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SEISMICITY OF INDIAN STABLE CONTINENTAL REGION

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Abstract

Homogenized catalog of earthquakes in the Stable Continental Region (SCR) of India of moment magnitude Mw ≥ 4 for the period 1341-2015 has been prepared. It indicates two earthquakes of Mw 7-8, seven of Mw 6-6.9, some 125 of Mw 5-5.9 and some 215 other M 4.0 to 4.9 or felt earthquakes. The ancient rift regions of Kachchh, Narmada and also the West Coast region have given larger earthquakes compared to other parts. Seven earthquakes of Mw ≥ 6 in 74 years during 1927 to 2001 give a repeat time of about 10 years for SCR, India. However, at an individual site such earthquakes may recur after thousands of years as the strain rate is low 10^{-9} with a deformation of 2 mm/year as estimated from GPS measurements. As most parts of Peninsular India experience seismicity it is critically stressed. The pre-existing faults get reactivated due to strain accumulation or fault weakening. Though most of the areas show strike-slip, large earthquakes are associated with reverse faulting along nearly E-W planes in the Kachchh Rift, the Narmada rift and elsewhere due to tectonic inversion from tensile to compressive stress since India-Eurasia collision 50MaBP. Strike-slip faults trend NW or NE, the former are older of Gondwana time while the latter are generated after India-Eurasia collision. The compressive stress direction changes from NNW to N and then to NE direction from western to central part and then to eastern part of the Peninsula indicating rotational tendency of the Peninsula. Though majority of the shocks are shallower than 13 km and are associated with subterranean sounds, the focal depths of the order of 35 km are along the rifts and southern shear zones where the lower crust could be brittle due to under-plating, pillow lavas, mafic intrusion or dehydration. Around the hypocenter of the 2001 M7.7 Bhuj earthquake a high velocity and rigid mafic intrusive body has been inferred in a large zone. The Bhuj earthquake nucleated from a fluid filled zone at depths of 15-25 km. Low velocity zones are found at shallower depths of about 5 km in Koyna and Latur. As the faults are usually old and small the earthquakes of M>7 are not expected in Peninsular India except in Kachchh. Due to smaller rupture sizes the moment release is usually high. The aftershock sequences are usually long and exceptionally long in cases of a dozen reservoir triggered earthquakes.

Keywords: Catalog of earthquakes, Stable Continental Region, Seismicity of India, Tectonics

1. Introduction

Knowledge of seismicity and seismotectonics is required for assessment of earthquake hazard in the Stable Continental Region (SCR) of India where even moderate earthquakes seem to have higher hazard potential in larger areas due to dense population, non engineered structures and efficient transmission of wave energy. Such knowledge will go a long way in understanding earthquakes in other SCR regions where such earthquakes are less frequented. The paper describes the important aspects of seismicity and tectonics of SCR of India. For the purpose of this paper the area of India (5°-28°N, 68°-90°E) other than Himalaya and NE India is considered as the Peninsular India or Stable Continental Region of India. In this article a revised catalogue of earthquakes of magnitude ≥ 4 has been presented from 1341 to 2009 making use of all the available catalogues. The fault plane solutions published by us and others have been compiled giving inferences about stress map and area-wise current tectonics. The estimates of source parameters available for some earthquakes have also been reported. Earthquake hazard in areas of swarm type of seismicity in last four decades has been assessed.

2. Monitoring of Seismicity

The first seismological station in India was established in Calcutta (Alipur) on 1st September 1898. Bombay and Kodaikanal seismological observatories were started in 1898-99 with Milne seismographs soon after 1905 Kangra earthquake. It was shifted to Agra in 1929 and a Milne-Shaw seismograph was added. This observatory was shifted to Delhi in 1944. During 1930s Dehradun and Nizamia observatory, Hyderabad started functioning. The number of stations rose to 8 in 1950 and 15 in 1960, when more sensitive seismographs like Benioff, Sprengnether and Wood-Anderson were deployed. During 1960-63, Delhi, Poona, Shillong and Kodaikanal stations were equipped with sensitive and calibrated seismographs under the project of Worldwide Standardized Seismographs Network (WWSSN). An observatory with similar instruments was established at the National Geophysical Research Institute. Bhabha Atomic Research Center established a seismograph array at Gauribidanur. At present the national network has about 50 seismograph stations. Local networks have been established in several sites during 1980s. Ten stations of the India Meteorological Department have been revitalized with digital seismographs in 1997 and 10 others subsequently. With the present national network of about 50 stations earthquakes of magnitude 4 and above are well located, while in areas of intense seismicity, the location capability is M3 or less.

3. Earthquake Catalogs

The paper presents a catalog of about 350 earthquakes of magnitude ≥ 4 (intensity ≥V) from 1341 to 2015 for the stable continental region of India (Appendix - 1) and the seismotectonic inferences based on it. The catalog appears to be complete for M≥5 since 1826. Three earthquakes of Calcutta (1737, intensity X, 300000 deaths), Bombay (1618, intensity IX, 2000 deaths) and Mathura (1803, intensity IX) have been deleted as in the first two cases damage was due to cyclones and the epicenter for the third one was in Garhwal Himalaya. The catalog has been prepared making use of all the available catalogs. Oldham (1883) described significant Indian earthquakes from earliest time through1869. Kelkar (1968) brought to light a number of additional events in Maharashtra for 200-years period. Tandon and Srivastava (1974) published a catalog of earthquakes of magnitude 5 and above up to 1970. Using all these sources, Chandra (1977) compiled quite a reliable catalogue for earthquakes of intensity ≥ VI and magnitude ≥5 for the Indian Peninsula. Bapat et al. (1983) prepared the catalog of earthquakes for India and surrounding regions using the data from USGS catalog and other sources.

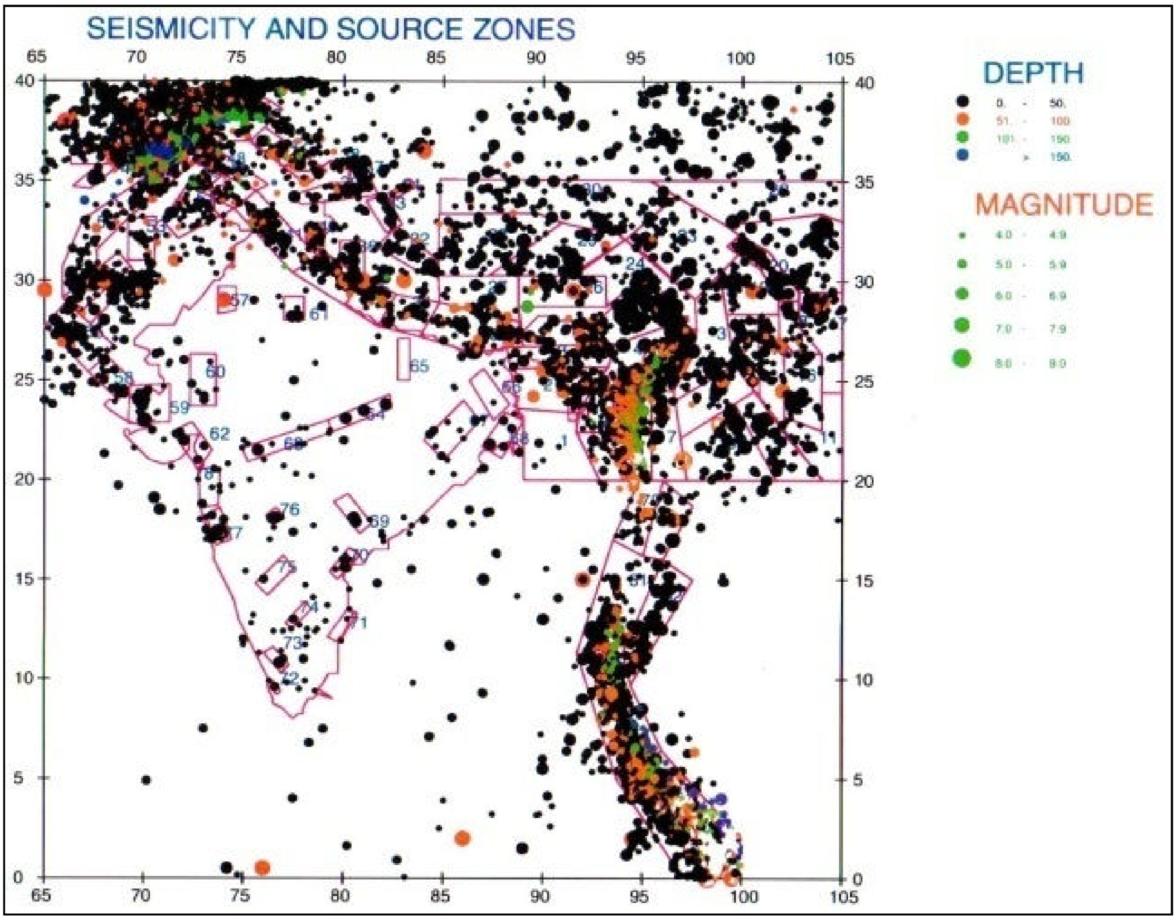

Fig.1. Epicenters of earthquakes of M ≥ 4 of intensity ≥ V in the Indian region from earliest time to 2015. As the epicenter of the 2004 Sumatra-Andaman earthquake of M9.3 is Sumatra, it is not shown here.

The USGS catalog has some omissions and wrong entries for the Indian region. In all these catalogs, earthquakes prior to 1800 and during 1869-1900 are hardly given. Srivastava and Ramachandran (1985) tried to fill this gap for the later period by scanning the newspapers. Malik et al. (1999) list historical earthquakes of Kachchh region. NGRI Seismological Observatory has prepared a catalog of all felt and recorded earthquakes in the Peninsula from earliest time to 1997. Martin and Szeliga (2010) have compiled and Szeliga et al. (2010) analyzed the intensities of about 500 earthquakes of India. For the earthquakes prior to 1960, instrumental determinations of magnitude are not generally available. In such cases, magnitude, M has been estimated from maximum intensity, I_0 by using the relation,

$$M= (2/3)\ I_0+1.$$

This formula gives a magnitude of 5 for intensity VI and a magnitude of 5.7 for intensity VII. Several earthquakes of magnitude 5 are observed to have caused intensity VI. Conversion of intensity VII to M5.7 appears to be reasonable as many such earthquakes like Bhadrachalam (1969, Mw 5.7) and Cachar (1984, M5.7) and some others were associated with intensity VII. Only a few earthquakes of M<5.7 are known to have given intensity VII, e.g. Mw 5.4 Broach (1970) and M 5.6 Nicobar Island (1982) earthquakes. Estimation of Mw from regression given by Johnston (1994) from isoseismal areas appears to be valid. For example, we estimate Mw 5.7 from the isoseismal V area (480 km x 300 km) for Bellary-Sholapur earthquake and Mw 6.2 for the Latur earthquake. Kaila and Sarkar (1978) have presented isoseismal maps for some of the Indian earthquakes. The intensity values for some earthquakes have been revised to lower values based on actual damage description.

It is now generally accepted that an earthquake catalog is homogenized with moment magnitudes (Johnston, 1994). The moment magnitudes have been taken from different sources and estimated by me from isoseismals for past large earthquakes as well as digital data for smaller recent earthquakes. For other earthquakes mb (or equivalent ML or the M estimated from intensity value is considered to be Mw as the following empirical relation derived by Jaiswal (2010) indicates only a minor average difference of < 0.1:

Mw = mb + 0.07
where, $R^2 = 0.78$for $4.8 \le mb \le 7.0$

For this study, data are taken from Harvard catalog from 1976 onward and for earlier period (1411 to 2005) from some publications that includes 19 earthquakes of mb 4.8 – 6.9 and Mw 5.0 – 7.6 for the period 1967 – 2005.

4. Seismicity of the SCR India

The SCR or Peninsular India has experienced at least two earthquakes of M≥7, seven earthquakes of M 6-6.9, some 125 earthquakes of M 5-5.9, and some215others of M 4-4.9. Moment magnitudes are determined /quoted for a dozen earthquakes. From this data the b-value for the Indian SCR is obtained to be 0.75. Instrumental focal depths are given for thirty earthquakes and assigned for 10 earthquakes. Though the majority of earthquakes have depths <13 km, depths of the order of 35 km are in Narmada-Son and southern shear zones. The foreshock-aftershock activity is pronounced for upper crustal earthquakes, but quite subdued for lower crustal earthquakes. Swarm activity areas of lengths > 10 km are identified as more potential areas for M≥6 earthquakes. Seven earthquakes of magnitude ≥6 in 74-years period during 1927 to 2001 give an average repeat time of 10 years for SCR of India (Table 1, Fig.2). However, such earthquakes may recur after thousands of years at an individual site. Earthquakes in the Kachchh region are infrequent but of high intensity giving a high moment release. Thus, Kachchh is most seismic. The other regions in order of decreasing moment release are western India, Narmada - Son belt and the Eastern Ghats belt including the southern mobile (shear) zone. The compression axis changes from NNW to N from western marginal area tocentral parts of India. It further changes to NNE direction in the eastern marginal area. This indicates the effect of counterclockwise rotational tendency.

Fig. 1 shows the epicenter of earthquakes of M≥4 in the Indian region from earliest time to 2015. The number of earthquakes of M≥5 indicates higher frequency during 1821 to 1880 and then again during 1951 to 2000 when great earthquakes in Himalaya were absent. Peaks are observed around 1860 and 1960. Seismicity in Peninsula was low during the periods when Himalaya had great earthquakes (Rastogi and Sharma, 2013, 2016).

Until recently, the Peninsular India was described as a stable shield and region of only slight seismicity. Except the Kachchh earthquake of 1819 of magnitude 7.8, which caused 2000 deaths, no other earthquake in the Peninsular India caused deaths until 1950s. Yet during the decade of 1960's and in early 1970's a number of strong damaging earthquakes occurred. The Koyna earthquake of December 10, 1967 caused 177 deaths and the Broach earthquake of March 23, 1970 took a toll 26 lives. In the 1990's, the Latur earthquake of 1993 caused 7610 deaths and Jabalpur earthquake of 1997 caused 39 deaths. The 2001 Bhuj earthquake caused 14,000 human deaths. These earthquakes have changed the long –held belief of the slight seismicity of the Peninsular India.

5. Tectonics of the Peninsular India

The deep faults in India taken from the 1968 Tectonic Map of India prepared by Oil and Natural gas commission of India and modified after Reddy et al. (1988) are shown in Fig. 2. For most of these faults the deep seismic sounding studies (Kaila, 1982) confirm the depths of 35 km or more. Valdiya (1973) and Powar (1981) described additional tectonic features. The important features are described here.

The major tectonics of Indian SCR consists of faulted Proterozoic (younger Precambrian viz. Aravali belt, Cuddapah basin and Narmada rift on the Archean basement of granites, gneisses and schists followed by formation of NW-SE trending Godavari and Mahanadi Grabens in Paleozoic times. Kachchh and Cambay rifts formed during Mesozoic. The Deccan basaltic lava erupted during late Cretaceous-early Tertiary period (65 Ma) has covered most of the western part of the Peninsular India. Continent-continent collision took place during Eocene (50 Ma). Major tectonic activity had ceased in Tertiary times, expect for minor movements. The northward movement of the Indian plate and the continued convergence process along the Himalaya has transmitted large northerly compression in the Indian Peninsula, causing NE-SW oriented faults. As stated above, the other tectonic features like ENE-WSW trending Narmada-son graben and NW-SE trending Godavari and Mahanadi Grabens are older. Sometimes the NW-SE faults have been displaced by the younger NE-SW faults. Present day tectonics as indicated by seismicity study shows preponderance of strike-slip faulting either along the NE-SW or NW-SE trending faults by reactivation or reverse faulting due to upliftment of tectonic blocks. Normal faults along Narmada, Godavari and Koyna rifts are also reactivated occasionally. However, faults in the Peninsular India are small and so only moderate earthquakes have occurred except in Kachchh. Many of the faults in SCR are down to ~ 35km depth as confirmed by deep seismic sounding and gravity surveys (Kaila, 1982; Mishra, 2011). Kachchh rift was formed during Mesozoic.

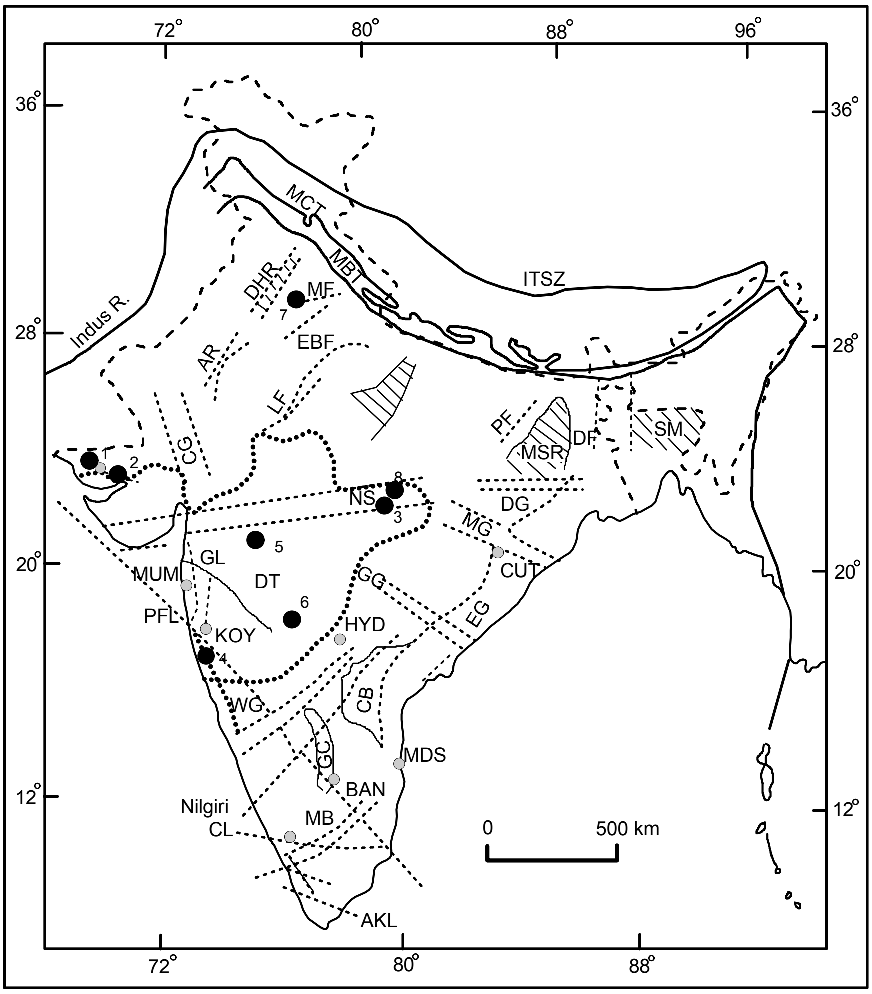

Fig.2. Simplified tectonic map of India based on the Tectonic Map of India prepared by ONGC in 1986. Locations of M≥6 earthquakes are also shown, most of which are in the areas of past volcanism. Location no. 9 for the 2001 Bhuj earthquakeis nearly same as that of no.2. Deccan Trap (DT) boundary is shown by dotted line. ISZ = Indus Suture Zone, MCT = Main Central Trust, MBT = Main Boundary Thrust, CG = Cambay Graben, DHR = Delhi-Hardwar Ridge, MF = Moradabad Fault, EBF = Etah-Budaun Fault, LF = Lucknow Fault, FR = Faizabad Ridge, PF = Patna Fault, MSR = Monghyr-Saharsa Ridge, DF = Dhubri Fault, SM = Shillong Massif, NS = Narmada-Son rift, MG = Mahanadi Graben, GG = Godavari Graben, EG = Eastern Ghat Belt, CB = Cuddapah Basin, CG = Closepet Granite, CL = Cauvery Lineament, AKL = Achankovil Lineament.

Kachchh, Western India- The landscape of Kachchh can be divided into four major E-W trending geomorphic zones. From south to north they are: (a) the coastal zone on the Gulf of Kachchh, (b) the rocky Kachchh mainland (mostly Mesozoic rocks), (c) the raised mud flats comprising the Banni Plains, and (d) the vast saline wasteland comprising the Great Rann in the north and the Little Rann in the east. Mesozoic rocks occupy the uplifted Pachcham, Khadir and Bela islands. The Banni Plains and the Rann occupy the lowlands. The structural features in the Kachchh Rift Block (KRB) have been described by Biswas (1987) and Malik et al. (1999). They appear as East-West trending active fold and thrust belts. The KRB is bounded to the north by the Nagar Parkar fault and to the south by North Kathiawar fault (Biswas, 1987 and GSI, 2000). The Kachchh Mainland is bordered by a fault in the north. On the mainland, along the Katrol Hill Range lie the Katrol Hill fault and its northwest continuation, the Vigodi fault.

Within the KRB, in the north, the major E-W trending faults are the Allah Bund and Island Belt faults. Both these faults lie in the Great Rann. Banni fault is in the Banni Plains and is associated with the Banni uplift. Separating the Banni Plain from the Hill Range of the Kachchh mainland is the Kachchh Mainland fault. The Wagad fault is an en-echelon fault and is a step-over continuation of the Kachchh Mainland fault.

The area signifies E-W trending failed rift. The Kachchh rift basin was formed in early Jurassic and has been associated with great earthquakes of Mw 7.8 in 1819 and Mw 7.6 in 2001, which are some of the rare intracontinental great earthquakes. There was one more significant earthquake of Mw 6.0 at Anjar in 1956. Earthquakes in the Kachchh region are relatively infrequent but of very high intensity making the region to be of maximum moment release in the Indian Peninsula. After the continent-continent collision, the preexisting normal faults were reactivated as strike-slip faults and now as reverse faults. The 2001 Bhuj earthquake occurred along a reverse fault at a depth of 23km with upliftment of southern side in an area north of Kachchh Mainland Fault. About 14,000 people were killed due to this earthquake. The maximum damage is seen at Bhachau in a NE-SW trending area of 40 km x 20 km. Around the hypocenter a high velocity and rigid mafic intrusive body has been inferred in a large zone which accumulates high stress / strain. The Bhuj earthquake nucleated from a fluid filled zone at depths of 15-25 km (Mandal et al. 2004). Kachchh region has significant horizontal deformation that can cause earthquakes. However, there is unusually high uplift up to 2cm/y as revealed by GPS and DInSAR data (Rastogi et al., 2012, 2014).

The Bhuj earthquake sequence has continued for over 15 yr. It had twenty-one M ≥ 5 earthquakes along different faults in the area (Appendix-2). Some of these which are definitely mainshocks along different faults are included in Appendix 1. As some other faults are close to the cauasative faults, many others may be mainshocks and not the aftershocks. There were 272 shocks of M 4 to 4.9, only a few of which are definitely main shocks and are listed in Appendix -1.

West Coast-Western Ghats Region-A system of NNW trending faults is believed to exist under the Deccan traps along the west coast and Western Ghats. Some 28 small to moderate earthquakes have occurred in the last century in the area between the latitudes of 16^{o} to 22^{o} N, not counting the Koyna earthquakes. The West Coast of India represents a fault scarp of probable Pliocene age. This fault is characterized by a strong positive Bouguer anomaly with a steep gradient. Some major tectonic structures are as follows:

1. Western Ghats: The Sahyadri Mountains along the west coast form the Western Ghats which joins the Eastern Ghats near Nilgiris in the south. The crest of the Western Ghats forms the continental divide which may be a major fault with about 1 km steep, west facing basalt escarpment only 50 km from the coast. NNE-SSW and NW-SE trending faults have also been inferred in the Koyna area. Significant earthquakes in Western Ghats are: (i) Mahabaleshwar earthquake of August 1764 of Intensity VII and (ii) Koyna earthquake of December 10, 1967, of Mw 6.3 and Intensity VII in which 177 people were killed. The Koyna sequence has continued for over 50 yr. It has been argued that all of eighteen M ≥ 5 earthquakes have occurred along different faults in the area. Hence, such earthquakes are included in Appendix 1 and also listed separately in Appendix 3. Some of the M 4 to 4.9 shocks which are not aftershocks are listed in Appendix - 1. Some others may also not be aftershocks, hence some 186 such shocks are listed in Appendix 4.
2. N-S trending Panvel Flexure (18^{o} -20^{o} N) on the western side of which the Deccan Traps show steeper dips.
3. Cambay Graben: The N-S trending Cambay graben near to west coast is approximately 200 km long and 50-60 km wide. The Narmada fault trending ENE-WSW terminates the graben at its southern margin. It is bounded by nearly N-S trending deep discontinuous normal faults. Some 5 km of Tertiary sediments were deposited over the Deccan traps. There are a number of transverse faults striking E-W and ENE-WSW, which have divided the graben into blocks. Bombay-Surat earthquake of December 25, 1856 of intensity VII might have occurred in the region.

Narmada-Son Lineament- The Narmada-Son Lineament (NSL) divides the Indian Peninsular shield into the northern and southern blocks. It is the most active Paleozoic zone in India and evolved during the Archaean and Proterozoic periods as well as with magmatism of Cretaceous age. The episodic reactivation of the NSL is evidenced by the presence of varied rock formations ranging in age from late Archaean to early Proterozoic. Two prominent deep faults, termed the Narmada South and Narmada North faults (NSF and NNF), with EEW-WSW strike have been mapped extensively in the region (Acharya et al., 1997). The presence of these faults has also been reported on the basis of deep seismic sounding (Kaila et al., 1987) which have been carried out across the NSL. No major activity along the NNF seems to have taken place since the Vidhyan reactivation in the Meso-Proterozoic period. In contrast, the NSF has witnessed reactivation since Quaternary. Earthquakes with magnitude greater than six have occurred in the NSL zone in the past (Gupta et al. 1997) and most of them are considered to be associated with NSF.

Eastern Ghats-The NE-SW trending Eastern Ghats belt forms the largest Precambrian mountain range having its extension from Nilgiri to Cuttack. The belt consists mostly of Charnockites and Khondalites. The trend follows the outline of the Cuddapah Basin to its east. This range was evolved during Eastern Ghat Orogeny, which closed around 1600 Ma. The old faults get activated in response to present day stress field.

Ongole- This prominent seismic zone in the Eastern Ghats belt trends NE-SW and small earthquakes are frequent. March 27, 1967 earthquake was of magnitude 5.4.

Godavari, Mahanadi and Damodar valley grabens- The NW-SE trending Godavari and Mahanadi grabens as well as Damodargraben were formed during Upper Paleozoic to Mesozoic time, when the Indian Peninsula experienced tensions resulting in fracturing and faulting in the earth's crust leading to the formation of rifts and grabens (Fig. 2). These grabens were filled with Gondwana sediments. Mw 5.7 Bhadrachalam earthquake of April 13, 1969 occurred along the Godavari graben.

Southern Shear Zone- About 25 earthquakes of M≥4 occurring since 1828 in Karnataka Plateau were associated with eight major lineaments which are active faults as depictedby topographical peculiarities developed in recent time like: (i) Massifs (Anamalai-Elaimalai and Nilgiri massifs) and linear hillocks which are remnants of uplifted ridges, (ii) Anomalous deflections and ponding of the rivers and the streams, and (iii) The existence of the zones of shearing (Valdiya, 2010).

Moyar-Bhawani Shear Zone- Trending nearly east west (Fig. 2), it separates the Peninsular Gneisses & Granites from the high – grade metamorphosed terrain of Charnockite-Khondalite (granulites) in the south.

Achankovil Lineament- It trends in NW-SE direction and is considered to be a contact between two lithospheric blocks.

6. Depth of Earthquakes

In Peninsula, majority shocks are shallower than 13 km (Table 1) with subterranean sounds. Shocks of focal depths <10 km are associated with blast sound, while those of > 10 km are associated with rumbling sound. Local stress or strain accumulation at less than 10 km is visualized due to low velocity layers in some areas like Koyna and Latur. If foreshocks have focal depth < 3 km, mainshocks are of M<4 and if foreshocks have focal depth ≥ 4 km, mainshocks are larger. Focal depths as deep as 36 km are along the rifts and southern shear zones where the lower crust could be brittle due to under-plating, pillow lavas, mafic intrusion or dehydration and higher temperature (Mandal and Pandey, 2010). Strain accumulation is within or around such anomalous zones like high density intrusive.

7. Isoseismals

Isoseismals for several earthquakes prepared from damage surveys and media reports are shown in Fig. 3. Although isoseismal trend depends on ground condition and earthquake source directivity, most isoseismals trend in fault direction. The higher isoseismals, namely VI–VIII for the Latur earthquake (18◦N, 76.5◦20 E) and VIII–X for the Bhuj earthquake (not shown in the figure) (23.326◦E, 70.317◦21 E), trend NE–SW, i.e., perpendicular to the strike of the causative reverse faults may be due to source directivity.

8. Fault Plane Solutions and Moment Release

Present day tectonics (inferred from 17 fault-plane solutions) shows preponderance of strikes-slip faulting along NE-SW faults or reverse faulting due to uplift of tectonic blocks. Reverse faulting is observed along the failed rifts of Kachchh and Narmada – Son indicating a change

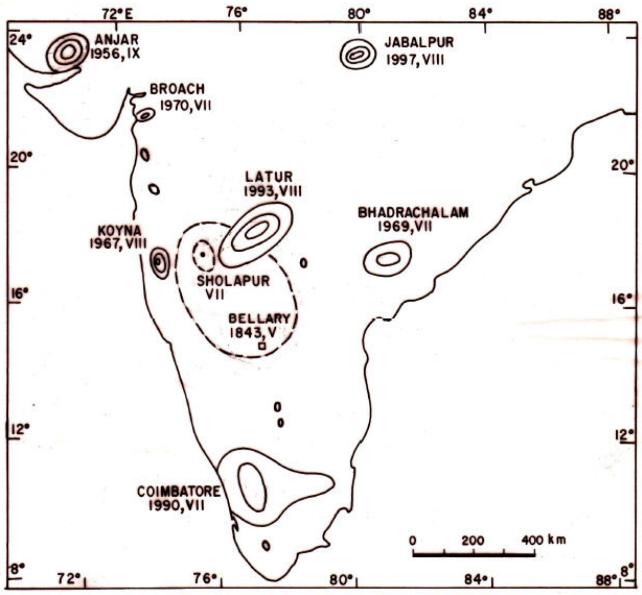

Fig. 3. Isoseismals VI and higher for some earthquakes. Isoseismal VI is only shown as small ellipse for Valsad, Dhamni, Hyderabad, Bangalore, and Tirupattur earthquakes proceeding from north to south. Isoseismals VI and VII are shown for Koyna, Bhadrachalam, Bellary, and Coimbatore earthquakes. Isoseismals VI, VII, and VIII are shown for Anjar, Jabalpur, and Latur earthquakes. Trends of isoeismals X, IX, and VIII for Bhuj earthquake are similar to those for Anjar earthquake. However, isoseismals VII and VI are aligned N–S.

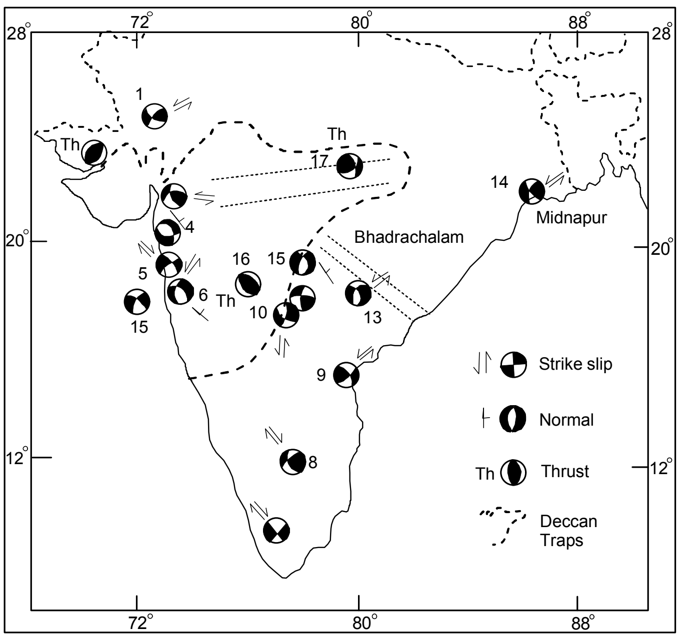

Fig. 4: Fault-plane solutions in Indian SCR. 1. Mount Abu, 2.Anjar, 3.Broach, 4.Valsad, 5. Bhatsa, 6. Koyna 1967, 7.Koyna 1980, 8.Idukki, 9.Banglore, 10.Ongole, 11.Osmansagar, 12.Hyderabad, 13.Sriramsagar, 14.Bhadrachalam, 15.Midnapur, 16.Jabalpur, 17.Latur.

Table 1. Depth of Earthquakes in the Peninsula

Area	Year	Depth(km)	Magnitude	REF
Instrumental Estimates:				
Koyna	1967	4.5	6.3	LAN
Bhadrachalam	1969	10.0	5.7	GUP
Broach	1970	11.0	5.4	CHU
Osmansagar	1982	2.0	3.5	RAS
Bhatsa	1983	5.0	4.9	RAS
Valsad	1986	7.0	4.6	RAS
Idukki	1988	5.0	4.5	RAS
Latur	1993	2.8	6.1	SEE
Koyna	1993	8.4	5.0	RAS
Koyna	1994	10.6	5.4	RAS
Surya	1994	1.5	3.8	RAS
Jabalpur	1997	35.0	5.8	IMD
Assigned Depth:				
Kutch	1819	0-30	7.8	AJ
Anjar	1956	13-18	6.5	TAN
		15.0		C-G
Hyderabad	1983	13.0	4.5	RAS
Sriramsagar	1984	2.0	3.2	RAS
Banglore	1984	12.0	4.6	RAS
Tirupattur	1984	3.0	4.5	RAS

Note: Bellary (1843), Coimbatore (1900), Son Valley (1927) and Satpura (1938) earthquake are likely to be of focal depth around 35 km.

LAN= Langston (1976), RAS= Rastogi (1992), SEE= Seeber (1996), C-G= Chung and Gao (1995), CHU= Chung (1993), AJ= Johnston (1994).

of past tensional regime to current compression. There is no evidence of new faults being created in the Peninsula and these being small, only moderate earthquakes have occurred except in Kachchh.

I have worked out fault-plane solutions (FPS) for Hyderabad (1983, M4.5), Bangalore (1984, M4.6) and Koyna (1980) earthquakes and Composite FPS for five other earthquakes (Rastogi, 1991, 1992). Chandra (1977) worked out FPS for six earthquakes, which occurred at Mt. Abu, Koyna, Ongole, Bhadrachalam and Midnapore. Chung and Gao (1997) determined FPS for Bhadrachalam and Broach earthquakes and Chung (1995) for the Anjar earthquake. Gupta et al. (1998) determined FPS for the Latur earthquake and USGS for the Jabalpur earthquake. The nature of faulting indicated by these fault-plane solutions (Fig. 4, Table 2)) is as follows:
The Midnapore, 1960, Ongole, 1967 and Bhadrachalam, 1969 earthquakes indicate left-lateral slip along NE striking faults in East Coast area. The Mt. Abu, 1969 earthquake at 15 km depth indicates left-lateral slip along an E-W trending fault in the Aravali.

Large earthquakes are associated with reverse faulting along nearly E-W planes in Kachchh, Narmada rift and elsewhere due to tectonic inversion from tensile to compressive stress in last 10Ma. Most of the areas show compressive stress. There is tensional stress at some areas eg. north & south of Koyna which has compressive stress. Most of the areas show strike-slip faulting along NE or NW faults. NE faults: Younger, generated after India-Eurasia plate collision. NW faults: Older (Mesozoic time or so).Horizontal strain rate is low ≈ 10^{-9} with 2mm/yr deformation estimated from GPS in the Peninsular India. Hence, there has to be vertical strain as small shocks are occurring almost everywhere indicating that the region is critically stressed. Western India is rising as indicated by 1-2 km higher elevation as compared to eastern part and neotectonic uplift. In fact, the vertical strain is indicated to be high by new GPS and InSAR results in Kachchh (Rastogi et al., 2012). Continuing push of the northward moving Indian Plate causes popping up of the deeper part of the crust and reactivates the faults, giving rise to earthquakes periodically.

Normal faulting deduced for Valsad 1986 earthquake south of Tapti and Koyna 1980 earthquake indicates reactivation of normal faults. The Koyna earthquake of 1967 indicated left-lateral slip along a NNE-SSW trending fault. Bhatsa 1983 earthquake, which occurred about 200 km north of Koyna and is related to West Coast tectonics, showed right-lateral slip along a NW-SE trending fault.

Idukki earthquake of 1988 indicates right-lateral slip parallel to the NW-SE trending Achankovil lineament. The Bangalore earthquake of 1984 showed right-lateral slip along a NW-SE trending shear. Osmansagar earthquake of 1982 and Hyderabad earthquake of 1983 indicate slip along N-S or E-W lineaments. In the Narmada Son belt, the Broach earthquake of 1970 indicated reverse faulting along an E-W trending fault while the Jabalpur earthquake of 1997 and Anjar earthquake of 1956 indicated reverse faulting along NE-SW trending faults. The compressive stress direction for different earthquakes obtained from the fault plane solutions is trending nearly north.

The source parameters like fault dimension, stress drop, seismic moments etc. worked out for some of the earthquakes by us and other workers are listed in Table 3. Area wise moment release is given in Table 4. Due to the large Mw7.8 earthquake of 1819 and Mw 7.6 earthquake of 2001, the moment release is quite high (10^{28} dyn.cm) in the Kachchh region. In other regions it ranges from $8.3x10^{25}$ to $1.6x10^{25}$ dyn.cm which in order of decreasing moment release are Narmada Rift, West coast region, East coast Region, central part of the peninsula and Aravali Ridge.

9. Earthquake Swarms

Foreshock swarms as in Koyna, Latur and other places (Fig.4) precede many large earthquakes in peninsular India. The epicenters during such swarms were located in stretches of over 10 km. For smaller mainshocks the foreshocks are in areas of dimensions less than 10 km in length. In the Koyna area, foreshocks started in 1962 and the main earthquake occurred in 1967 while in Latur the foreshock swarm occurred during October 1992 to February 1993 and the main earthquake occurred in September 1993. The areas where swarm types of earthquakes have occurred in recent years (Rastogi 2010) are shown in Fig.4 and some such swarms are described below:

Valsad area in southern Gujarat (20.56° N 73.39° E) has been experiencing earthquakes of magnitude up to 4.6 from 1986 in a stretch of 60 km extent. The Tirupattur area in Tamilnadu (12.47°N 78.60°E) had experienced a swarm in 1984 and some earthquakes after that in an area of extent exceeding 10 km. Other areas of swarm activities have been Khandwa (1993) in Madhya Pradesh (21.67°N 76.20°E) and Kalwan near Nasik (20.5°N, 74.0°E) in Maharashtra (1995) and Darsi-Ongole area in Andhra Pradesh (15.60°N, 80.10°E).

10. Discussions

The SCR of India is under stress as revealed by the prevalent earthquakes. The N-S compression found from the fault-plane solutions indicates that this stress is mainly due to collision of Indian and Eurasian plates. Isostatic imbalance due to erosion may add up to the ambient stress. Along some faults, additional stresses may be caused by topographic differences, lateral density inhomogeneities (due to under plating or pillow lavas in rift zones or low-velocity layers) or fault geometry like existence of conjugate faults or kinks.

A 200 km thick lithosphere with 4-7% higher Sn velocity was inferred beneath north India from Himalaya to Narmada, Godavari and Mahanadi rifts area by Pn and Sn Path anomalies observed from reference event method (Fig. 6 from the presentation of *Engdahl et al., 2003*). Data considered was aftershocks well-located by clusters of stations in Bhuj and Koyna areas in western India and Chamoli in Himalaya which were considered as reference events. Travel-time errors of these shocks were noted at Indian network stations to estimate the path anomalies. Sn was observed to be earlier by 2 to 12 s. The high strength lithosphere in north India could act as a strain concentrator.

The present mode of deformation is predominantly strike slip. The past areas of tension at Kachchh and Narmada-Son are showing compression and thrust faulting. From fault plane solutions the compressive stress direction is obtained to be broadly trending in north direction. However, for some earthquakes in the western marginal area it trends in NNW direction. In the central parts it trends to north. It further changes to NNE direction for some earthquakes in the eastern half of the peninsula. This indicates the effect of counter clockwise rotational tendency.

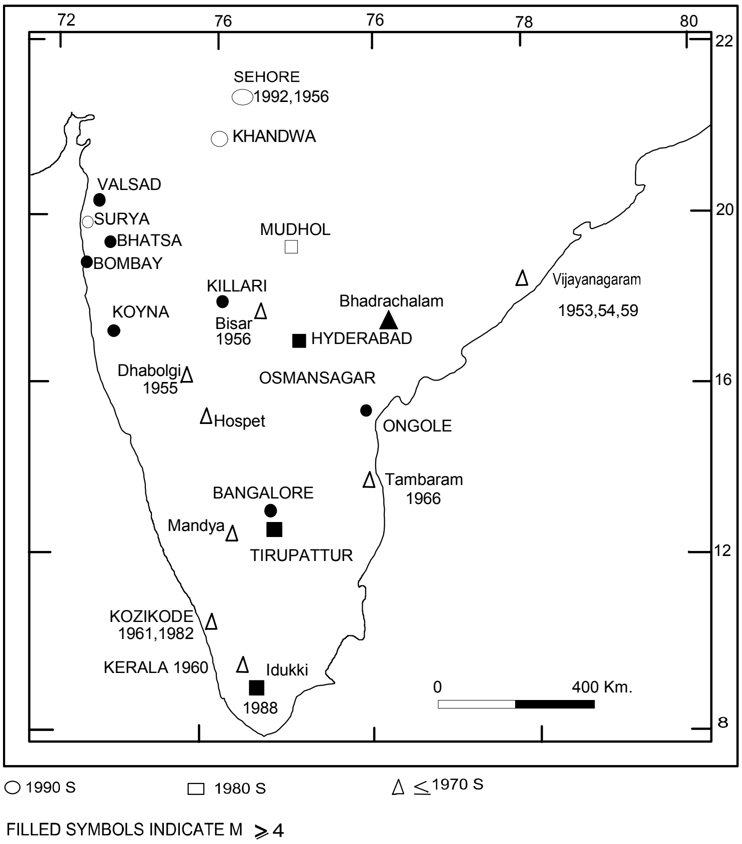

Fig. 5. Locations of swarm-type activities in recent times.

Most earthquakes occur along pre-existing faults. At Latur, drilling through the causative fault of 1993 M 6.2 earthquake indicated that it is an old fault with 6m Cumulative slip (Gupta et al., 1998). As the rocks are old, faults are short and strain rates are low, only the moderate earthquakes are experienced in Peninsular India as in other SCR regions in general. There are some exceptions like Kachchh and New Madrid regions where high strain rates cause major and great earthquakes. Because of shallow focal depths, large population and non-engineered structures even the moderate earthquakes in the Indian SCR are destructive. Though a large earthquake (of M≥6.0) may not recur at an individual site for thousands of year, it may hit anywhere in the Peninsula at an interval of about 10 years.

Most of the earthquakes are associated with a long aftershock sequence. Foreshocks also occur for upper crustal earthquakes (e.g. Koyna, Bhadrachalam, Broach and Latur) but not for lower crustal earthquakes (e.g. Jabalpur, Bellary, Coimbatore, Son, Satpura and Bhuj). It has been noticed that if foreshocks have occurred in stretches longer than 10 km, large earthquakes of M > 6 have followed and never otherwise.

In terms of moment release, the Kachchh region is outstanding because of the Mw 7.8 earthquake of 1819 and Mw 7.7 earthquake of 2001. These earthquakes have given large moment release of over 10^{28}dyn.cm. The other areas have moment release of 10^{25}-10^{26}dyn.cm. In order of decreasing severity these regions are Narmada-Son rift, West coast and East coast, Central Peninsula, and Aravali ridge.

Table 2. Fault plane solutions of SCR India
(S: Strike-slip, N: Normal, T: Thrust type of fault-plane solution)

Earthquake Location	NP1		NP2		P-axis		T-axis		
	DIP		DIP						
	AZ	DIR.	AZ	DIR	AZ	PLG	AZ	PLG	Type
1. Mt. Abu	128	54 218	68	55 338	8	0	98	55	S
2. Anjar	235	47 NW	62	43 SE	329	3	93	85	T
3. Broach	273	58 N	35	49 SE	336	5	239	57	T
4. *Valsad	278	54 S	310	40 NE	312	73	201	7	N
5. *Bhatsa	314	60 NE	44	90 SE	175	20	274	20	S
6. Kyona 1967	26	78 296	296	90 26	160	6	67	30	S
7. Kyona 1980	318	50 NE	328	40 SW	188	82	53	6	N
8. *Idukki	310	90 NW	40	90 SW	355	0	85	0	S
9. Banglore	332	60 SW	62	90NW	15	17	111	18	S
10. Ongole	47	90 317	137	71 47	180	13	274	13	S
11. *Osmansagar	22	90 NW	112	80 SW	337	8	67	8	S
12. Hyderabad	4	70 W	94	90 S	48	15	142	15	S
13. *Sriramsagar	315	46 NE	6	56 W	152	62	253	5	N
14. Bhadrachalam	57	70 327	150	82 60	195	20	102	9	S
15. Midnapur	111	72 201	52	32 322	181	22	55	55	S
16. Jabalpur	307	33 NE	71	70SSE	164	23	310	62	T
17. Latur	112	42 NE	292	48 SW	22	3	202	87	T

Table 3. Source Parameters of Some of the Earthquakes in the Stable Continental Region of India

Year	Earthquake location	MO ×10*25	Mw dyn.cm	D (km)	L (km)	W (km)	SD MPa	Dur.(s)	U(m)	Acc.(g)
1819	Kachchh	500.00	7.8	0-15	140	30			5	
1900	Coimbatore		5.8							
1927	Son		6.4							
1938	Khandwa		6.3							
1956	Anjar	1.00	6.0	15	90		16.2	2.2	7	
1956	Khurja		6.1							
1967	Koyna	8.20	6.3	4.5	18	12	4.7		1.1	0.6
1969	Bhadrachalam	0.46	5.7	10			1.7			
1970	Broach	0.14	5.4	11			0.9			
1993	Latur	1.90	6.1	2.8	5.5	7	7		1.7	0.3
1997	Jabalpur	0.54	5.8	35	6.4		6.8	3.8	0.4	0.2
2001	Bhuj	290.00	7.6	25	70	36	16	20.0	8.5	0.7

Note: Mo= Seismic Moment in dyn cm, Mw= Moment magnitude, D= Depth, L= Fault Length, W= Fault Width, SD= Stress Drop, Dur.= Source Duration, U= Slip, Acc.= Acceleration.

Table 4. Region-wise moment release in SCR India

Kutch		Narmada		West Coast		East Coast		Interior		Aravalli	
Mw	Mo	Mw	Mo	Mw	Mo	Mw	Mo	Mw	Mo	Mw	Mo
7.8	5.6×10^{27}	6.4	4.4×10^{25}	6.3	3.1×10^{25}	5.7	4.6×10^{24}	6.1	1.6×10^{25}	6.1	1.6×10^{25}
6.5	6.3×10^{25}	6.3	3.1×10^{25}	5.8	5.6×10^{24}	5.5×9	17.1×10^{24}	5.5	1.9×10^{24}	5.5	1.9×10^{24}
5.5×2	3.8×10^{24}	5.8	5.6×10^{24}	5.7	3.9×10^{24}	5.4	1.4×10^{24}	5.0×2	7×10^{25}	5.3	1×10^{24}
		5.5	1.9×10^{24}	5.6×3	8.4×10^{24}	5.3×2	2×10^{24}				
		5.0	3.5×10^{23}	5.5×8	15.2×10^{24}	5.2×2	14×10^{23}				
				5.4×4	5.6×10^{24}	5.0×16	56×10^{23}				
				5.3	1.0×10^{24}						
				5.2	7.0×10^{23}						
				5.1	5.0×10^{23}						
				5.0×17	59.5×10^{23}						
Total:	5.6×10^{27}		8.3×10^{25}		7×10^{25}		3.1×10^{25}		1.6×10^{25}		1.6×10^{25}

Note: Mw=2/3 logMo-10.7; Type of faulting, T=thrust, S=strike slip, N=normal, *Composite fault-plane solutions.

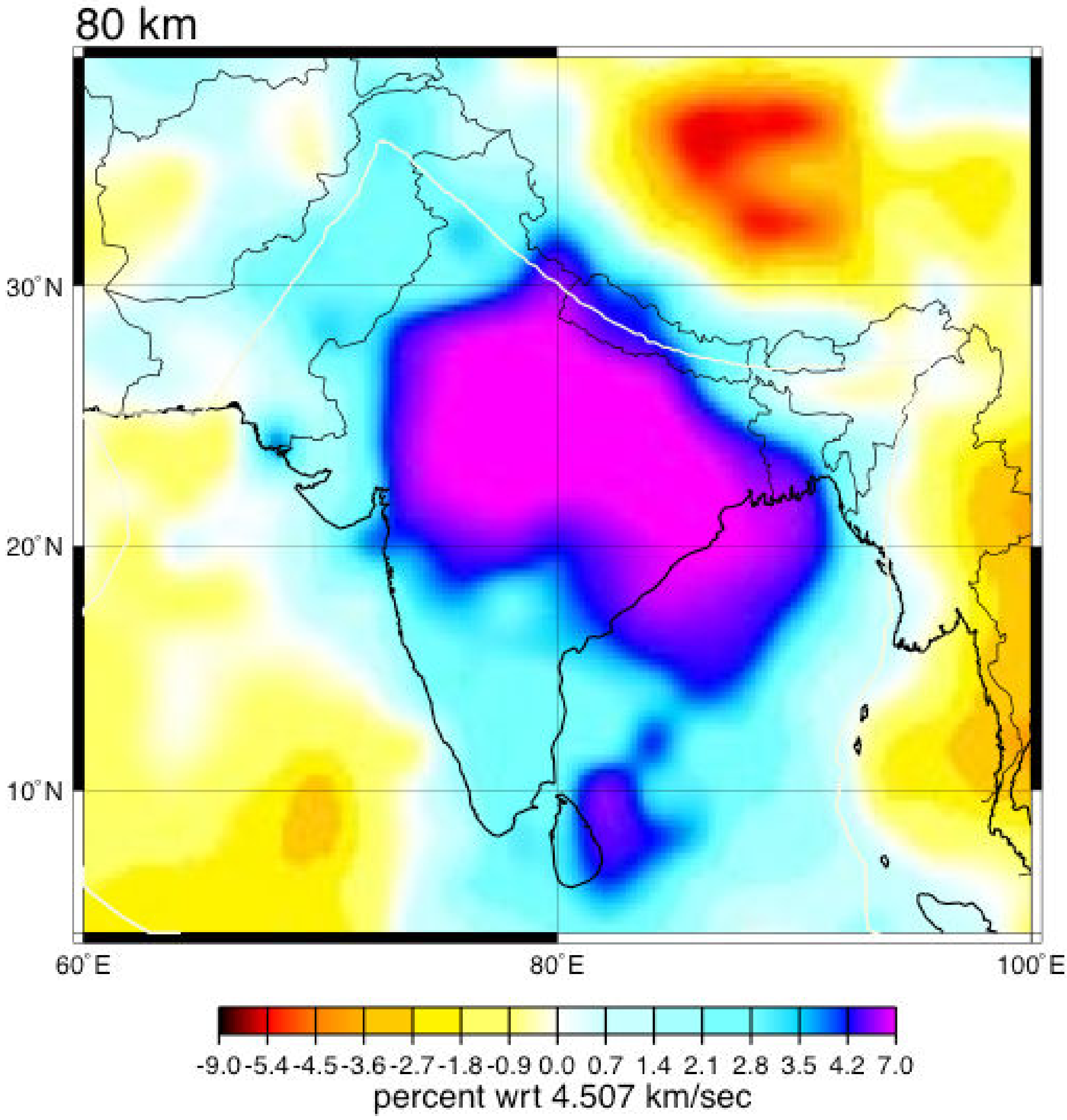

Fig. 6. A 200 km thick lithosphere with 4-7% higher Sn inferred beneath north India from Himalaya to Narmada, Godavari and Mahanadi rifts area by Pn and Sn Path Anomalies as observed by reference event method (from presentation of *Engdahl et al., 2003*)

11. Concluding Remarks

The catalogue of earthquakes of M≥4 has been revised by including up to date data from various sources. The Peninsular India has experienced 2 earthquakes of magnitude 7-7.9, 7 earthquakes of magnitude 6-6.9 and 125 earthquakes of magnitude 5-5.9 (intensity VI-VII). About 215 earthquakes of M 4-4.9 or strongly felt are included in this catalog. Seven earthquakes of magnitude ≥ 6 in 74 years (1927-2001) give a repeat time of about 10 years for the entire Peninsula. However, such earthquakes may recur after thousands of years at an individual site. The areas of seismicity in order of decreasing severity are Kachchh, Narmada – Son zone, West-coast region, and, Eastern Ghats belt.

In Peninsular India, mostly smaller faults at shallow depths are reactivated due to N-S plate tectonic stress. The possibility of any major earthquake, except in the Kachchh area, is less. However, earthquake hazard in SCR of India is increasing rapidly due to increasing population and non-engineered structures as evidenced by about 10,000 human deaths due to 1993 Latur earthquake and 14,000 for 2001 Bhuj earthquake.

Stress in Peninsula is due to plate tectonics, backlash of northward push and isostatic buoyancy. Continuing push of the northward moving Indian Plate causes popping up of the deeper part of the crust and reactivates the faults, giving rise to earthquakes periodically. The pre-existing faults are reactivated due to strain accumulation and / or fault weakening. Local concentration may be due to topography and density contrast like under-plating, high density mafic intrusives, high density upper mantle, pillow lavas at deeper crust, low velocity layers at shallow depths and fault kinks or conjugate faults.

Horizontal strain rate is low ≈ 10^{-9} as estimated from only 2mm/yr deformation estimated from GPS measurements across SCR, India. As small shocks are occurring almost everywhere the region is likely to be critically stressed.Hence, there may be vertical strain as indicated by evidences of neotectonic uplift in the south and high vertical deformation rate inferred from new GPS and InSAR measurements in Kachchh.

Acknowledgement
Some portions of the text have been reproduced from Rastogi (2010) for easy accessibility.

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Appendix – 1

List of SCR India earthquakes of M≥4 or strongly felt

D M Y	TIME GMT	LAT ° N	LONG ° E	AREA	INT	MAG	REF
1341		12.5	75	Malabar Coast	VI	5.7	BAL
1594		19.1	73.2	Mahim, Vasai	IV		KEL
09 12 1678		19.1	73.2	Vasai &Agashi	VI	5	KEL
1684		21.2	72.9	Surat			OLD
1702		19.7	73.1	Nr Bhima R.	IV		KEL
09 12 1751		19.1	73.2	Vasai	VI		KEL
05 02 1752		18.7	73.4	Lohagarh	V		KEL
31 10 1757		18.2	74.2	Toke and Dhom	V		KEL
1760		18.5	73.9	Poona	IV		KEL
13 07 1762		22.6	88.4	Calcutta	V		OLD
04 06 1764		24	88	Banks of Ganga	VIII	6.3	OLD
08 1764		17.9	73.7	Mahabaleshwar	VII	5.7	KEL
29 05 1792		18.5	73	Revadanda	V		KEL
19 10 1800	22:40	15.6	80.1	Ongole	VI	5	OLD
10 12 1807		13.1	80.3	Madras	VI		OLD
13 04 1808		22.6	88.4	Calcutta	V		OLD
04 06 1808		25.5	80.3	Banda	V		OLD
01 04 1810		22.6	88.4	Calcutta	IV		OLD
13 05 1810		22.6	88.4	Calcutta	V		OLD
01 02 1811	8:50	22.6	88.4	Calcutta	VI	5	OLD
23 02 1812		18.5	73.9	Poona	IV		KEL
11 07 1816		22.6	88.4	Calcutta	IV		OLD
08 1816		13.1	80.3	Madras	V		OLD
16 09 1816	22:30	13.1	80.3	Madras	VI	5	OLD
16 06 1819	1:15	23.6	69.6	Kutch	XI	7.8M	OLD
20 06 1819		12	79.6	Pondichery	V		OLD
27 01 1820		23.2	69.9	Bhuj	V		OLD
13 11 1820		23.2	69.9	Bhuj	IV		OLD
31 12 1820		14.5	80	Nellore	V		OLD
10 01 1821		9.5	76.6	Travancore	IV		OLD
13 08 1821		22.7	72.7	Kaira, Damaun	V		OLD
29 01 1822	7:30	12.5	79.7	Madras	VI	5	OLD
16 08 1822		22.6	88.4	Calcutta	VI		OLD
02 03 1823		13	80	Madras	VI	5	OLD
03 04 1823		22.6	88.4	Calcutta	V		OLD
26 11 1823		22.6	88.4	Calcutta	V		OLD
20 03 1826		16.1	73.6	MojeMorvade	VI	5	KEL

01 1827		22.6	88.4	Calcutta	V		OLD
06 01 1827		17.7	83.4	Visakhapatnam	V		OLD
19 01 1827		22.6	88.4	Calcutta	V		OLD
08 07 1828		22.6	88.4	Calcutta	VII		OLD
20 07 1828	7:30	23.2	69.9	Bhuj	VI	5	OLD
22 08 1828		13	75	Malabar Coast	VII	5.7	OLD
18 09 1828		22.6	88.4	Calcutta	V		OLD
12 03 1829		13	77.6	Bangalore	V		OLD
18 09 1829		22.6	88.4	Calcutta	VI	5	OLD
04 10 1832		15.8	73.7	Majkur	VI	5	KEL
04 10 1833		25.7	82.7	Jaunpur	V		OLD
24 01 1836		22.9	88.4	Chandernagore	V		OLD
15 06 1837		19.5	85.1	Ganjam	VI		OLD
11 05 1839		25.3	86.5	Jamalpur	VI		OLD
15 09 1841		9.5	76.6	Travancore	V		OLD
16 01 1842		26	83	North-West	VI		OLD
21 05 1842	15:30	25	87	Bengal	VII	5.7	OLD
23 05 1842		25	87	Bengal	V		OLD
09 10 1842		22.3	73.2	Baroda	V		OLD
08 02 1843		23	72.7	Ahmadabad	V		OLD
03 1843		15.2	76.9	Bellary, Deccan	IV		OLD
31 03 1843	23:00	15.2	76.9	Bellary,Shola pur	VII	5.7Mw	OLD
01 04 1843		15.2	76.9	Bellary, Deccan, Sholapur	VII		OLD
19 04 1845		23.8	68.9	Lakhpat	VIII	6.3	OLD
19 06 1845		23.8	68.9	Lakhpat	VII	5.7	MIL
24 07 1845		22.7	88.4	Serampore, Calcutta	V		OLD
26 07 1845		22.7	88.4	Serampore	V		OLD
06 08 1845	6:00	22.7	88.4	Serampore	VII	5.7	OLD
27 05 1846	Night	23	80	Narmada	VI	5	OLD
05 05 1847	11:30	22.6	88.4	Calcutta	VI	5	OLD
20 02 1848		22.6	88.4	Calcutta	V		OLD
26 04 1848	17:30	24.4	72.7	Mt. Abu	VII	5.7	OLD
30 11 1848		22.6	88.4	Calcutta	IV		OLD
02 01 1849		24.4	72.7	Erinpura (Abu)	VI	5	SRI
22 01 1849		22.6	88.4	Calcutta	IV		OLD
28 02 1849		26.5	88.5	Titalyah	VI		OLD
23 11 1849		9.5	76.6	Travancore	V		OLD
26 12 1849		18.9	72.9	Bombay	IV		OLD

07 05 1850		22.6	88.4	Calcutta	V		OLD
09 02 1851		22.6	88.4	Calcutta	VII		OLD
09 02 1852		22.6	88.4	Calcutta, Serampore	IV		OLD
11 1854		18.9	72.9	Bombay	IV		OLD
17 03 1856		9.9	78.1	Madura (Madurai)	V		OLD
11 08 1856		8.7	77	Trevandrum	V		OLD
25 08 1856		8.7	77	Trevandrum	V		OLD
01 09 1856		9.5	76.6	Travancore	V		OLD
25 12 1856		20	73	Bombay, Surat	VII	5.7	MIL
16 03 1858		21.5	87	Balasore	V		OLD
13 08 1858		11.4	76	Malabar	V		OLD
23 08 1858	1:30	11.4	76	Malabar	VI	5	OLD
24 08 1858		17.8	83.4	Waltair	IV		OLD
03 10 1858		19.5	85.1	Ganjam	IV		OLD
12 10 1858	8:00	18.3	84	Chicacole	V	5	OLD
30 12 1858		12.4	78.4	Salem District	V		OLD
31 12 1858		21	75	Khandeish	V		OLD
03 01 1859	2:30	12.5	79	North Arcot	VI	5	OLD
05 02 1859		12.5	78.6	Tirupattur	V		OLD
20 07 1859	22:30	16.3	80.5	Guntur	VI	5	OLD
02 08 1859		16.3	80.5	Guntur	V		OLD
09 08 1859		16.3	80.5	Guntur	V		OLD
24 08 1859		17.7	83.4	Visakhapatnam	V		VIS
17 12 1859		11.6	78.1	Selam	V		OLD
17 12 1859		12.5	78.6	Tirupattur	V		OLD
17 01 1860		11.9	78.2	Shevaroys	V		OLD
20 01 1860		11.9	78.2	Shevaroys	IV		OLD
02 02 1860		13.7	79.4	Tirupati	V		OLD
25 02 1860		19.4	84.9	Berhampur	V		OLD
16 02 1861	13:30	22.6	88.4	Calcutta	VII	5.7	OLD
04 03 1861		11.9	78.2	Shevaroys	V		OLD
18 04 1861		22.6	88.4	Calcutta	IV		OLD
31 07 1861		25.4	83	Varanasi	VI	5	MIL
26 08 1861		25.4	83	Varanasi	V		MIL
08 11 1863	14:00	21.8	75.3	Burwani	VI	5	OLD
05 01 1864		10.8	78.7	Trichinopoly	V		OLD
29 04 1864		22.3	72.8	Ahmedabad	VII	5.7	OLD
30 08 1864		25.6	85.2	Patna	V		OLD
30 08 1864		26.8	80.9	Lucknow	V		OLD

02 08 1865		12.7	78.7	PALAR HILLS	V		OLD
24 12 1865	22:30	23.4	88.5	Krishnanagar	VI	5	OLD
25 12 1865		23.4	88.5	Krishnanagar	VI		OLD
23 01 1866	14:40	21.8	87.8	Contai	VI	5	OLD
23 05 1866		25	87	BENGAL	VIII	6.3	OLD
03 01 1867		16.1	79.6	Kennalapud	IV		OLD
06 01 1867		16.1	79.8	Vinukonda	IV		OLD
07 03 1867		13.1	80.3	Madras	VII	5	IMD
11 03 1867		16	80.3	Guntur-Ongole	V		FOO
03 07 1867		12	79.6	Villupuram	V		MIL
31 07 1868		24	85.4	Hazaribagh	VI	5	OLD
30 09 1868		24	85	Manbhum	VII	5.5	OLD
09 06 1869		22.6	88.4	Calcutta	V		OLD
04 07 1869		20.2	74.2	NASIK, CHANDORE	V		OLD
12 07 1869		20.9	74.8	DHULIA	V		OLD
01 09 1869	14:00	14.5	80	Nellore	VI	5	OLD
02 09 1869		14.5	80	Nellore	V		OLD
19 12 1869		17	82.3	Kakinada	V		OLD
19 12 1870		17.7	83.4	Visakhapatnam	V		VIS
31 01 1871		22	73.1	Baroda	VI	5.5	IMD
14 04 1872		22	72	Bhavnagar	VI	5	SRI
22 11 1872		18.8	80	Sironcha	VI		SRI
10 1876		17.7	78.6	Secunderabad	VI	5	SRI
15 12 1882		24.8	72.4	Mt. Abu	VII	5.7	SRI
23 12 1888		22.6	88.4	Calcutta	V		MIL
17 06 1891		20.8	87	Serajgunj	V		MIL
07 02 1900	Night	10.8	76.8	Coimbatore M6.0	VII	5.8Mw	AJ
27 04 1901		12	75	N.of Calicut	VI		TRI
14 01 1903		24	70	Kutch	VII	5.7	IMD
17 05 1903		23	80	Jabalpur	VI	5	TRI
15 08 1906							
29 09 1906		23.4	88.5	Calcutta	VI	5.5	
06 12 1906		22.6	88.4	Calcutta	VI		MIS
12 07 1907		26	72	Mallani	VI		TRS
07 01 1916		13	77.6	Bangalore		5	IMD
17 04 1917		18	84	Vizianagaram	VII	5.5	IMD
21 04 1919		22	72	Bhavnagar	VII	5.5	TAN
13 03 1922		22	71	Patdi	V		TAN
1927		17.7	83.4	Visakhapatnam	V		GUB
02 06 1927	16:37	23.5	81	Son Valley	VII	6.4Mw	AJ

				M6.5			
20 07 1935		20	73	Bombay	VI	5	TAN
14 03 1938	0:48	21.5	75.7	Satpura 6.3 M	VII	6.3Mw	AJ
06 1938		22.3	71.6	Paliyad	VI	5	TAN
19 07 1938		22.4	71.8	Paliyad	VI	5	TAN
23 07 1938		22.4	71.8	Paliyad	VII	5.5	TAN
31 10 1940		22.5	70.4	Dwaraka	VI	5	TAN
14 06 1950		24	71.2	Bhuj	V		TAN
1951		17.3	73.2	Jaigarh	V		REP
26 07 1953		9.9	76.3	Cochin	VI	5	GUB
05 01 1954		18	81.3	Kottagudem	V		GUP
20 11 1954		27.5	82.5	N of Gonda			SHL
21 07 1956	15:32	23	70	Anjar	IX	6.5Mw	AJ
10 10 1956		28.1	77.7	Khurja		6.1Mw	AJ
13 10 1956		15.6	80.1	Ongole	VI	5	IMD
25 08 1957		22	80	Balaghat		5.5	IMD
17 10 1957		21	79	North of Nagpur		5.5	IMD
01 11 1958		22	85	S.E. Bihar			SHL
25 11 1958		26.5	86.5	N.E. of Darbhanga			SHL
09 08 1959		18.1	83.5	Vizianagaram	IV		RAO
21 08 1959		15.8	80.2	Uppugunduru	IV		RAO
12 10 1959		15.7	80.1	Ongole	VI	5	ISS
13 10 1959		15.6	80.1	Ongole	VI		RAO
17 12 1959		11.7	78.1	Salem and	V		GUR
23 12 1959		18.1	83.5	Vizianagaram	V		RAO
08 10 1960		16	80.3	Ongole	V	5	GUB
11 07 1961		27.1	81	N. of Lucknow			CGS
12 03 1962		24.1	70.9	Rann of Kutch			CGS
01 09 1962		24	73	North Gujarat		5	IMD
28 09 1962		17	73.5	Ratnagiri	V		KAR
09 04 1963		22.5	85.8	Singhbhum			CGS
08 05 1963	14:15	21.7	84.9	Thethanagar, SE Bihar		5.2	USG
13 07 1963		24.9	70.3	Thar		5.6	USG
05 12 1963		17.3	80.1	N. OF GUNTUR			CGS
15 04 1964	16:35	21.7	88	Midnapore	VII	5.5	USG
09 06 1964		21.7	87.7	Contai			IMD
04 10 1964		11.3	75.8	Calicut	V		GUR
04 06 1965	3:37	17	73.4	Ratnagiri		5.4	IMD
26 03 1965		24.4	70	Kutch		5.3	IMD

19 11 1965		18.8	73.1	Alibag			IMD
13 12 1965		19.2	73	55km from Kolaba	IV		TNC
23 03 1966		25.9	90	Dhubri		4.4	CGS
04 05 1966		18.7	73	Alibag	V		REP
27 03 1967	8:09	15.6	80.1	Ongole		5.4	USG
25 04 1967	3:53	18.2	73.4	Mahad		5.6	IMD
11 05 1967		27	75.2	Jaipur	V		IMD
19 05 1967		17	73.5	Ratnagiri	V		GUH
20 06 1967		18.7	73	Alibag	V		GUH
16 07 1967		23.5	87.5	E. of Asansol	V		SHL
11 08 1967		16	80	Vinukonda			IMD
13 09 1967	6:23	17.4	73.75	Koyna		5	IMD
10 12 1967	22:51	17.3	73.76	Koyna6.0mb, 6.3Ms	VIII	6.3M_w	DDS
10 12 1967	23:52	17.4	73.7	Koyna		5	USG
11 12 1967	20:49	17.3	73.7	Koyna		5.2	USG
12 12 1967	6:18	17.6	73.9	Koyna		5.4	USG
12 12 1967	15:48	17.4	73.9	Koyna		5	USG
12 12 1967	18:20	17.35	73.75	Koyna		5	USG
24 12 1967	23:49	17.5	73.9	Koyna		5.5	USG
25 12 1967	17:37	17.2	73.9	Koyna		5.1	USG
12 01 1968		17.4	73.7	Koyna	IV		IMD
25 01 1968		17.4	73.7	Koyna	IV		IMD
07 02 1968		17.4	73.7	Koyna	VI		IMD
04 03 1968		17.4	73.7	Koyna	VI		IMD
29 07 1968		17.6	80.8	Bhadrachalam and Kottagudem		4.5	GUP
15 08 1968		12	79	Mamandur	IV		GRA
29 10 1968	10:00	17.4	73.7	Koyna		5.4	USG
04 11 1968		16.2	74	N.ofSavantvad i		3.5	IMD
07 03 1969		17.2	73.6	Sangameshwar	V		GUH
26 03 1969		22.6	78.1	N. of Mahadeo Hills		4.2	IMD
13 04 1969	15:24	17.9	80.6	Bhadrachalam	VII	5.7Mw	CHU
14 04 1969		18	80,50	Bhadrachalam		5.2	IMD
03 05 1969	13:23	23	86.6	Bankura		5.7	IMD
27 06 1969		17.4	73.7	Koyna	IV		IMD
20 08 1969		27	75	Nr Sambhar lake		4.5	IMD
15 09 1969		17.6	80.5	Kottagudem			IMD
24 10 1969	11:45	24.8	72.4	Mt. Abu		5.3	USG
23 03 1970	1:52	21.7	73	Broach 5.4	VII	5.4Mw	CHU

				mb			
06 04 1970	22:30	17.15	73.74	Koyna		5.0	USG
16 04 1970		17.4	73.7	Koyna	V		IMD
27 05 1970		17.4	73.7	Koyna		4.5	IMD
08 06 1970		17.4	73.7	Koyna	V	4.1	NGRI
17 06 1970		17.4	73.7	Koyna	V	4.1	NGRI
30 08 1970		21.6	72.7	Broach		3.5	IMD
25 09 1970		17.4	73.6	Koyna		5	IMD
26 09 1970		18	74	Koyna		5.5	IMD
17 01 1971		12.4	77	Mandya. Mysore		4.2	ARO
06 03 1971		12.4	77	Mandya. Mysore		4.2	ARO
27 03 1971		12.4	77	Mandya. Mysore		4.3	ARO
18 06 1971		21.7	73	Broach	IV		IMD
28 07 1971		15.6	80.1	Ongole, A.P.	V		IMD
24 04 1972		12.4	77	Mandya, Mysore	IV		IMD
16 05 1972		12.4	77	Mandya, Mysore		4.6	ARO
17 05 1972		12.4	77	Mandya, Mysore		4.5	ARO
29 07 1972		11	77	Coimbatore	VI		IMD
26 06 1973		27	75.2	Jaipur	IV		IMD
12 07 1973		23.2	80	Jabalpur	IV		IMD
17 10 1973	15:24	17.4	73.7	Koyna		5	USG
15 11 1973		17	76.3	Sindri	V		CHA
12 05 1975	15:09	13.8	75.3	Shimoga	VI	5	GOS
02 09 1980	16:39	17.24	73.82	Koyna		5.3	USG
20 09 1980	10:45	17.25	73.75	Koyna		5.3	UDG
19 01 1986	5:42	21.2	84.9	Orissa		5	HYB
10 11 1991	15:31	26.92	70.95	Jaisalmer		5.7	HYB
24 08 1993	17:49	20.6	71.4	OffcoastSuras htra		5	USG*
29 09 1993	22:26	18.09	76.5	Latur 6.3 Ms	VIII	6.2Mw	USG
08 12 1993	1:42	17.19	73.75	Koyna		5	USG
01 02 1994	9:31	17.31	73.74	Koyna		5	USG
31 08 1994	23:31	26.23	78.17	Gwalior		5	HYB
22 05 1997	22:52	23.08	80.06	Jabalpur 6.1 Mb	VII	5.8Mw	USG
31 05 1998		19.04	73.11	Mumbai		3.6	IMD
08 10 1998		19.54	73.5	NE of Mumbai		4.5	NGRI
12 03 2000	18:03	17.17	73.71	Koyna	VI	5.2Mw	RAS
06 04 2000	22:30	17.15	73.74	Koyna		5.0	USG
22 06 2000		19.93	79.1	Ghugus	V	4.2	IMD,

							NGRI
05 09 2000	00:32	17.17	73.75	Koyna	VI	5.3	USG
09 12 2000				Bhavnagar	VII	4.2	IMD
26 01 2001	3:16	23.44	70.31	Bhuj, Guj	IX	7.7 Mw	ISC
17 05 2001	16:04	17.27	73.93	Maharashtra		4	ISC
12 06 2001	12:41	22.22	83.94	Chattisgarh		4.8 Mb	USG
02 08 2001	4:08	17.19	74.08	Maharashtra		4.3	ISC
25 09 2001	14:56	11.95	80.21	Near coast of Tamilnadu		5.2 Mwc	USG
02 05 2002	14:29	27.44	75.72	Nathoosan,Raj .		4.1	ISC
10 08 2003	11:17	27.37	75.98	Rajasthan		4	ISC
20 10 2003	0:39	23.88	86.32	Jharkhand		4	ISC
27 05 2004	0:22	26.28	89.22	West Bengal		4.2Ms	ISC
14 03 2005	9:43	17.28	73.87	Koyna, Maha		4.7	ISC
15 03 2005	2:07	17.23	73.99	Koyna, Maha		4.1	ISC
07 06 2005	21:32	17.42	74.02	Koyna, Maha		4	ISC
14 08 2005	6:33	17.39	74.12	Koyna		4	ISC
30 08 2005	8:53	17.08	73.77	Koyna		4.5	ISC
03 02 2006	0:54	23.9	70.5	Rapar, Kachchh		5	NGRI
07 03 2006	18:20	23.8	70.7	Kachchh, Guj		5.2	IMD
06 04 2006	12:02	23.8	70.6	Kachchh, Guj		4.7	IMD
06 04 2006	17:59	23.5	70.3	Kachchh, Guj		5.5	IMD
10 04 2006	22.05	23.5	70.1	Kachchh, Guj		4.8	IMD
17 04 2006	16:40	17.2	74	Satara, Maha		4.2	IMD
21 05 2006	20:28	16.8	73.7	Ratnagiri, Maha		4.2	IMD
23 06 2006	5:34	23.7	70.1	Kachchh,Gujar at		4.6	IMD
23 06 2006	21:19	23.7	70	Kachchh,Gujar at		4	IMD
17 07 2006	13:47	26.8	89	Jalpaiguri, WB		4	IMD
20 08 2006	2:37	23.3	69.9	Kachchh, Guj		4.2	IMD
31 08 2006	5:36	26.4	89.7	West Bengal-Assam Boundary		4.3	IMD
18 09 2006	12:45	23.9	87.7	Birbhum, WB		4	IMD
30 09 2006	0:16	22.33	70.21	Khankotda, Jamnagar, Guj	V	4	ISR
13 05 2007	13:41	23.2	70.4	Kachchh, Guj		4	IMD
06 09 2007	7:09	18.1	76.7	Latur, Maha		4.1	ISR
08 10 2007	1:12	23.3	70.2	Kachchh, Guj		4.8	IMD
06 11 2007	0:27	21.12	70.51	Junagarh, Guj		4.8	IMD
06 11 2007	9:38	21.16	70.54	Junagarh, Guj		5	ISR

24 11 2007	10:57	17	74	Koyna, Maha		4.3	IMD
06 02 2008	6:09	23.4	87.08	West Bengal		4.1	ISC
09 03 2008	11:03	23.39	70.33	Kachchh, Guj		4.9	ISR
06 06 2008	21:16	24.7	85	Gaya, Bihar		4.3	IMD
05 07 2008	16:55	24.4	88.5	West Bengal		4.1	IMD
29 07 2008	19:10	17.4	73.7	Satara, Maha		4.2	IMD
16 09 2008	21:47	17.9	73.9	Satara, Maha		4.8	IMD
05 10 2008	11:33	20.9	70.4	Junagarh, Guj		4	IMD
04 01 2009	5:20	21.9	75.3	Madhya Pradesh		4.2	IMD
05 01 2009	7:04	22.92	88.62	West Bengal		4	ISC
26 03 2009	4:44	22.39	85.9	Jharkhand		4.1mb	USG
09 04 2009	1:46	27.1	70.7	Jaisalmer, Raj		5.3	IMD
28 10 2009	13:40	23.7	70	Kachchh, Guj		4.5	IMD
29 10 2009	19:56	26.6	90	Kokrajhar Assam		4.2	IMD
14 11 2009	13:03	17.1	73.8	Koyna, Maha		4.8	IMD
12 12 2009	11:51	17.2	73.8	Koyna, Maha		5	IMD
12 12 2009	16:25	17.2	73.8	Koyna, Maha		4	IMD
12 12 2009	21:54	17.2	73.8	Koyna, Maha		4.1	IMD
15 08 2010	6:08	26.4	74.3	Ajmer, Raj		4	IMD
02 09 2010	3:09	23.71	72.14	Gujarat, India		4	ISC
02 09 2010	8:39	23.88	71.87	Patan, Gujarat		4.4	ISR
09 11 2010	22:46	25.2	73.7	Rajsamand, Raj		4.8	IMD
29 04 2011	2:47	21.27	70.49	Talala, Gujarat		4.1	ISR
23 05 2011	23:43	21.1	70.53	Talala, Gujarat		4	ISR
17 05 2011	16:00	23.55	70.57	North Wagad, Kachchh,Gujarat		4.2	ISR
13 08 2011	2:59	23.45	70.4	South Wagad, Kachchh, Guj		4.5	ISR
20 10 2011	17:18	21.2	70.7	Junagarh Guj		5.3	IMD
12 11 2011	7:01	21.1	70.5	Junagarh		4.3	IMD
05 03 2012	7:41	28.7	76.6	Haryana-Delhi Border Region		5	IMD
15 04 2012	5:27	17.31	73.73	Koyna, Maha		4.3	ISC
14 04 2012	3:23	23.5	71	Rann of Kachchh		4	IMD
14 04 2012	5:27	17.4	73.8	Satara, Maha		4.9	IMD
14 04 2012	6:17	17	73.5	NrRatnagiri		4	IMD
19 06 2012	20:14	23.64	70.28	Kachchh		5	ISR
18 10 2012	2:33	23.8	81.4	Dt.Shahdol, MP		5	IMD

08 12 2012	7:06	23.13	70.42	Rann of Kachchh		4.5	ISR
24 02 2013	0:57	26.3	75.6	Tonk, Rajasthan		4.1	IMD
30 03 2013	18:33	23.57	70.38	Rann of Kachchh		4.5	ISR
29 07 2013	13:07	23.45	70.58	Vamka, Kachchh		4.5	ISR
05 08 2013	7:27	27	70.7	Jaiselmer, Raj		4	IMD
03 09 2013	19:46	24.28	69.78	Khavda,Kachchh		4.1	ISR
09 03 2014		23.35	70.29	Bhachau,Kachchh		4.1	ISR
25 02 2015	0:39	16.7	80.1	Dt. Guntur, AP		4	IMD
09 05 2015	01:01	23.46	73.31	18km NNW of Bhachau,Kachchh		4.2	ISR
06 10 2015	00:28	24.06	70.20	70km NW of RaparRann of Kachchh		4.3	USG
15 12 2015	02:35	23.47	86.19	18km S of Chas Bihar-WB Border		4.5	USG

Appendix - 2

List of earthquakes of magnitude M≥5.0 in Kachchh during 2001 to 2009 (NGRI/ISR/USGS)

S.No.	year	Mn	date	hr	mn	Sec	Lat	long	Depth	Ml	Mb	Ms
1	2001	1	26	3	16	40.5	23.42	70.23	16	6.9	7.7 (Mw)	
2	2001	1	26	3	33	29.17	23.25	69.84	10	5.5	5.3	
3	2001	1	26	3	55		23.399	70.599	10	5.0	4.9	
4	2001	1	26	3	58	59.47	23.246	69.47	10	4.8	5.0	
5	2001	1	26	4	23	41.97	23.421	70.119	10	5.2	5.2	
6	2001	1	26	4	48	14.25	23.25	70.35	10	5.2	5.1	
7	2001	1	26	7	32	28.74	23.425	70.076	9.2	5.2	5.2	
8	2001	1	27	4	36	8.41	23.40	70.38	9.7	5.1		
9	2001	1	28	1	2	10.7	23.65	70.64	9.2	5.7	5.8	6.0
10	2001	1	28	11	10	43.61	23.25	70.39	9	4.7	5.4	4.6
11	2001	2	3	3	4	32.89	23.66	70.43	9.1	5.1	5.3	5.0
12	2001	2	8	16	54	41.02	23.73	70.44	9.2	5.2	5.1	4.9
13	2001	2	19	2	11	14.5	23.52	70.235	9.1	5.0	4.6	4.8
14	2001	2	19	8	24	20.16	23.57	70.07	10	5.2	5.4	5.5
15	2001	3	4	7	54	23.47	23.17	70.46	19	5.0	4.8	4.7

16	2003	8	5	11	8	1.91	23.69	70.43	10		5 .0	4.7
17	2006	2	3	0	54	25.4	23.2	70.73	3	4.4	4.5	5.0Mw
18	2006	3	7	18	20	43.4	23.78	70.73	10	5.2	5.5	5.7Mw
19	2006	4	6	12	2	54.59	23.73	70.68	10	4.7	5 .0	
20	2006	4	6	17	59	18.2	23.34	70.39	29.3	5.5	5.5	5.6Mw
21	2012	6	19	20	14	0.4	23.645	70.283	11.1	5.0		5.1Mw

Appendix - 3

A LIST OF M ≥5.0 KOYNA-WARNA EARTHQUAKES (1967-2000)

SN	D	M	Y	OTIME HR	MIN	Lat. (N)	Long. (E)	Magnitude NGRI	MERI	USGS	Focal Depth (km)	Focal Mech. Solution	Mag. Used
1	13	09	1967	06	23	17.40	73.75		5.2			S-S	5.2(Gu*)
2	10	12	1967	22	51	17.38	73.75	6.3	7.0	6.0	10.0	S-S	6.3
3	10	12	1967	23	52	17.36	73.77		5.0				5.0
4	11	12	1967	20	49	17.27	73.86			5.2			5.2
5	12	12	1967	06	18	17.34	73.70			5.4		Normal	5.4
6	12	12	1967	15	48	17.28	73.68			5.0			5.0
7	12	12	1967	18	20	17.35	73.75			5.0			5.0
8	24	12	1967	23	49	17.24	73.82		5.0	5.5			5.5
9	25	12	1967	17	37	17.40	73.66			5.1			5.1
10	29	10	1968	10	00	17.35	73.72		5.2	5.4	5.0		5.4
11	17	10	1973	15	24	17.29	73.75	5.2	5.2	5.0	5.9	S-S	5.2
12	02	09	1980	16	39	17.24	73.76	5.3	4.3	4.9	8.0		5.3
13	20	09	1980	10	45	17.25	73.70	5.9	4.9	5.3	12.0	Normal	5.3
14	08	12	1993	01	42	17.19	73.75	5.2	5.1	5.0	8.4	Normal	5.2
15	01	02	1994	09	31	17.31	73.74	5.5	5.4	5.0	10.6	S-S	5.4
16	03	12	2000	18	03	17.16	73.73	5.6	5.2	4.9	5.0	S-S + minor Normal component	5.2
17	06	04	2000	22	30	17.15	73.74	5.1	4.8	5.0	7.8	S-S + minor Normal component	5.1
18	09	05	2000	00	32	17.17	73.75	5.6	5.2	5.3	6.9	Normal	5.3
19	12	12	2009	11:51		17.20	73.80					IMD	5.0

Gu*:Guha et al.,1974; S-S: Strike-slip

(Note: Epicentral locations have been taken from Gupta et al. (1980), Rastogi&Talwani (1980), Talwani et al. (1997) and Maharashtra Engg. Research Institute, Nasik, Maharashtra, India.

Appendix - 4

Catalog for Koyna earthquakes of M≥4.0

SN	D M Y	H:M	LAT N	LONG E		NGRI MS	MERI ML	USGS mb
1.	13.09.67	06:23	17°-24.00’	73°-45.00’			5.2	
2.	13.09.67	06:47	17 -20.00	73 -45.00			4.5	
3.	13.09.67	06:51					4.0	
4.	13.09.67	07:01					4.0	
5.	13.09.67	08:43					4.0	
6.	13.09.67	11:32					4.0	
7.	10.12.67	22:51	17-22.61	73-45.10	10.70	6.3	7.0	6.0
8.	10.12.67	23:52					3.8	5.0
9.	11.12.67	20:49					5.4	5.2
10.	12.12.67	06:18				3.6	5.4	
11.	12.12.67	15:48					3.6	5.0
12.	12.12.67	18:20	17-17.09	73-41.20	5.99		4.7	
13.	13.12.67	05:09	17-17.04	73-46.38	10.86		4.6	
14.	13.12.67	19:19	17-21.78	73-49.48	2.92		4.6	
15.	14.12.67	09:16	17-20.04	73-46.30	11.65		4.1	
16.	14.12.67	15:06	17-21.71	73-45.10	9.21		4.1	
17.	14.12.67	23:40	17-17.28	73-42.99	9.17		4.0	
18.	22.12.67	14:48					4.8	
19.	24.12.67	03:41	17-23.95	73-46.91	5.89		4.0	
20.	24.12.67	04:23	17-23.48	73-44.12	11.51		4.0	
21.	24.12.67	23:49	17-14.44	73-49.04	11.77		5.0	5.5
22.	25.12.67	00:15	17-16.28	73-44.68	7.86		4.2	
23.	25.12.67	00:47	17-11.42	73-39.81	3.18		4.2	
24.	25.12.67	17:37	17-24.27	73-39.41	1.05	4.6	5.1	
25.	25.12.67	17:59	17-18.10	73-44.36	8.50		4.1	
26.	03.01.68	04:35	17-22.43	73-41.52		5.0		4.0
27.	11.01.68	04:37						4.1
28.	16.01.68	03:33	17-24.36	73-45.61	10.55		4.0	
29.	07.02.68	08:09	17-19.92	73-41.37	5.96		4.3	
30.	09.02.68	22:52	17-15.97	73-44.20	11.64		4.2	
31.	12.02.68	09:13	17-23.95	73-45.10	5.91		4.5	
32.	04.03.68	21:36	17-18.57	73-45.10	11.23		4.2	
33.	31.08.68	02:53	17-26.10	73-40.80	9.49		4.1	
34.	20.09.68	10:11	17-25.69	73-45.10	4.19		4.2	
35.	29.10.68	10:00	17-23.95	73-45.10	5.00	5.2	5.4	
36.	05.12.68	22:52	17-23.95	73-41.25	5.00			4.3
37.	21.01.69	22:32					4.1	3.6
38.	13.02.69	18:26	17-20.79	73-39.32	5.92		4.2	4.3

39.	07.03.69	14:28	17-17.02	73-41.35	7.70	4.4	4.7
40.	03.06.69	23:26				4.2	3.5
41.	27.06.69	20:05	17-23.49	73-49.43	3.17	4.5	4.7
42.	22.07.69 21:49					4.0	3.7

	Magnitude	NGRI	MERI	USGS
43.	03.11.69 23:22	4.1	4.5	
44.	04.11.69 05:11	4.2	3.7	
45.	01.01.70 22:30	4.3		
46.	16.04.70 14:46	4.0	3.6	
47.	27.05.70 12:45	4.8	4.4	
48.	08.06.70 05:30	4.1	3.8	
49.	17.06.70 06:48	4.1	3.6	
50.	21.09.70 03:02	4.0	3.7	
51.	25.09.70 04:12	4.6	4.2	
52.	26.09.70 16:36	4.6	4.4	
53.	23.01.71 04:39	4.2	3.7	
54.	14.02.71 01:30	4.0	4.2	
55.	29.05.71 00:27	4.1		
56.	10.08.71 04:30	4.0	3.4	
57.	10.08.71 06:15	4.3	4.2	
58.	22.11.71 10:39	4.2		
59.	01.05.72 21:11	4.2	3.6	
60.	11.05.72 11:49	4.5	3.9	
61.	05.07.72 23:15	4.0	3.2	
62.	11.11.72 04:01	4.1	3.1	
63.	19.04.73 08:45	4.1	3.8	
64.	17.10.73 08:03	4.0	3.2	
65.	17.10.73 14:40	4.1	3.2	
66.	17.10.73 15:24	5.1	5.2	5.0
67.	24.10.73 18:05	4.6	3.6	
68.	11.11.73 06:48	4.6	2.5	
69.	17.02.74 14:06	4.5	4.7	
70.	28.04.74 09:30	4.0	3.8	
71.	29.05.74 18:26	4.2	3.5	
72.	29.07.74 23:17	4.8	4.3	4.9
73.	07.08.74 04:23	4.1	3.5	
74.	28.08.74 20:20	4.5	3.8	
75.	11.11.74 15:11	4.3	3.8	
76.	20.12.74 14:16	4.2	3.8	
77.	10.02.75 18:35	4.1	3.6	
78.	02.09.75 23:17	4.2	4.0	
79.	02.12.75 07:40	4.2	3.8	
80.	24.12.75 13:25	4.3	3.6	
81.	14.03.76 05:16	4.8	3.9	
82.	22.04.76 10:46	4.3	3.7	
83.	02.06.76 11:00	4.5	2.4	
84.	16.09.76 14:04	4.2	3.4	
85.	26.09.76 06:48	4.5	3.6	
86.	12.12.76 00:52	4.2	3.9	
87.	19.09.77 00:03	4.7	4.0	

88.	04.11.77 18:57	4.0	3.5		
89.	04.11.77 20:35	4.2	3.6		
90.	04.11.77 20:54	4.4	3.5		
91.	29.11.78 05:30	4.0	3.2		
92.	12.12.78 15:02	4.7	4.0		
93.	26.01.79 19:12	4.0	3.4		
94.	26.09.79 20:02	4.0	3.6		
95.	06.02.80 22:13	4.6	4.4		
96.	19.08.80 22:32	4.3	3.6		
97.	02.09.80 16:39	5.3	4.3	4.9	5.5MS
98.	02.09.80 16:47	4.5	3.8		
99.	20.09.80 07:28	5.5	4.7	4.9	
100.	20.09.80 10:45	5.8	4.9	5.3	
101.	20.09.80 11:22	4.5	3.5		
102.	20.09.80 14:27	4.0	3.6		
103.	20.09.80 23:44	4.2	3.6		
104.	21.09.80 00:00	4.0	3.2		
105.	21.09.80 03:52	4.0	3.4		
106.	21.09.80 08:18	4.0	3.5		
107.	21.09.80 18:19	4.2	3.7		
108.	22.09.80 11:59	4.3	3.6		
109.	25.09.80 13:38	4.3	3.6		
110.	27.09.80 08:54	4.5	3.5		
111.	30.09.80 13:37	4.2	3.6		
112.	03.10.80 15:20	4.4	3.9		
113.	04.10.80 16:37	5.1	4.1	4.5	
114.	04.10.80 19:10	4.3	3.6		
115.	05.10.80 16:09	4.0	3.2		
116.	16.10.80 21:26	4.1	2.2		
117.	17.10.80 21:47	4.1	3.8		
118.	21.10.80 05:02	4.2	3.3		
119.	26.10.80 01:32	4.5	3.7		
120.	26.10.80 01:33	4.4	3.6		
121.	25.01.81 20:30	4.0	3.7		
122.	25.04.82 23:04	4.4	4.3		
123.	05.05.82 07.32	4.2	4.0		
124.	10.09.82 02:42	4.4	3.9		
125.	05.02.83 22:53	4.3	4.4	4.2	
126.	21.03.83 15:02	4.1	3.8		
127.	13.05.83 05:53	4.1	3.5		
128.	28.05.83 18:08	4.2	3.8		
129.	25.09.83 18:55	4.8	4.6	4.6ISC	
130.	10.11.83 08:55	4.5	3.9		
131.	25.09.84 07:47	4.6	3.8	4.2	
132.	14.11.84 11:58	4.7	4.4	4.6	
133.	21.12.84 17:26	4.1	4.0		
134.	27.05.85 06:58	4.1	3.7		
135.	29.10.85 08:33	4.0	3.5		
136.	29.10.85 13:59	4.2	3.6		
137.	15.11.85 07:03	4.3	3.8		

138. 21.11.85 09:28	4.0	3.8	
139. 21.11.85 11:39	4.1	3.6	
140. 15.12.85 13:11	4.3	3.9	
141. 28.12.85 14:52	4.0	3.7	
142. 24.07.88 05:33	4.8	4.1	
143. 15.08.88 22:16	4.0	3.4	
144. 15.08.88 23:27	4.1	3.4	
145. 11.09.88 20:40	4.4	3.8	4.3
146. 29.10.89 07:30	4.2	3.6	
147. 03.07.90 13:28	4.1		
148. 06.01.91 22:14	4.4		4.4
149. 20.02.92 05:43	4.1		
150. 01.04.92 01:35	4.0		
151. 27.08.93 22:13	4.1	3.5	4.1
153. 28.08.93 08:30	4.0	3.6	
154. 03.09.93 23:03	5.0	4.7	4.6ISC
155. 04.09.93 00:53	4.3	4.0	
156. 22.10.93 01:15	4.1	4.3	4.4
157. 08.12.93 01:42	5.2	5.1	5.0
158. 21.12.93 10:10	4.1	4.0	
159. 22.01.94 11:12	4.0	3.7	
160. 01.02.94 09:31	5.5	5.4	5.0
161. 29.03.94 07:51	4.3	3.8	
162. 31.10.94 06:10	4.2	3.9	
163. 12.03.95 08:22	5.1	4.7	4.7
164. 13.03.95 03:09	4.9	4.4	
165. 20.03.95 06:58	4.1	3.7	
166. 15.04.95 22:59	4.1	3.7	
167. 05.09.95 00:53	4.0	3.8	
168. 08.11.95 20:06	4.1	3.9	
169. 15.11.95 04:09	4.1	3.8	
170. 25.02.96 01:03	3.9	3.6	
171. 26.04.96 12:19	4.6	4.4	
172. 25.04.97 16:22	4.3	4.4	
173. 11.02.98 01:09	4.7	4.3	
174. 14.02.98 00:59	4.4	4.3	
175. 07.06.99 15:45	4.3	4.2	

			MAGNITUDE		
	Lat	Long	NGRI	MERI	Others
176. 12.03.2K18:03	17.16	73.73	5.6	5.2	4.9 USGS
177. 06.04.2K22:30	17.15	73.74	5.1	4.8	5.0 USGS
178. 14 03 2005 09:43	17.28	73.87			4.7 ISC
179. 15 03 2005 02:07	17.23	73.99			4.1 ISC
180. 07 06 2005 21:32	17.42	74.02			4.0 ISC
181. 14 08 2005 06:33	17.39	74.12			4.0 ISC

182. 30 08 2005 08:53	17.08	73.77	4.5	ISC
183. 12 12 2009 11:51	17.2	73.80	5.0	IMD
184. 12 12 2009 16:25	17.2	73.80	4.0	IMD
185. 12 12 2009 21:54	17.2	73.80	4.1	IMD
186. 15 04 2012 05:27	17.31	73.73	4.3	ISC