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KOTHAGUDEM (ANDHRA PRADESH) EARTHQUAKE OF APRIL 13, 1969, BROACH (GUJARAT) EARTHQUAKE OF MARCH 23, 1970 AND SEISMICITY OF PENINSULAR INDIA †

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INTRODUCTION

Historical and recent data on Indian earthquakes compiled by Oldham [12], Milne [10], Gutenberg and Richter[8] and in the bulletins of International Seismological Summary (ISS), India Meteorological Department (IMD), United States Coast and Geodetic Survey (USCGS) etc. reveal that though significant Indian earthquakes occur along the Himalayan arcs [3] which are parts of long and highly active Alpide tectonic belt covering considerable part of Eurasia, yet marginal areas of Peninsular Shield of India such as Narmada-Tapi-Son valley, Eastern coastal areas, Nilgiri hills and Palghat gap & coastal areas of Maharashtra & Gujarat exhibit seismic activity on a much reduced scale both in respect of magnitude and frequency of occurrence of earthquakes, leaving the central part of the Peninsular Shield comprising of parts of Maharashtra, Madhya Pradesh, Orissa, Andhra Pradesh, Tamil Nadu and Mysore as a broad aseismic continental block characteristic of other similar Shield areas of the world [15]. Marginal activities similar to Indian Shield around a centrally ancient nucleus of aseismic mass are also prevalent in other Shield and stable areas of the world such as Australian Shield, Canadian Shield, Brazilian Shield and stable masses of Africa and Arabia [8] etc. This marginal activity of the Indian Shield is perhaps associated with rejuvenation of old fault zones such as Gondwana troughs and other ancient fractured zones in Peninsular Shield or with comparatively recent fault zones like West coast faulting, Narmada-Tapi-Son graben systems etc. The level of activity in the Peninsula (except the Kutch region) can be rated as below moderate to low with very rare occurrence of earthquake of magnitude 5.0 and above. In fact, in marginal areas of the shield, only about sixty or so earthquakes of magnitude 5.0 and above are known to have occurred in historical and recent times since 1341 A D. [7]. Detailed data of earthquakes occurred prior to 1900 A D. are not easily available. Thus for quantitative assessment of seismicity of the marginal areas of the Shield detailed consideration is given to Coimbatore earthquake (1900), Rewa earthquake (1927), Satpura earthquake (1938), Ongole earthquake (1967) and specially to Koynanagar earthquake (1967), Kothagudem earthquake (1969), and Broach earthquake (1970), along with related geotectonic features.

EARTHQUAKES IN PENINSULAR INDIA

Occurrence of earthquakes of magnitude 5.0 and above in the Peninsular India and neighbourhood are shown in Figs. 1 and 2. The data showing increase in frequency of occurrence of earthquakes in Fig. 2 is unreal and the same only confirms paucity of data in earlier year – a fact which seriously delimits the proposed assessment of seismicity of the area. Apart from the list of earthquakes in the Peninsular India [7] wherein scanty earthquake descriptions are only available, somewhat greater details of half a dozen or so of earthquakes occuring in the Peninsular India (except Kutch area) are available and can be utilised for assessment of broad seismicity of the area especially of the marginal portions. Coimbatore (1900) and Satpura (1938) earthquakes have heen investigated by Basu [4] and Mukherjee [11] respectively and have maximum epicentral intensities VII and were felt upto several hundred

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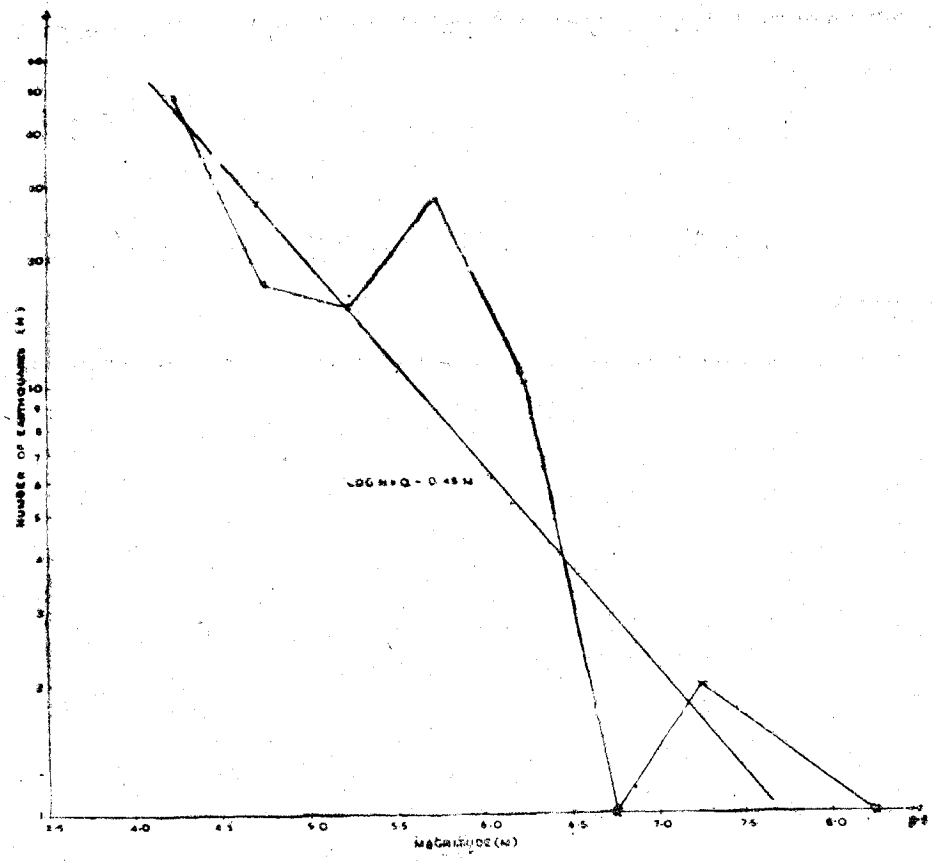


Fig. 1. Relationship between Number of Earthquakes and Corresponding Magnitudes for Earthquakes in Peninsuar India and Neighbourhood.

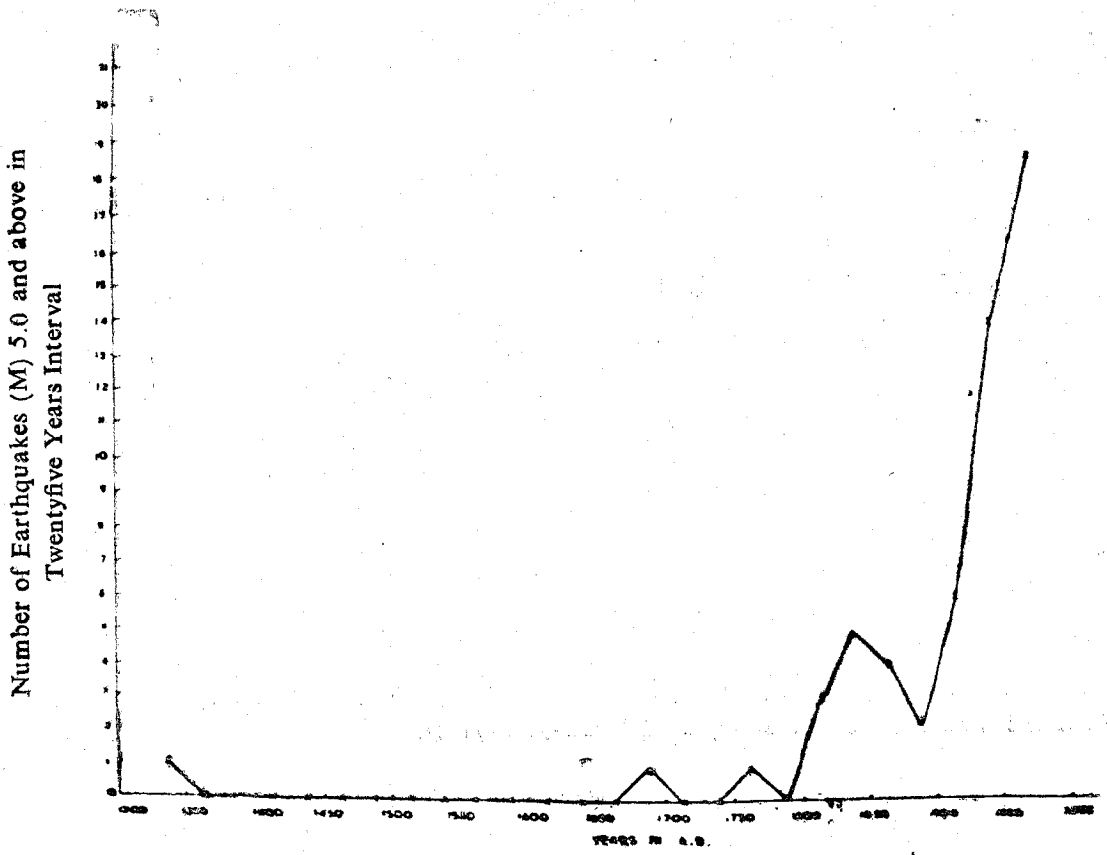


Fig. 2. Year wise Distribution of Earthquakes of Magnitude five and above in Peninsular India and Neighbourhood.

kilometres in hard rocky formations in Peninsular India. The macro-seismic data available for these earthquakes permit reasonable assessment of intensity distributions. However, the recent Rewa (1927) and Ongole (1967) earthquakes have not been investigated in detail and their probable field intensitities have been assessed indirectly from their magnitudes only. The three other very recent earthquakes in the area namely at Koynanagar (1967), at Kothagudem (1969) and at Broach (1970) have been very extensively investigated and they provide very valuable data for assessing seismicity of the area. Macroseismic data of Koynanagar earthquake (1967) [7] show that epicentral intensities VIII and IX (?) were localised due perhaps to very shallow focus and hard foundation while the felt area was spread

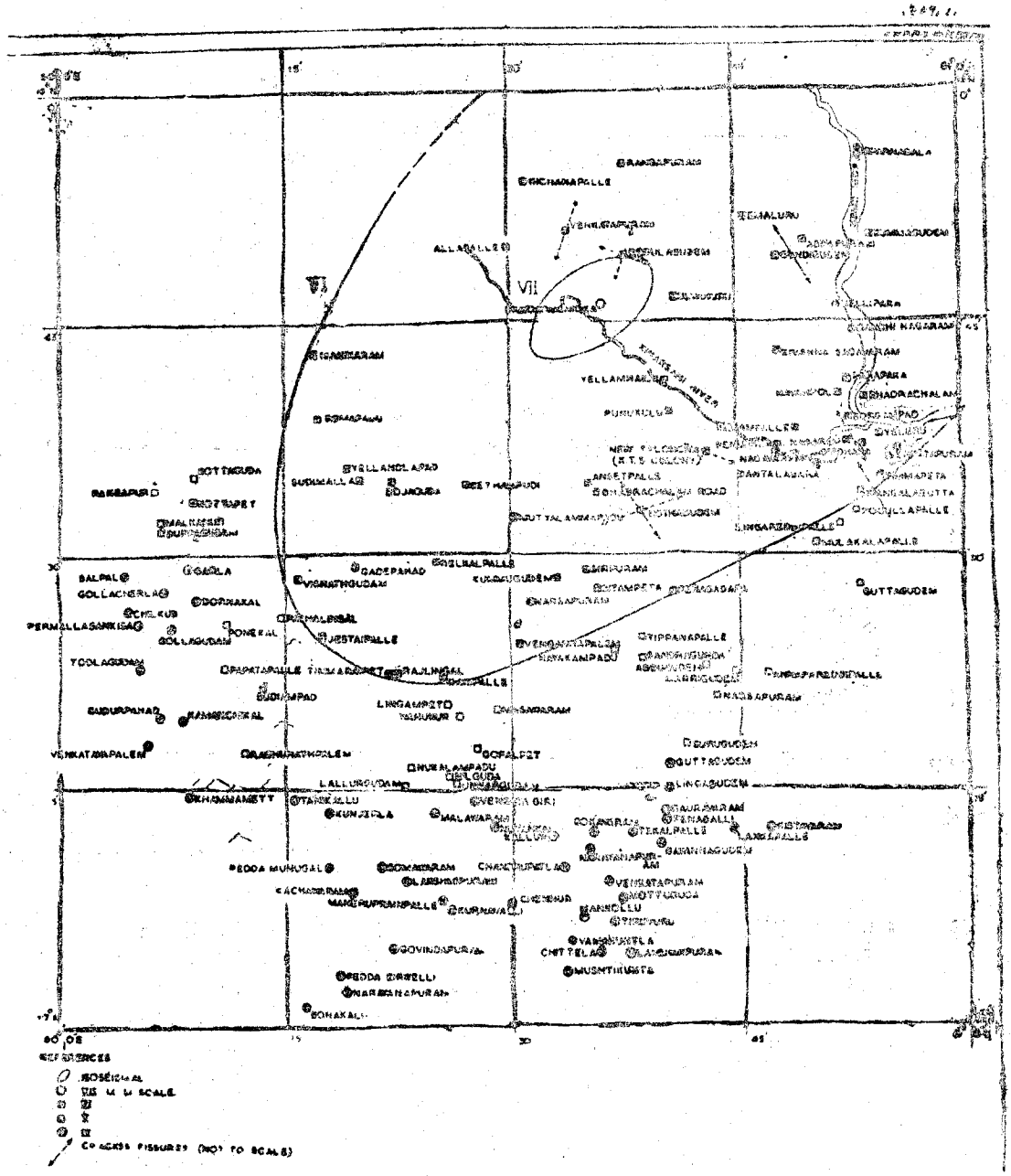


Fig. 3. Field Intensity in M.M. Scale. Assessed from Inspection of Damage and Isoseismal VII and VI of Kothagudem (A.P.) Earthquake of April 13, 1969.

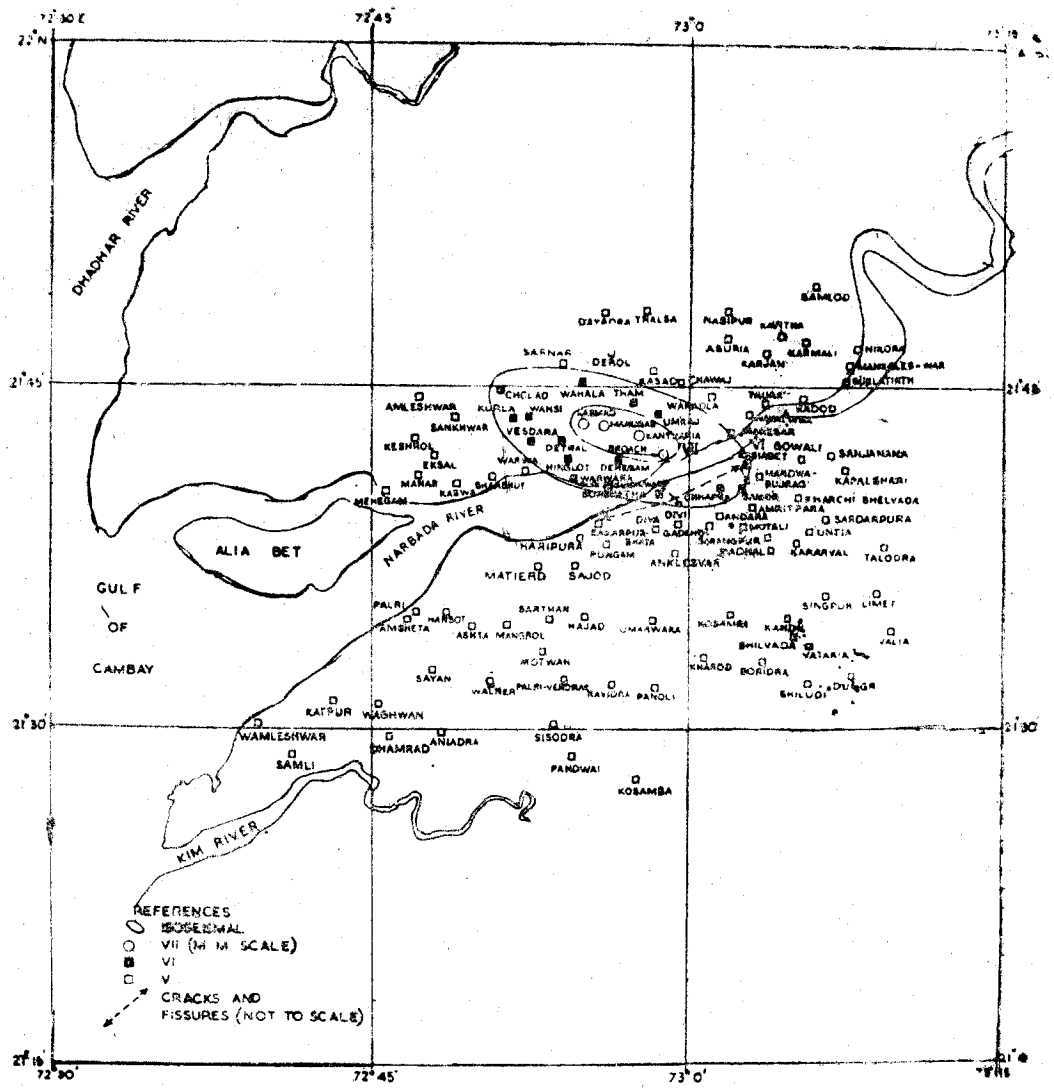


Fig. 4 Field Intensity in M.M. Scale. Assessed from Inspection of Damage and Isoseismal VII and VI of Broach (Gujarat) Earthquake of March 23, 1970.

over a radius of about 700 km. Data from detailed field investigations of Kothagudem (1969) and Broach (1970) earthquakes are given in Figs 3, 4 and 5. The pattern and extent of isoseismals of these earthquakes also are similar to Koynanagar (1967) earthquake [7]. Table I shows the various parameters of these seven earthquakes in the marginal areas of the Peninsular India. In both the earthquakes ground fissures were formed, especially in the later earthquake a ground fissure of about 15 km in length in alluvium was formed along the southern bank of the river Narmada. In Broach earthquake (1970) spouting of fresh and cool water through fissured ground, very loud sounds in the epicentral zone, disturbance in the Narmada river waters, extreme rotatory motions experienced by residents of Broach etc. were noticeable features. Thick alluvial bed of the northern bank of Narmada perhaps considerably accentuated the seismic movements and contributed to these extreme local phenomena at the epicentre although the earthquake was of magnitude 5.7 only. These

TABLE 1

Parameters of Important Peninsular Earthquakes

Earthquake	Epicentre	Magnitude (M)	Maximum known Intensity (M.M.)	Radius of felt area	Depth of focus from various methods			
					$X = h \tan 30°$ (Major Dutton)	$I_o - J = -S_1 \log \cos e$ & $e = \tan^{-1} R_j/h$ (Blake)	Phases pP—P	Other methods
Coimbatore (1900)	10°45′ N, 76°45′ E	6.0	VII	500 km	—	55 km	—	70 km (Basu)
Rewa (1927)	24°00′ N. 82°11′ E	6.5	--	—	—	—	—	—
Satpura (1938)	21°32′ N. 75°50′ E	6.2	VII	560 km	—	43 km	—	—
Ongole (1967)	15°48′ N. 80°00′ E	5.8	—	—	—	—	11 km	—
Koynanagar (1967)	17°30′ N, 73°44′ E	7.0	IX	700 km	25 km	7 km	—	12 km(7)
Kothagudem (1962)	17°55′ N, 80°37′ E	6.0	VII	650 km	68 km	21 km	12 km	33 km (USCGS)
Broach (1970)	21°41¹ N, 73°12′ E	6.7	VII	350 km	10 km	9 km	12 km ±	10 km (USCGS)

h = Depth of focus.

I_o = Maximum intensity at the epicentre (M.M. Scale).

j = Intensity chosen corresponding to average distance Rj from centre of macro-seismic area.

M = Magnitude.

S_1 = a Constant = 5.35.

x = Distance from the centre of macro-seismic area at which the intensity is 0.75 of maximum intensity (I_o).

extreme and unusual features are generally absent in Kothagudem earthquake (1969) due perhaps to hard rocky foundation of the area. However, in Kothagudem earthquake (1969), there is marked change in seismic intensity by one to two units of M.M. scales in adjacent places lying on granites and sandstones across Gondwana fault. Both these two earthquakes are perhaps due to activities associated with the known faults (Fig. 5).

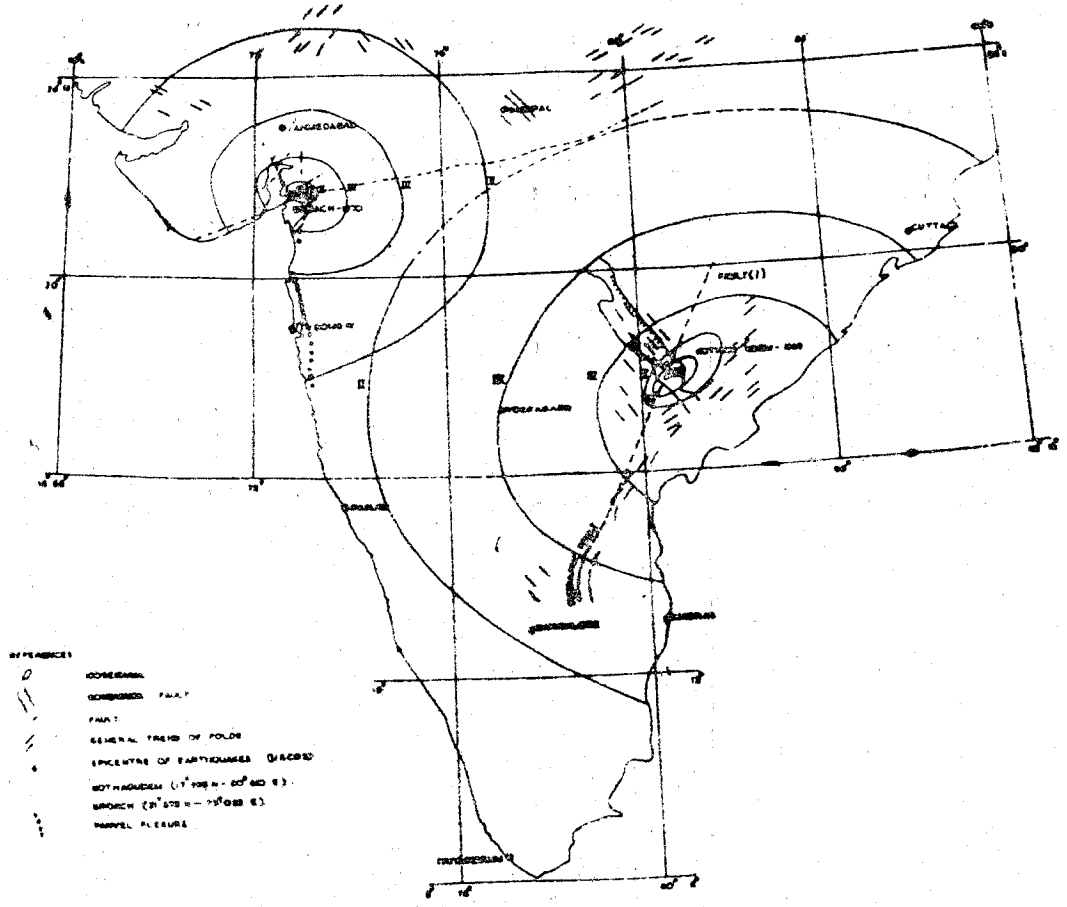


Fig. 5. Isoseismal V.I to II of the Kothagudem (A.P.) Earthquake of April 13, 1969 and of Broach (Gujarat) Earthquake of March 23, 1970 along with Tectonic Features of Macro-Seismic area.

Distribution of earthquake epicentres (magnitudewise) with higher isoseismals of prominent earthquakes in Peninsular Shield, and gravity anomaly in Fig. 6 confirm that Peninsular India is only active in marginal areas like several other Shields of the world with a central aseismic nucleus of continental mass. The prominent exception may be the Bellary earthquake (1843) occurring well within the central aseismic block and the other low magnitude earthquakes with epicentres specially in the Godavari Basin in Maharashtra, though reports of stray and rare occurrence of still very low magnitude earthquakes over wide areas of Peninsula are prevalent. Close scrutinity also reveals that the epicentres of larger earthquakes here are generally situated in areas of negative gravity anomaly. Thus perhaps crustal downwarp associated with negative gravity anomaly induces crustal stresses as postulated earlier by Glennie [5]. Evidence of corroboration of Glennie's hypothesis in Peninsular India specially for very recent earthquakes is quite significant. In fact, Glennie's hypothesis though not pursued, may deserve fresh look in view of accumulation

of vast seismological and geophysical data the worldover during the last half a century. Causes for this marginal activity may be connected with the Himalayan Orogeny, simultaneous displacement and rotation of the Indian continental mass and consequent marginal stresses on the resistive Peninsular triangular block. The decay of earthquake intensity with distance in Fig. 7 shows though initial drop in intensity in most cases is significant, considerable energy propagates to larger distances–may be through channel effect of L_g phase. In general, Peninsular earthquakes are very shallow with higher isoseismals concentrated very near the epicentres and are generally felt to very large distances compared to their magnitudes reflecting special crustal features of the Shield.

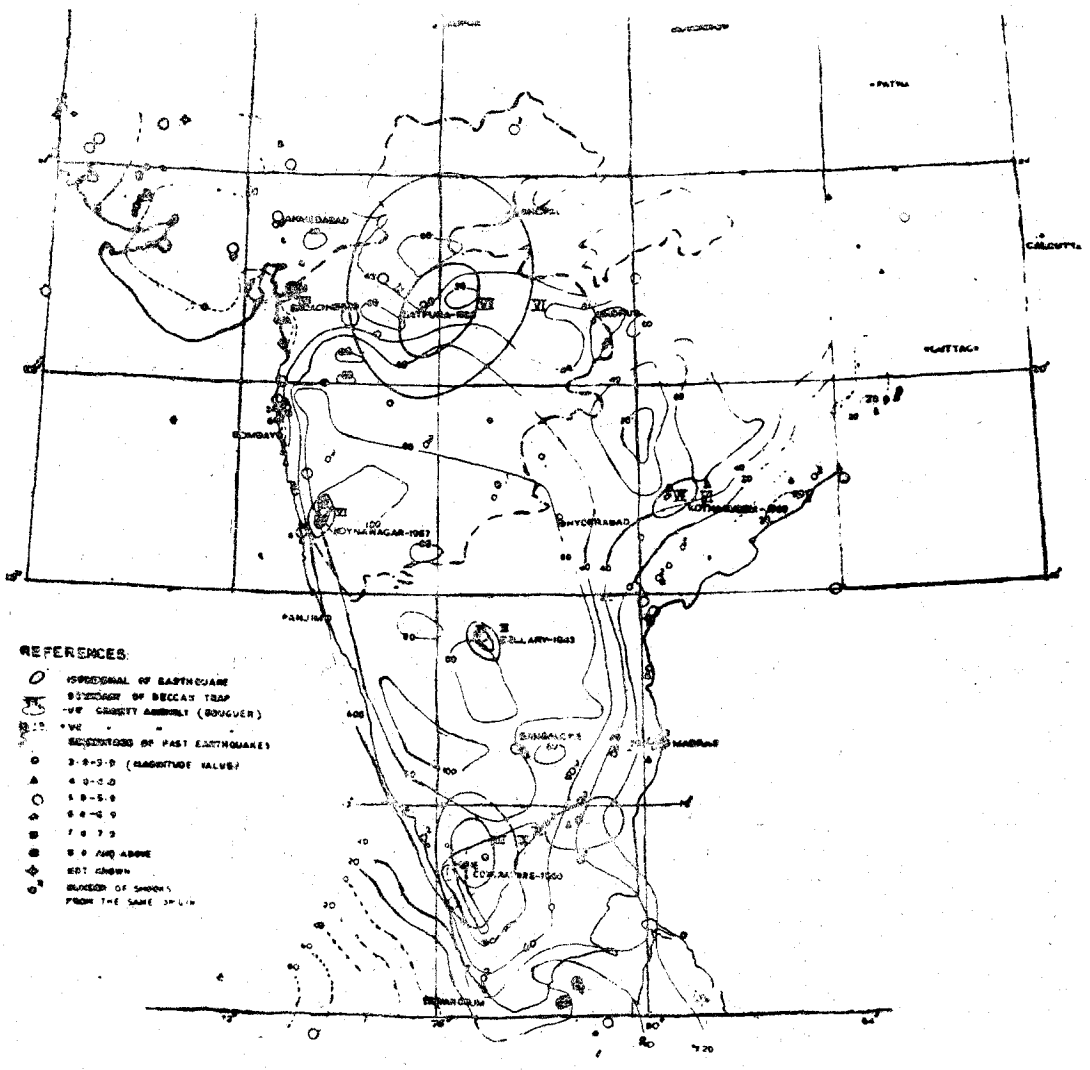


Fig. 6. Epicentral Map of Peninsular India and Neighbourhood along with Associated Geological and Geophysical Data and Isoseismals (VII and VI) of Six Known Severe Earthquakes since 1843 A D.

SEISMIC REGIONALISATIONS

The data on earthquakes in Fig. 6 and related geotectonic features [1,2,9] provide material for seismic regionalisation of Peninsular India. Zones of earthquake epicentres in the Narmada - Tapi - Son valley, Eastern coastal areas, Nilgiri hills, Palghat gap and coastal areas of Maharashtra and Gujarat as mentioned earlier.

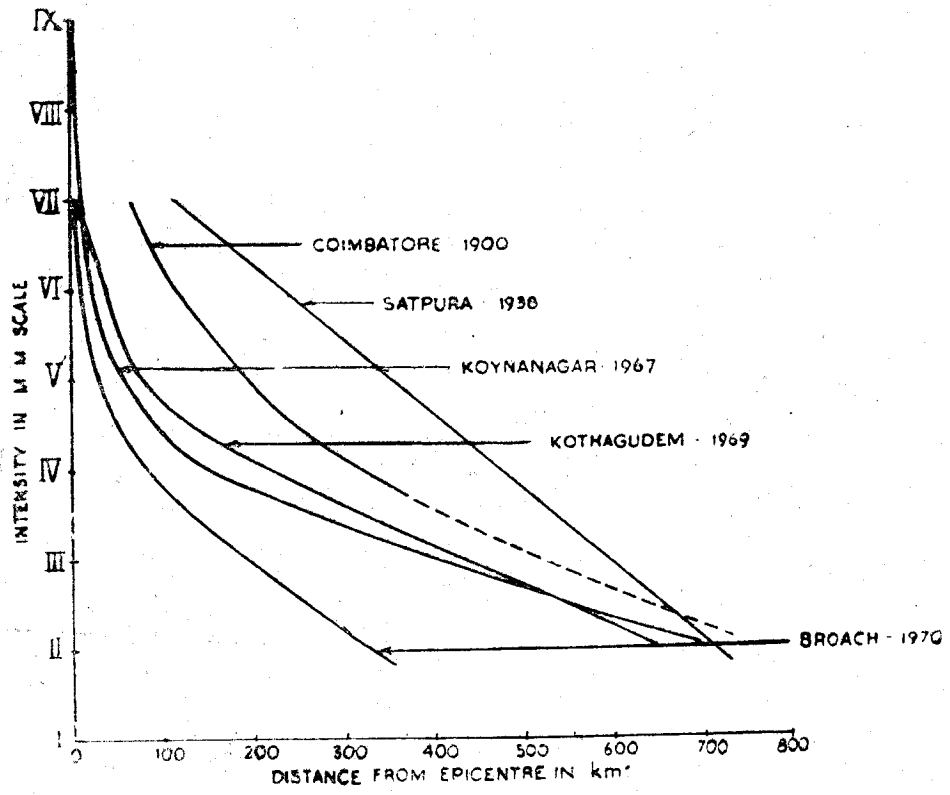
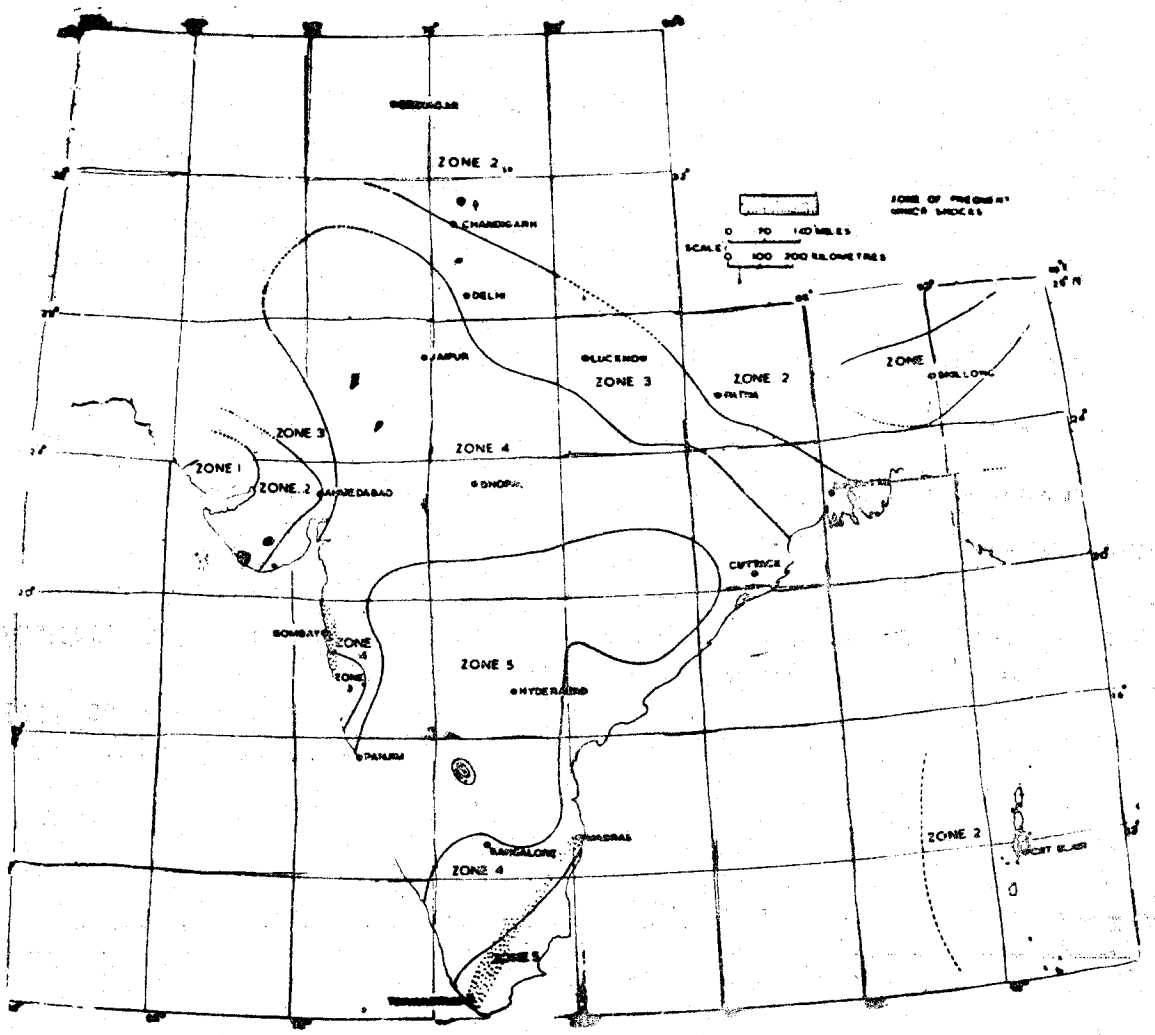


Fig. 7- Variation of Intensity (M.M. Scalce) with Distance from Epicentre of Five Known Severe Earthquakes in Peninsular India.

Tectonic maps published by the Geological Survey of India [13] and by Arogyaswamy [2] specially for the Peninsular India broadly corroborate the marginal activity of the Shield although the Deccan trap region at the West coast is a special area. Considering the triangular Peninsular block as a whole, the prevailing forces at West coast and the Narmaba-Tapi-Son valley are tensional with relatively small shearing component while the same at the East coast are some-what compressional – a fact which is consistant with the anticlockwise rotation of Indian block subsequent to the disruption of Gondwana land. The basis for seismic regionalisation of the Indian Peninsula used here is same as that used by one of the the authors[6] earlier. The regionalisation map in Fig. 8 shows that the marginal areas of the Shield can be rated Zone 4 with a central aseismic block–the only exception being Zone 3 at the West coast. There are also small areas near Bombay and in South India where minor earthquakes are quite frequent ; while swarms of earth tremors are a common feature isolated parts of Gujarat and in Narmada valley. Similar level of seismicity is prevalent in marginal areas of other Shield and stable masses of the world – a fact which may be of significant importance in understanding the overall stability and behaviour of these ancient continental nuclei during long period of their existance.

Figs. 9, 10, 11 and 12 show significant seismograms of Satpura earthquake (1938) [11], Ongole earthquake (1967), Kothagudem earthquake (1969) and Broach earthquake (1970) recorded in Stations in Peninsular India. Though normal phases have been identified on the seismograms, it is estimated that large energy in the seismograms is associated with continental phase L_g - a common feature of the Peninsular earthquakes. Seismograms of the Koynanagar earthquake (1967) in Indian stations also corroborate the predominance of



Description of the Zones. Equivalent Earthquake Intensity in Modified Mercalli Scale.
Zone 1 Very Heavy Damage XI, Zone 2 Heavy Damage IX and X
Zone 3 Moderate Damage VII and VIII, Zone 4 Minor Damage VI
Zone 5 No Damage, Below VI.

Fig. 8. Seismic Regionalisation Map of India. Available earthquake records between 1941–1970 A.D. are included in preparation of the map.

Instrumental Constants

Compt. = N—S
T_o = 12 secs.
V_s = Static Magnification

Details of earthquake

Origin Time = $14^d\ 00^h$ 48m 30s (G.M.T)
Epicentre = 21°32′ N ; 75°50′ E (IMD)
Magnitude = 6.2 (IMD)

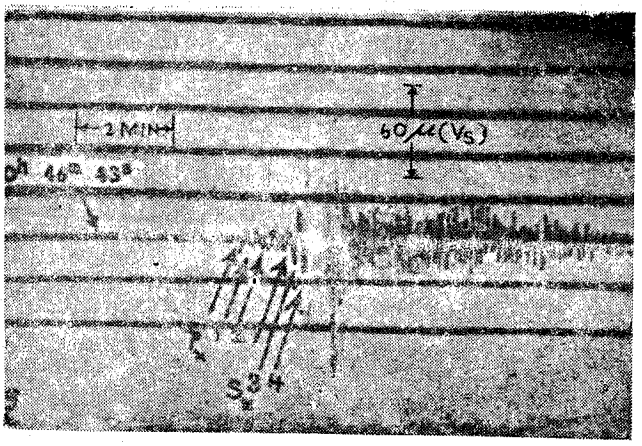
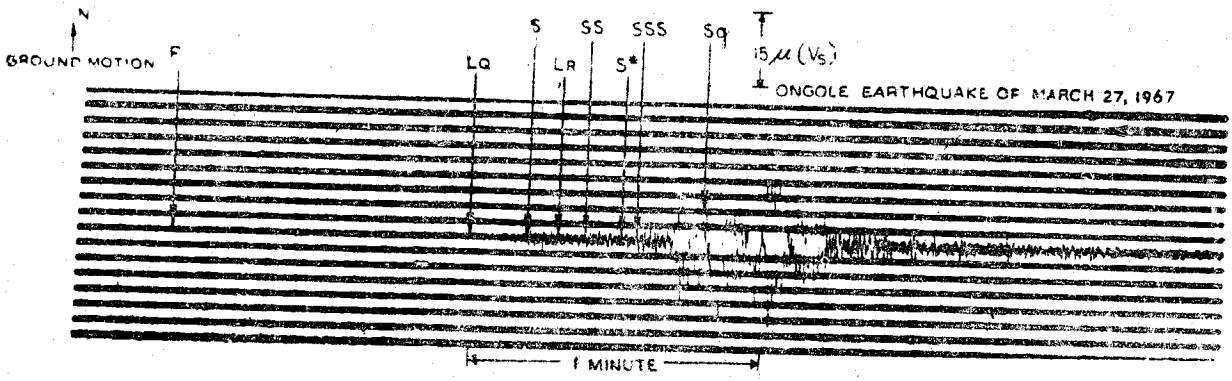
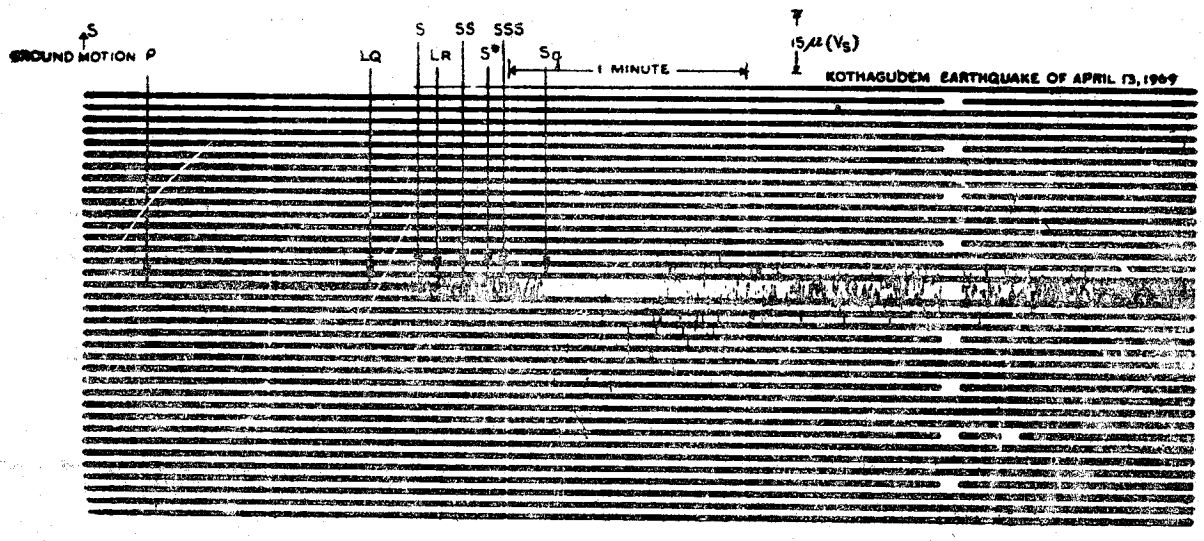


Fig. 9. Milne-Shaw Seismogram of Satpura (AP) Earthquake of March 14, 1938 recorded at Hyderabad observatory (Lat. 17°26′ N, Long 78°27′ E)



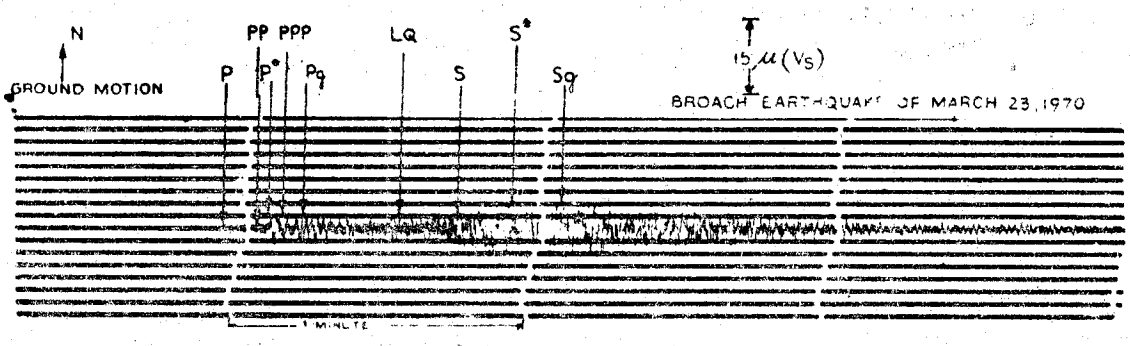
Instrumental constants		Details of Earthquake	
Component	= N – S	P	= $27^d\ 08^h\ 11^m\ 18^s$ (GMT)
T_o	= 0.8 sec.	S	= $08^h\ 12^m\ 31^s$
ε	= 50 : 1	Epicentre	= Lat. 15° 48′ N ; Long 80° 00′E (IMD)
V_s	= Static Magnification	Magnitude	= 5.8 (IMD)

Fig. 10. Wood-Anderson Seismogram of Ongole (A.P) Earthquake of March 27, 1967 Recorded at Koyna Dam Observatory (Lat. 17° 24′ N, Long. 93° 40′E)



Instrumental constants		Details of Earthquake	
Component	= N – S	P	= $13^d\ 15^h\ 26^m\ 97^s$
T_o	= 0.8 sec.	iS	= $15^h\ 26^m\ 35^s$
ε	= 50 : 1	Epicentre	= Lat. 17°55′ N : Long. 80°37′E (USCGS)
V_s	= Static Magnification	Magnitude	= 6.0 (CWPRS)

Fig 11. Wood-Anderson Seismogram of Kothagudem (Andhra Pradesh) Earthquake of April 13, 1969 Recorded at Satara Observatory (Lat. 17°41′ N; Long. 74°00′E)



Instrumental constants

Component	= N—S
T_o	= 0.8 sec.
ε	= 50 : 1
V_g	= Static Magnification

Details of Earthquake

P	= $23^d\ 01^h\ 53^v\ 53^s$ (GMT)
iS	= $01^h\ 54^m\ 40\ 5s$
Epicentre	= Lat. 24°41′ N, Long. 73° 12′E
Magnitude	= 5.7 (CWPRS)

Fig. 12. Wood Anderson Seismogram of Broach (Gujarat) Earthquake of March 23, 1970 Recorded at Khadakwasla (South) Observatory (Lat. 18°27′N ; Long 73°47′E)

the L_g phase. Table II shows the crustal features assessed from Satpura earthquake (1938) [11] and Koynanagar earthquake (1967) [14] for the Peninsular India. Moho discontinuity which can be put between 40–50 km deep from Table II in Peninsular India is slightly deeper than normally obtained in continents — a fact which is consistant with negative gravity anomaly over wide areas of the Peninsula although shallower depth of Moho was expected for such an ancient continental mass.

TABLE – II

Crustal Features of Peninsular India

Phase	Velocity km/sec		Layer	Thickness of various layers (km)	
	Tandon [14]	Mukerjee [11]		Tandon [14]	Mukherjee [11]
P	5.67	—	Granitic	22.4	40.0
P*	6.64	—	Basaltic	18.5	10.4
P_n	8.24	7.73	Moho discontinuity	41.0 (depth)	50.0 (depth)
S_n	4.7	4.38			

CONCLUSION

Thus, Indian Peninsula has a centrally aseismic stable mass surrounded by marginal areas having epicentres of moderate to low magnitude earthquakes occurring rarely. This low

marginal instablity similar to other Shield areas of the world is adequately accounted for by the known geotectonic features in the area and by simultaneous displacement and rotation of the Indian Peninsular block.

ACKNOWLEDGEMENT

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