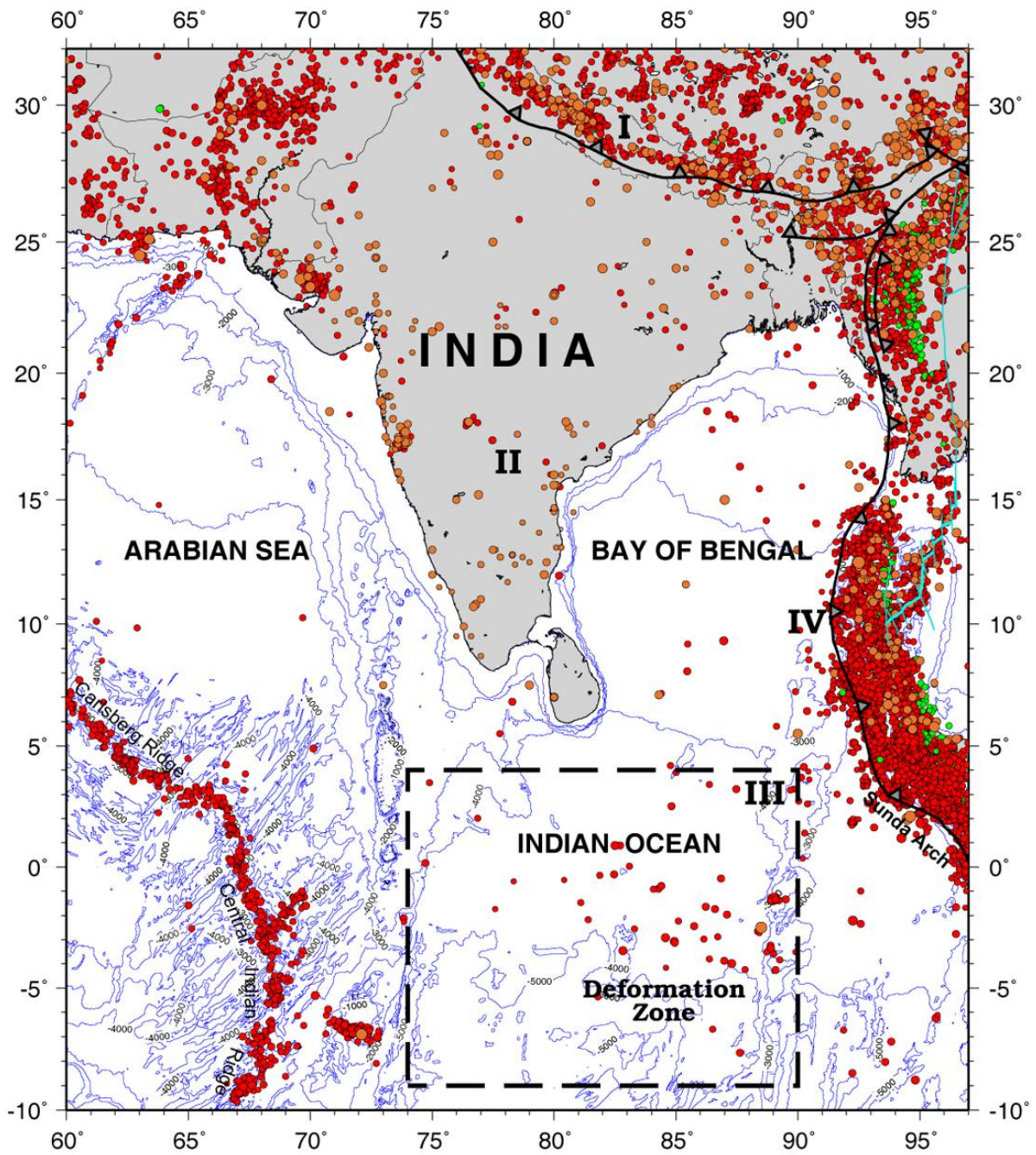


FIG. 2

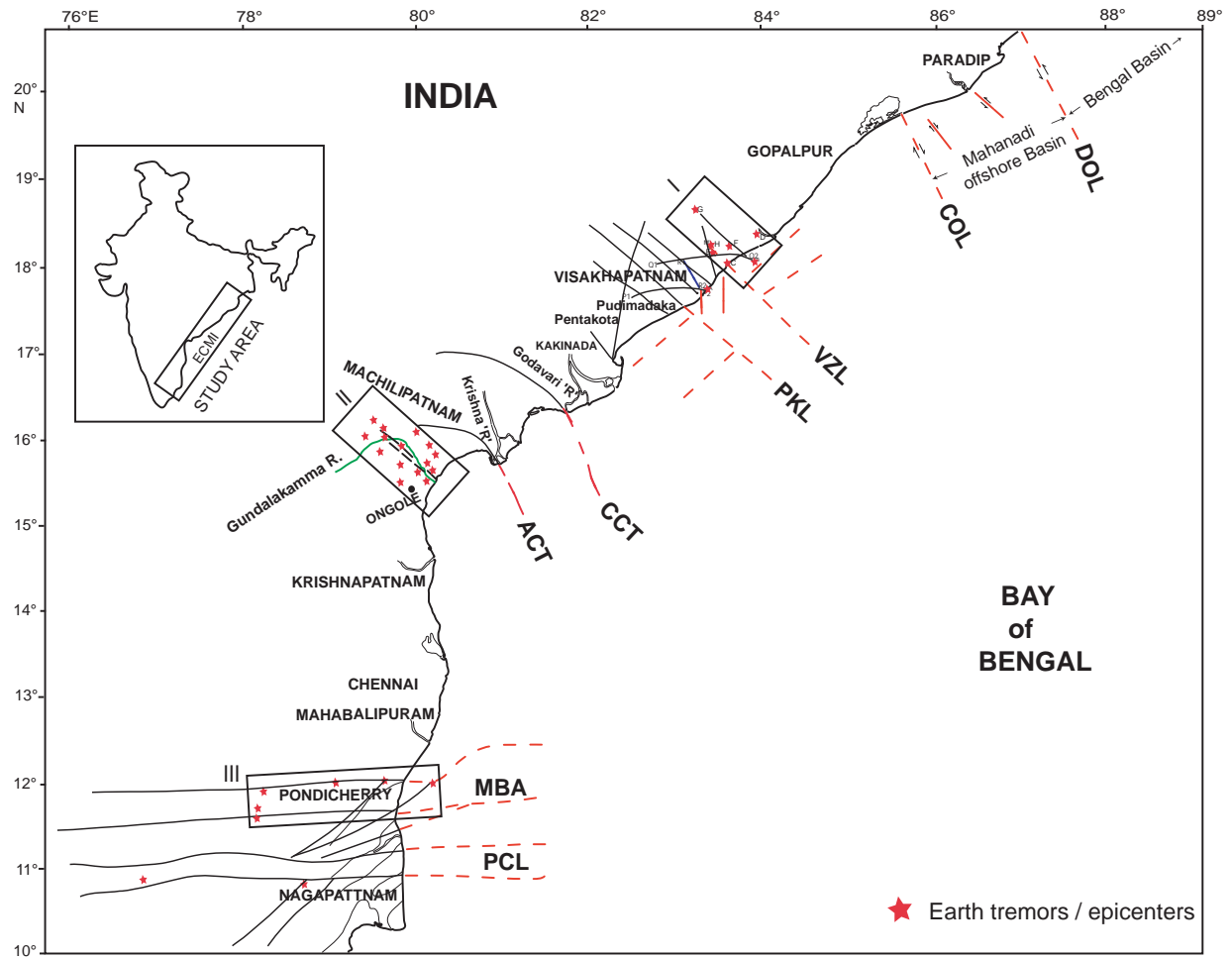


FIG: 3

Table-I Inferences on the neotectonic activity over the ECMI from Geophysical / Geological / Earthquake data

Block No./Name	Geophysical	Geological	Earthquake data Source: www.asc-india.org
I - Visakhapatnam	Two-dimensional model studies of marine magnetic data reveal the presence of some prominent Land-Ocean Tectonic lineaments, off Visakhapatnam and Vizianagaram (north of Visakhapatnam), with predominant NW-SE trends. They extend at least up to 40 m water depth in the offshore (Murthy et al 1987, Subrahmanyam et al 2007)	These lineaments correlate with the NW-SE folded and faulted charnockite basement structure of the Eastern Ghat Complex, extending from the coast to offshore. Some of these lineaments follow the minor river channels like the Kandivalasa river channel onland at Vizianagaram, north of Visakhapatnam. (Radhakrishna Murthy et al 1991, Radhakrishna Murthy and Rama Rao 2001)	Tremors of 1827 (M 4.3), 1927 (M 4.3), 1917 (M 5.5), 1995 (M 4.5), 2003 (M 3.3.), 2004 (M 3.3) to mention a few
II - Ongole	Magnetic data over the innershelf (coast to 30 m water depth) of Ongole region is characterized by high frequency, short wave length anomalies associated with shallow basement structures perpendicular to the coast	A major NW-SE trend of magnetic anomalies in the offshore region correlates well with the Gundlakamma River fault on the land which runs nearly for 100 km inland from Ongole (Reddy and Chandralkala, 2004)	1869, 1905, 1967 (M5.2), 1971 (M 4.9) to mention a few. Focal mechanism indicates strike-slip faulting along the Gundlakamma fault.
III - Pondicherry	Magnetic and free air gravity over the offshore Cauvery basin indicates W-E structural trends extending from the coast to 1900m water depth offshore. These studies also reveal that the basin is fault controlled (Subrahmanyam et al 1995, Murty et al 2002)	Two of these major lineaments namely the Moyar-Bhavani-Attur Lineament (MBA) and the Palghat-Cauvery Lineament (PCL) extend from almost the western end of the South Indian Shield to the eastern offshore. (Murty et al 2002)	Pondicherry earthquake (M 5.5), of 25th September 2001 can be considered as a fairly larger event for the South Indian shield so far. Its epicentre falls over the continental slope (1900 m water depth), about 40 km off Pondicherry with a focal depth of 10 km. The epicentre of the earthquake falls over the extension of the MBA lineament. (Murty et al 2002)