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A REPORT ON THE DECEMBER 2, 1994
WADAKKANCHERI EARTHQUAKE

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PREFACE

The recent years have witnessed an increasing awareness about earthquakes, their causes and mitigation. That, earthquakes are unavoidable and largely unpredictable catastrophes have been proved by their occurrences even in the least expected areas. Images of devastation caused by the recent Japanese earthquake are still alive, and deeply disturbing. Even a country that is most advanced in seismological research had to watch helplessly, as the earthquake demolished an elegant city to heaps of rubble.

As earthquakes may occur even in the least expected locations, like the one that hit Latur, Maharashtra, several view points and speculations arise. Quite often, these places may have no record of seismicity in the recent past and the scientists have very little background data to work with. Experiences from similar areas can be very useful for studying such earthquakes. Thus, documenting details of every earthquake adds to our understanding of the processes associated with it.

Kerala is not a high seismicity region. During the historic and recent past, no earthquakes of magnitude ≥ 6.0 have occurred in this state. However, small tremors have been reported from different parts of the state during the recent and historic past. The latest among these occurred near Wadakkancheri, Thrissur on December 2, 1994. This earthquake and its aftershocks created much alarm among the residents of Wadakkancheri. During the days that followed, the Thrissur district administration swung into action, and took several measures to help people understand the situation and deal with any casualties that might arise. The scientists and revenue officials worked together for several days gathering information from the affected areas by interacting with the public. The media acted as the most effective interface between the study team and the local residents.

Data collected by several other agencies have been useful for detailed studies about the earthquake. Seismic data collected at the stations operated by the Kerala State Electricity Board (KSEB), India Meteorological Department (IMD), Bhabha Atomic Research Centre (BARC) and National Geophysical Research Institute (NGRI) have been useful in this study. This report presents a synthesis of all relevant data available for the region.

Earthquake "awareness" and "preparedness" were unfamiliar terms to our community until very recently. The Latur earthquake of 1993 brought forth the need to look at every region's seismic potential more critically. Our cities and villages are undergoing development at such a fast pace that a moderate tremor can cause heavy damages. Studies conducted in earthquake affected areas are very helpful in assessing the seismic potential of a region and help design earthquake resistant structures.

As we have seen in Japan and elsewhere, large earthquakes can be so destructive that no reasonable precautions can eliminate all risks. Despite the scientific efforts, we can only guess the probability of major earthquakes, especially in regions where they occur once in thousands of years. Scientific studies, proper engineering and community response can certainly mitigate the damages, if not completely eliminate them. Only a well-informed public will be able make effective use of scientific observations and prepare themselves to face such natural calamities. To achieve this goal, observations made while studying an earthquake should be presented to the public in the right perspective in a simple format. The report that we present here is an attempt in that direction.

We hope this report will be helpful to the people to understand and assess the seismic potential of the region. A glossary is given at the end of the report for easy reference of the technical terms used in the report. A companion publication (in Malayalam) titled, "*Bhoochalanam-Ariyenda Karyangal*" (facts about earthquakes) which is released along with this report is designed to answer the questions raised by the public.

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I. INTRODUCTION

A small tremor was reported from Thalasseri-Desamangalam area about 10 km north of Wadakkancheri, in the early morning hours of November 27, 1994. This microtremor was felt in a small area and it did not, in the normal course of events, call for much attention. However, in the evening of December 2, 1994, a larger tremor was felt in an area of about 1000 km². The vibrations of this tremor were felt almost close to the suburbs of Thrissur town. It was also experienced in parts of Palakkad and Malappuram districts.

During the days that followed, several smaller tremors occurred, causing panic among the people. There have been damages to buildings in the area and some poorly constructed houses were heavily damaged. The tremors were accompanied by loud thundering sound that frightened people all the more. In Desamangalam and the nearby areas, the scare was so much that the people spent several nights in temporary tents erected in their yards. Occasional minor tremors with thundering sound are still continuing even at the time of preparation of this report.

Immediately after the December 2 tremor, scientists of the Centre for Earth Science Studies (CESS) together with the district and taluk authorities visited the affected areas. The persistence of tremors was naturally a cause of alarm. It became necessary to remain 'alert' in case a larger event occurred. The district administration made all possible arrangements to meet any causality that might occur. An earthquake control room was opened at the taluk office, Thalappilly, and services of the officers were made available, round the clock. An earthquake assistance centre was also opened at Thalasseri, to offer immediate help, in the event of an emergency. A number of study classes were conducted to clear the doubts in the minds of people and help them understand what was going on.

This report presents a brief account of our investigations of the Wadakkancheri earthquake sequence. The instrumental data recorded at these seismic stations operated by KSEB and IMD are also presented in this report. The rationale, with suggestions for a more systematic study of the seismicity of the site is also presented in this report. This report is organized under four main sections, viz., site investigations, instrumental data, seismicity of Kerala and its neighbourhood, implications of the Wadakkancheri tremors and finally, recommendations and suggestions for future course of action.

II. SITE INVESTIGATIONS

The December 2 tremor was felt in an area of about 1000 km², in Thrissur, Palakkad and Malappuram districts. More than 600 km² of the felt area is in Thrissur district. Maximum effects were reported from areas around Thalasseri, Desamangalam, Varavur, Arangottukara, Pallur and Chittanda. Detailed field studies were conducted around these areas. Field surveys were also carried out in other parts of Thrissur, Malappuram and Palakkad districts, to map the extend of the affected areas. Field studies included intensity surveys, mapping of ground cracks and any measurable displacements and investigating other coseismic processes such as water levels changes in wells.

i. Intensity Survey

The main part of the survey consisted of collecting information on when and how the earthquake was felt. Visible site effects like ground cracks and damage to structures were noted. These characteristics were used to assign an intensity to the tremor.

The December 2 tremor was felt by everyone in the Thalasseri and Desamangalam areas. Most people reported that the tremor was felt between 4:05 p.m. and 4:10 p.m. A few people who actually looked at their watches reported the time of occurrence as 4:05 p.m. A small tremor was also reported just before the main event. This tremor, probably a foreshock, was reported only from the immediate vicinity of the main event. The tremor at 4:05 p.m. was accompanied by thundering sound. Most people felt the ground vibrations. There have been a few reports of windows rattling, one case of broken window glasses and some incidence of pieces of plaster falling off the ceiling. There were no reports of any furniture being moved or things falling off the shelves or such effects typical of moderate-size earthquakes.

Buildings obviously suffered most of the damage. Unplastered/poorly plastered houses were affected most. Relatively well constructed concrete houses also developed numerous hairline cracks. Nearly 1500 buildings have been reportedly damaged by the earth tremors in Arangottukara, Thrissur and Thalasseri.

There were some instances where cracks developed on the floor of the houses. The most striking of this occurred in a moderately well constructed house with cemented floor. This house is located close to the mosque at Tali which suffered maximum damage. The residents of the house reported that a narrow crack developed on the floor during the small tremor on November 27, and it widened during the December 2 earthquake. This was a clear indication that the only foreshock that was felt, occurred very close to Tali. Thus, it is highly probable that the main shock also originated at the same place.

In summary, the December 2 tremor at 4:05 p.m. was felt by most people as vibrations accompanied by loud thundering sound. In the Modified Mercalli Scale intensity V is described as:

"Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects some time noticed. Pendulum clocks may stop".

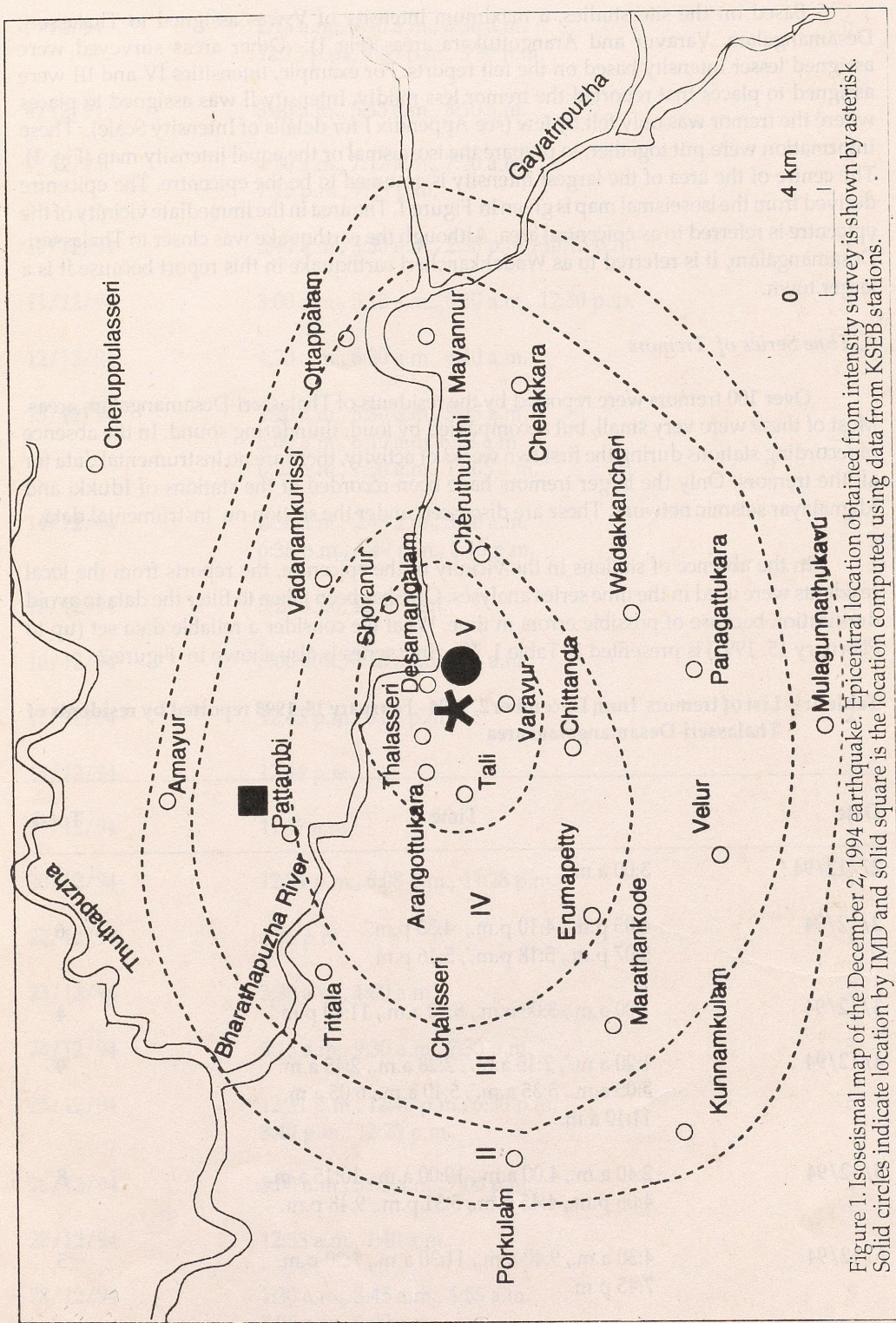


Figure 1. Isoseismal map of the December 2, 1994 earthquake. Epicentral location obtained from intensity survey is shown by asterisk. Solid circles indicate location by IMD and solid square is the location computed using data from KSEB stations.

Based on the site studies, a maximum intensity of V was assigned to Thalasseri, Desamangalam, Varavur and Arangottukara areas (Fig 1). Other areas surveyed were assigned lesser intensity based on the felt reports. For example, intensities IV and III were assigned to places that reported the tremor less mildly. Intensity II was assigned to places where the tremor was only felt by few (see Appendix I for details of Intensity Scale). These information were put together, to prepare the isoseismal or the equal intensity map (Fig. 1). The centre of the area of the largest intensity is assumed to be the epicentre. The epicentre derived from the isoseismal map is given in Figure 1. The area in the immediate vicinity of the epicentre is referred to as epicentral area. Although the earthquake was closer to Thalasseri-Desamangalam, it is referred to as Wadakkancheri earthquake in this report because it is a larger town.

ii. Time Series of Tremors

Over 100 tremors were reported by the residents of Thalasseri-Desamangalam areas. Most of these were very small, but accompanied by loud, thundering sound. In the absence of recording stations during the first two weeks of activity, there are no instrumental data for all the tremors. Only the larger tremors have been recorded at the stations of Idukki and Idamalayar seismic network. These are discussed under the section on instrumental data.

In the absence of stations in the vicinity of the epicentre, the reports from the local residents were used in the time series analyses. Care has been taken to filter the data to avoid duplication because of possible errors in time. What we consider a reliable data set (up to February 15, 1995) is presented in Table 1. The time series is also shown in Figure 2.

Table 1: List of tremors from December 2, 1994 - February 15, 1995 reported by residents of Thalasseri-Desamangalam area

Date	Time	Total
27/12/94	3:00 a.m.	1
2/12/94	4:05 p.m., 4:10 p.m., 4:35 p.m. 5:07 p.m., 5:18 p.m., 5:46 p.m.	6
3/12/94	1:00 a.m., 3:00 a.m., 8:10 a.m., 11:40 p.m.	4
4/12/94	1:20 a.m., 2:15 a.m., 2:28 a.m., 2:45 a.m. 3:05 a.m., 5:35 a.m., 5:40 a.m., 6:05 a.m. 11:10 a.m.	9
5/12/94	2:40 a.m., 4:00 a.m., 10:00 a.m., 10:15 a.m. 4:06 p.m., 4:45 p.m., 5:31 p.m., 9:48 p.m.	8
6/12/94	4:30 a.m., 9:40 a.m., 11:30 a.m., 7:30 p.m. 7:45 p.m.	5

7/12/94	2:15 a.m., 3:10 a.m., 8:30 a.m. 12:35 p.m., 1:55 p.m., 3:30 p.m.	6
8/12/94	3:40 a.m., 5:35 a.m., 8:10 a.m.	3
9/12/94	4:30 a.m., 7:12 a.m., 7:20 a.m. 7:15 p.m., 7:29 p.m.	5
10/12/94	2:40 a.m., 3:30 a.m., 2:30 p.m., 10:15 p.m.	4
11/12/94	3:00 a.m., 5:15 a.m., 6:10 a.m., 12:30 p.m.	4
12/12/94	4:20 a.m., 6:20 a.m., 6:40 a.m.	3
13/12/94	3:20 a.m., 5:30 a.m., 5:45 a.m. 6:00 a.m., 6:10 a.m. 6:23 a.m. 6:27 a.m., 7:30 a.m., 11:05 a.m.	9
14/12/94	2:30 a.m., 2:45 a.m., 3:00 a.m. 6:38 p.m., 6:40 p.m., 8:10 p.m.	6
15/12/94	3:22 a.m., 12:38 p.m.	2
16/12/94	3:00 a.m., 3:20 a.m., 3:28 a.m.	3
17/12/94	12:45 p.m., 6:07 p.m.	2
18/12/94	12:14 p.m.	1
19/12/94	11:17 a.m.	1
20/12/94	12:24 p.m., 6:08 p.m., 11:28 p.m.	3
22/12/94	6:35 p.m.	1
23/12/94	3:38 a.m., 4:00 a.m.	2
24/12/94	5:15 a.m., 9:30 a.m., 7:30 p.m.	3
25/12/94	12:31 p.m., 12:40 p.m., 6:30 p.m. 8:40 p.m., 12:25 p.m..	5
26/12/94	3:00 a.m., 3:35 a.m., 7:00 p.m.	3
27/12/94	12:55 a.m., 1:40 a.m..	
28/12/94	1:30 a.m., 3:45 a.m., 4:55 a.m. 5:05 a.m., 6:00 a.m.	5

29/12/94	3:30 a.m., 6:00 a.m., 6:35 p.m., 7:05 p.m.	4
30/12/94	3:30 a.m., 12:40 p.m.	2
01/01/95	3:30 a.m., 6:30 a.m., 7:30 p.m. 8:20 p.m., 8:40 p.m.	5
02/01/95	5:00 a.m.	1
16/01/95	3:55 a.m.	1
18/01/95	2:51 a.m.	1
21/01/95	7:00 a.m.	1
26/01/95	5:00 a.m.	1
28/01/95	4:35 a.m.	1
02/02/95	3:15 a.m.	1
04/02/95	5:45 a.m.	1
13/02/95	2:00 a.m.	1
15/02/95	3:00 a.m., 3:05 a.m., 4:10 a.m., 5:00 a.m.	4

* Recorded at Poringalkuthu.

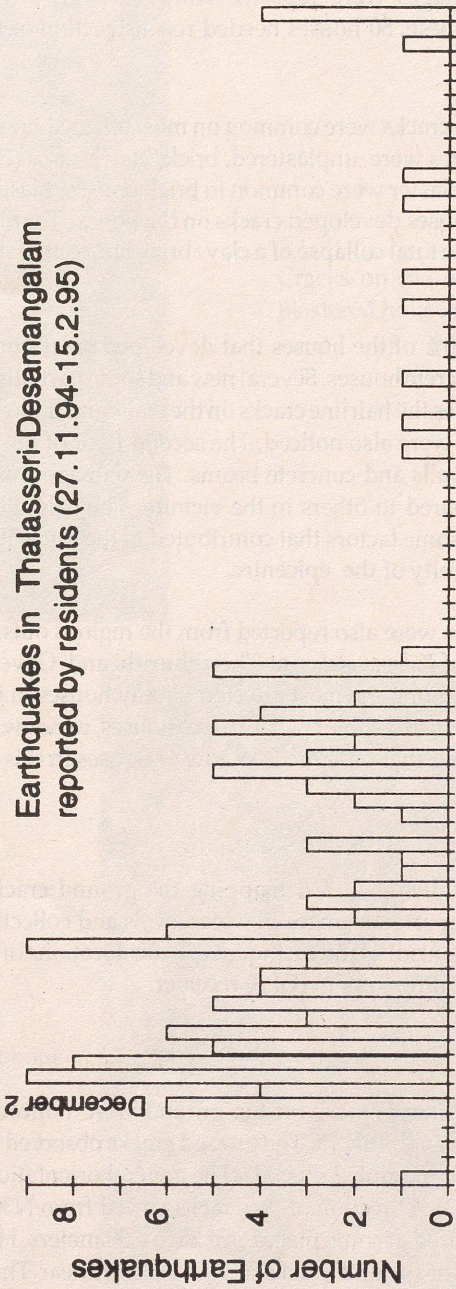
iii. Magnitude Estimate from Maximum Intensity

Magnitude of an earthquake is the measure of its size, determined from the recorded data. Usually, the maximum amplitude of the wave or the total duration of the recorded trace is used to calculate the magnitude. Magnitude of a tremor can also be estimated from intensity using the following empirical relation

$$M = 1 + \frac{2}{3} I_0$$

where M is the magnitude and I_0 is the maximum intensity observed.

For the maximum intensity of V, the magnitude of the December 2 earthquake is estimated to be 4.3. The magnitude estimate based on the instrument data is discussed in the subsequent sections.



November 27, 1994 - February 15, 1995

Figure 2. Frequency of occurrence of earthquakes from November 27 to February 15.

iv. Damage to Property

As per the reports of the revenue officials, over 3700 houses suffered minor damages. Maximum damages were reported from Varavur, Desamangalam, Arangottukara and Thalasseri. Of these, 50 houses needed reconstruction or major repair before they could be reoccupied.

Hairline cracks were common on most affected houses. Nearly 90% of the houses that suffered damages were unplastered, brick/clay houses (Photograph 1, Plate I). Incidence of fallen/broken plaster were common to brick houses, plastered with low quantity of cement. Several such houses developed cracks on the floors. There were reports of partial collapse of some house. The total collapse of a clay/brick house at Mayannur was the most significant of such instances.

About 10% of the houses that developed cracks on the walls were well constructed cement and concrete houses. Several new and some partially completed houses suffered minor damages. Besides the hairline cracks on the walls and floors, bend in the support pillars, cracks along the lintel were also noticed. The second floor of the mosque at Tali developed several cracks on the walls and concrete beams. The damage was relatively more extensive in this building, compared to others in the vicinity. The height of the building and the particular design may be some factors that contributed to the intensity of damage. Also, this building is in the close vicinity of the epicentre.

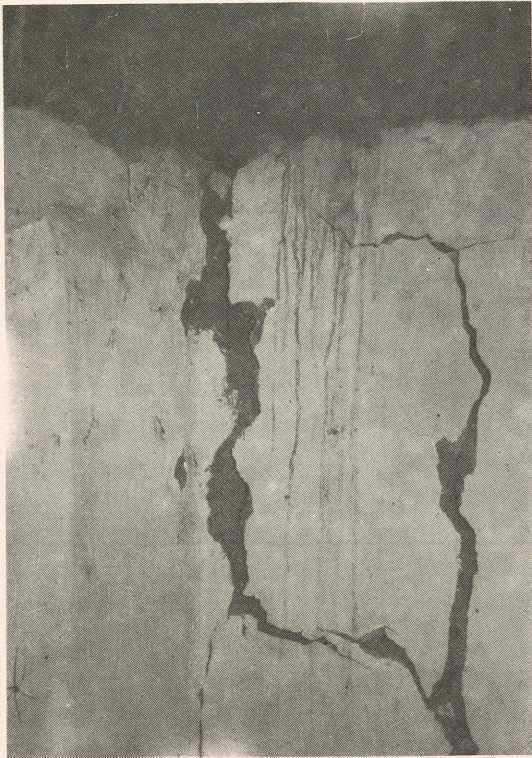
Damages were also reported from the regions outside the immediate epicentral area. The buildings of *Kalamandalam* at Cheruthurithi and Government Polytechnic at Kulapully, Shoranur are among the most affected. Many houses in the Sanskrit College quarters near Pattambi developed visible cracks. In two houses, window frames were displaced by 2-3 mm. It is worth noting that only the E-W row of houses in this colony were affected.

v. Field Observations

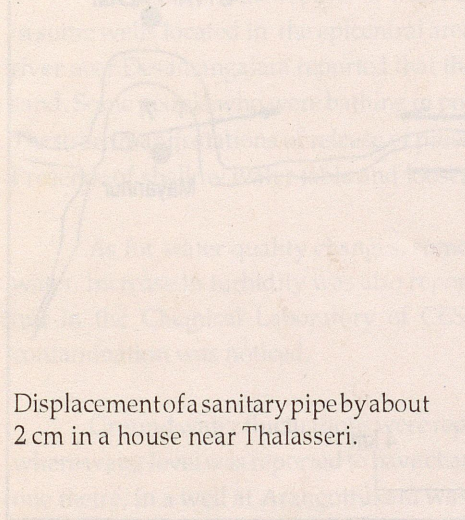
Field studies included mapping the ground cracks, measuring the displacements, investigating reported changes in water levels and collecting other field evidences that help study the mechanism of the earthquake. Exact locations of observations were obtained using a Global Positioning System (GPS) receiver.

(a) Ground cracks

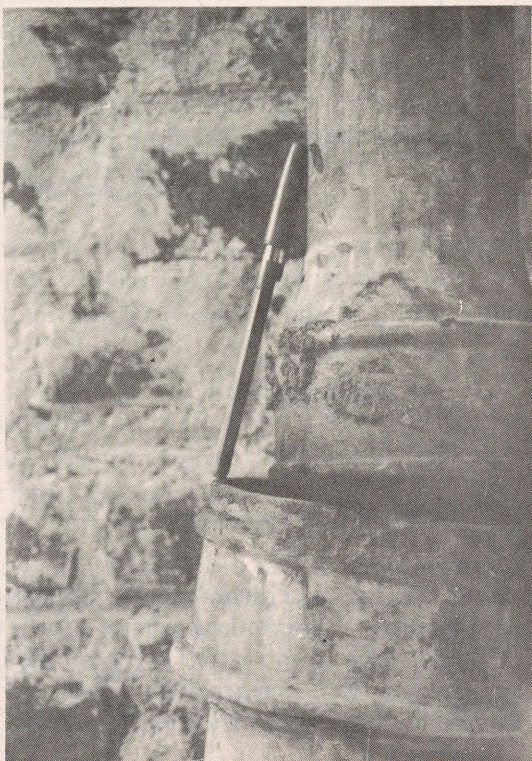
Several linear cracks on the ground were noticed at some locations in Thalasseri, Varavur and Arangottukara. The ground cracks observed at various locations were less than 2 mm wide (Photograph 2, Plate I). The general orientation of the cracks was in ENE to EW direction (Fig. 3). Direction of the cracks varied from N30° to N80°. The depth of the crack could be measured at some places as 0.25 to 0.50 meters. However a trial pit taken across one of the prominent ground cracks at Kadukasseri near Thalasseri did not reveal any useful information regarding the ground breakage. The one-metre-deep trench exposed purely shallow and superficial nature of the ground cracks. It was noted that these cracks, although related to the tremors, were mostly confined to the loose soil and some developed in the areas of land-fill.



Cracks on the wall of a poorly plastered house near Mayannur.



Displacement of a sanitary pipe by about 2 cm in a house near Thalasseri.



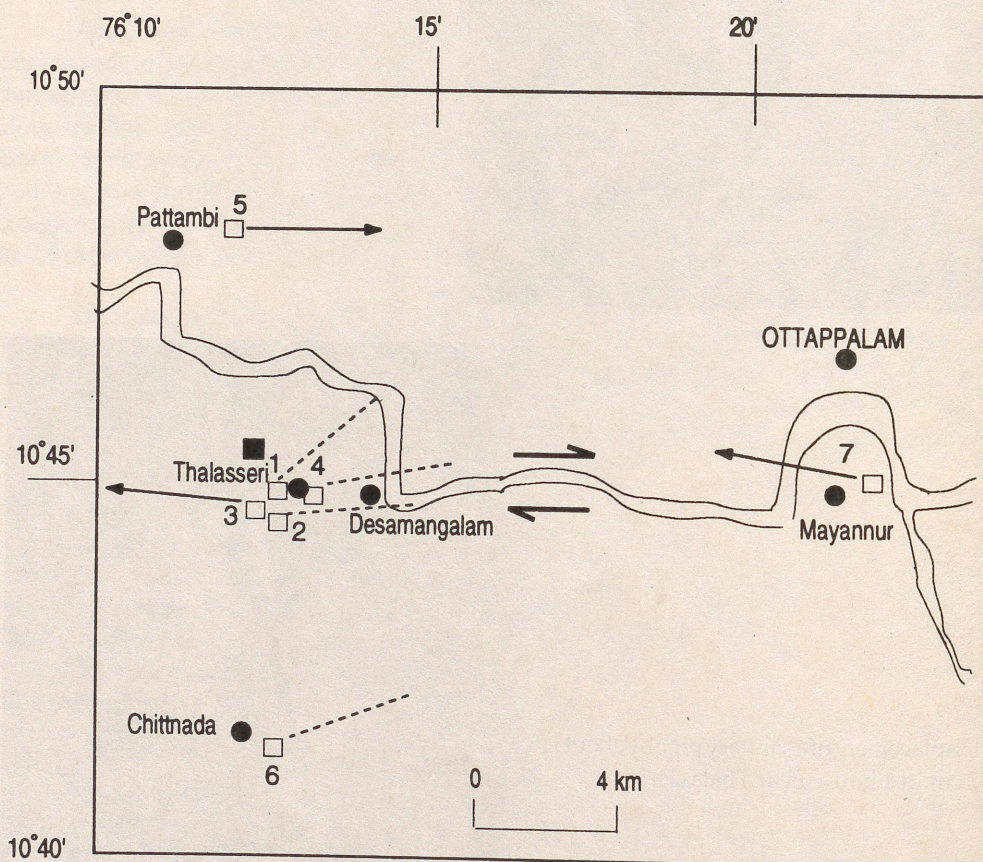


Figure 3. Directions of ground cracks and displacements in the affected area. Open squares show locations of observations. Arrows indicate the direction of displacement. Dashed lines show orientation of ground cracks (length of the lines are not to scale). Filled square shows the location of the well where increase in water level was observed. The inferred direction of movement along the E-W fault trending system is indicated by solid arrows.

(b) Displacement of objects

Minor displacement of objects were observed at some locations at Thalasseri, Arangottukara and Varavur. Dislocation of a sanitary pipe by about 2 cm was observed in a house under construction near Thalasseri (Photograph 3, Plate II). Movement of the support pillar by about 1 cm; displacement of 2 to 3 mm along cracked walls and shift in the window frames by 2 to 3 mm among other were observed displacements. These are indicated in Figure 3 together with the directions of displacement at these locations.

Most of the measurable dislocation occurred in the ENE to EW direction, with the preponderance of dislocation in the EW direction. The most conclusive evidence of westward movement was observed on the wall of a house, made of bricks and clay. This house located at Thalasseri did not develop any major cracks, but one of its walls appeared to have been warped in the east-west direction with the convex side towards west. The eastward displacement of window frames by about 3 mm in the Sanskrit College Quarters, located on the north bank of the Bharathapuzha river suggest movement in the opposite direction. From these evidences, we infer that the faulting occurred on an east-west trending strike-slip or thrust fault. The inferred sense of motion is shown in Figure 3.

(c) Water level changes

There were some reports of water quality changes as well as water level fluctuations in some wells located in the epicentral area. People working in the banks of Bharathapuzha river near Desamangalam reported that they noticed boils coming up in the water saturated sand. Some people who were bathing in ponds also experienced bubbles coming from below. These are manifestations of release of pressure, which can be felt more in the epicentral area. Presence of shallow water table and loose soil make them more perceptible.

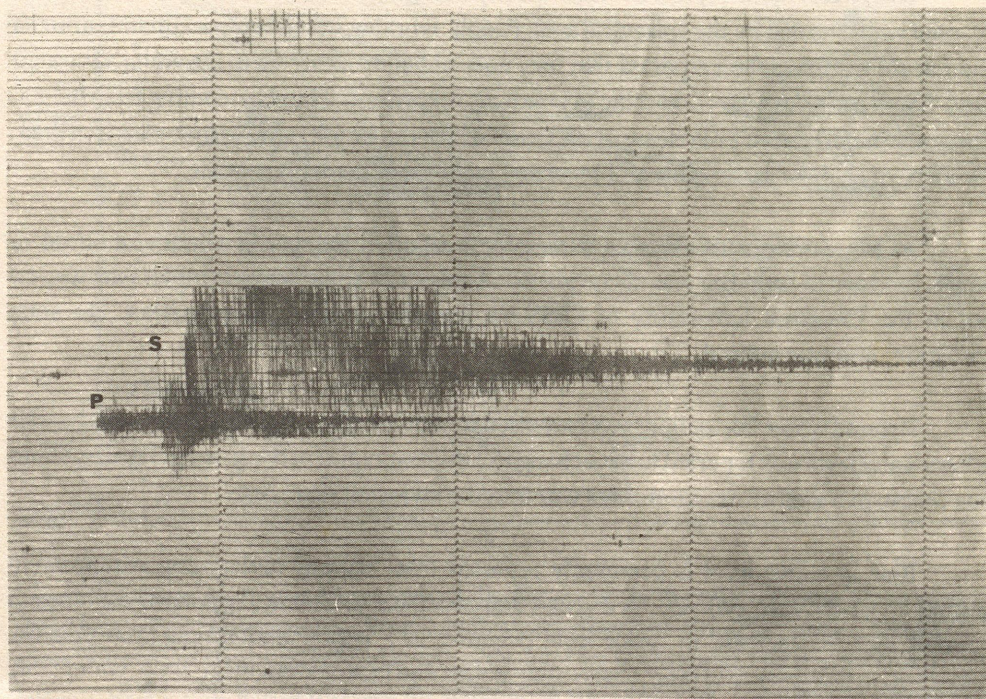
As for water quality changes, some people reported changes in colour and odour of water. Increase in turbidity was also reported. Analyses of some water samples was carried out in the Chemical Laboratory of CESS for possible sewage contamination. No such contamination was noticed.

Ground water fluctuations were reported from some areas. We visited some of the sites where water level was reported to have changed. Only one report of rise in water level by about one metre, in a well at Arangottukara was found convincing (Fig. 3).

Rise in water level is commonly reported from regions undergoing compression during an earthquake process. As discussed above, there are some supportive evidence to suggest that the increase in water level occurred in a region undergoing compression. However, in the absence of more observation points and lack of knowledge of the water table conditions prior to the earthquake, no conclusive inference could be drawn on this aspect.



Ground cracks observed near Thalasseri.



Record of the December 2 Wadakkancheri earthquake at Idukki observatory (source : KSEB)

III. INSTRUMENTAL DATA

There are no seismic stations in the immediate vicinity of Wadakkancheri. Stations operated by KSEB and a few other stations located in different parts of southern India recorded the larger events of the Wadakkancheri earthquake sequence that started on November 27, 1994. These data are presented in this section.

i. December 2, 4:05 p.m. Earthquake

The December 2 tremor was recorded by the seismic stations of NGRI, BARC, IMD and KSEB. Only the larger ones have been recorded by these stations. The Wadakkancheri main shock on Dec 2 (4:05 p.m. local time) was recorded by all the stations of the Idukki-Idamalayar nets (Table 2). The trace of the event as recorded by Idukki station is reproduced in Photograph 4 (Plate IV). The use of P and S arrival times of different stations are used in locating an earthquake is given in the Appendix II

Table 2: Arrival times of the P and S waves at various stations

Station	P-arrival hr : min : sec	S-arrival hr : min : sec	(S-P) sec	Ep. Dist km (appr.)
PGL	10 : 36 : 37.00	10 : 36 : 45.30	8.3	66.0
SHL	10 : 36 : 37.00	10 : 36 : 45.30	8.3	66.0
IDL	10 : 37 : 06.00	10 : 37 : 16.20	10.2	81.0
MCT	10 : 37 : 35.50	10 : 37 : 50.50	15.0	120.0
ALD	10 : 37 : 36.00	10 : 36 : 54.00	18.0	144.0
KUL	10 : 37 : 40.50	10 : 36 : 56.70	16.2	129.0
PLM	10 : 37 : 14.50	10 : 37 : 30.00	15.5	124.0
IDK	10 : 37 : 37.50	10 : 37 : 54.50	17.0	136.0
GBA	10 : 36 : 51.00			
NGRI	10 : 38 : 39.00	10 : 40 : 24.50		

* Arrival times are in GMT (IST is 5 hours and 30 minutes ahead)

The stations most closer to the source are Sholayar and Poringalkuthu. Of these, the Portacorder at Sholayar was out of order and the Wood - Anderson seismographs have not recorded the event well. The epicentral parameters of the earthquake located using data from KSEB stations are given in Table 3. Locations obtained from field studies and the location obtained by IMD are given in Table 3.

Table 3: Epicentral parameters of the Dec. 2, 1994 earthquake

1. Location using data from Idukki and Idamalayar seismic stations (using HYPO 71)

Date	Origin Time hr: min: sec	Lat°N	Long°E	No*	RMS**	Q***
02.12.94	10:36:34.00 (GMT) 16:06:34.00 (IST)	10.82	76.22	7	0.41	D

* No. of stations used ** Error indicator (permitted level - 0.1) *** Quality of the location (D is the poorest)

2. Location by IMD

Date	Origin Time hr: min: sec	Lat°N	Long°E	Mag
02.12.94	16:06:57.00 (IST)	10.75	76.25	3.8

3. Location from Isoseismal map and site investigations

Date	Origin Time hr: min: sec (IST)	Lat°N	Long°E	Mag
02.12.94	16:05:00.00	10.75	76.21	4.3

The location of the tremor based on various data sets can be quite different. The location derived from the field investigations (10.75°N, 76.21°E). The location given by IMD (10.75°N 76.25°E) is about 2 km to the west as indicated in Figure 1. Most of the aftershocks recorded by IMD using the local seismic stations are also located close to the above locations.

The location obtained from seismic stations of Idukki-Idamalayar network is close to Pattambi, further north of the locations obtained from isoseismals as well as the IMD location. The location from Idukki-Idamalayar network is poorly constrained due to various reasons, the most important being the large distance to the nearest station (Fig. 4). The poor azimuthal coverage (location of all stations in one direction), problems with the velocity model used (which helps the computer programme to calculate the distances to each station) and errors in the station locations (generally derived from toposheets and they can be in error by a few kilometres) are possible sources of errors.

In the absence of closer stations to locate an event, it may be more realistic to use field evidences and aftershock data to constrain the epicentral coordinates. Thus, we consider that the actual epicentre is closer to the location derived from the isoseismal map. This is further supported by the location based on the aftershocks (IMD locations).

ii. Other Events Recorded by Idukki-Idamalayar Network

As listed in Table 1, a number of perceptible aftershocks were reported by people living in the epicentral area. The Portacorder charts of the station at Poringalkuthu (December 1-31, 1994) were used to pick up possible events that occurred after the main event on December 2. The S-P was typically 8 to 8.5 seconds at this station. Some of the larger tremors were also recorded by other stations of the network. Events, identified as earthquakes originating from Thalasseri-Desamangalam areas are listed in Table 4. We have not attempted to locate these events because of the limitations of using distant stations which have already been discussed.

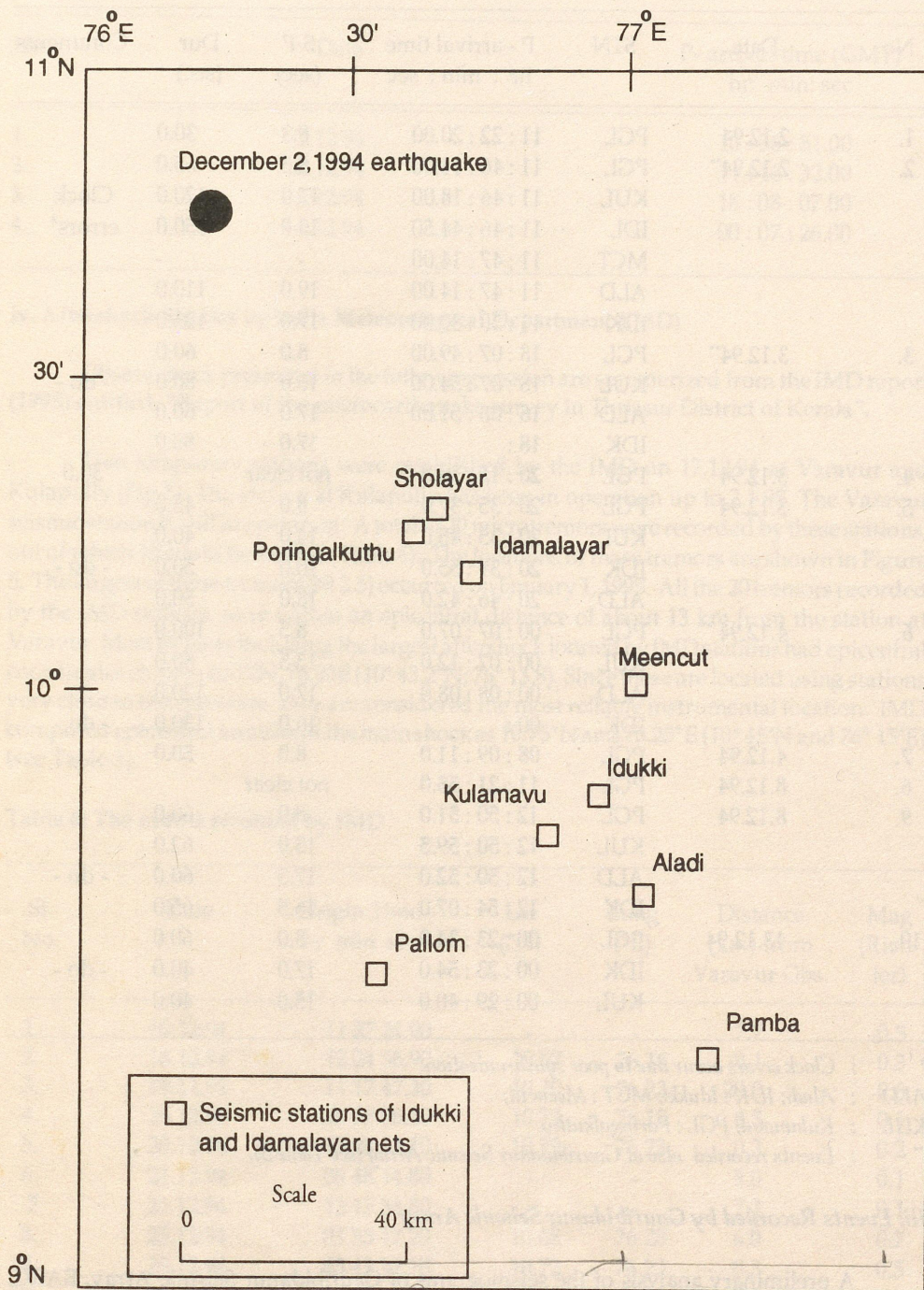


Figure 4. Azimuthal coverage of stations that recorded the December 2 earthquake.

Table 4: Events recorded at Idukki-Idamalayar seismic stations

No	Date	STN	P - arrival time hr : min : sec	S-P (sec)	Dur (sec)	Comments
1.	2.12.94	PGL	11 : 22 : 20.00	8.3	30.0	
2.	2.12.94**	PGL	11 : 46 : 14.00	8.5	65.0	
		KUL	11 : 46 : 18.00	15.0	120.0	Clock errors*
		IDL	11 : 46 : 44.50	10.0	150.0	
		MCT	11 : 47 : 14.00	-	-	
		ALD	11 : 47 : 14.00	19.0	110.0	
		IDK	11 : 50 : 30.00	17.0	125.0	
3.	3.12.94**	PGL	18 : 07 : 49.00	8.0	60.0	
		KUL	18 : 07 : 54.00	15.0	80.0	- do -
		ALD	18 : 08 : 51.00	17.0	60.0	
		IDK	18 :	17.0	80.0	
4.	3.12.94	PGL	20 : 15 : 30.0	not clear		30.0
5.	3.12.94	PGL	20 : 35 : 37.0	8.0	45.0	
		KUL	20 : 35 : 45.0	14.0	40.0	
		IDK	20 : 39 : 55.0	16.0	50.0	- do -
		ALD	20 : 46 : 42.0	18.0	50.0	
6.	4.12.94 **	PGL	00 : 07 : 07.0	8.5	100.0	
		KUL	00 : 07 : 12.0	15.5	80.0	
		ALD	00 : 08 : 08.0	17.0	120.0	
		IDK	00 :	16.0	130.0	- do -
7.	4.12.94	PGL	08 : 09 : 11.0	8.0	50.0	
8.	8.12.94	PGL	11 : 21 : 55.0	not clear		
9.	8.12.94	PGL	12 : 50 : 51.0	8.0	60.0	
		KUL	12 : 50 : 59.5	15.0	62.0	
		ALD	12 : 50 : 52.0	17.5	60.0	- do -
		IDK	12 : 54 : 07.0	16.5	65.0	
10.	13.12.94	PGL	00 : 23 : 34.0	8.0	60.0	
		IDK	00 : 23 : 54.0	17.0	40.0	- do -
		KUL	00 : 29 : 40.0	15.0	40.0	

* : Clock errors occur due to poor synchronisation.

ALD : Aladi; IDK : Idukki; MCT : Meencut;

KUL : Kulamaavu; PGL : Poringalkuthu.

** : Events recorded also at Gauribidanur Seismic Array (see Table 5).

iii. Events Recorded by Gauribidanur Seismic Array

A preliminary analysis of the seismograms of Gauribidanur Seismic Array, BARC, Bangalore indicates occurrence of four events that are consistent with other reports (G. Jayachandran Nair, personal communication). These are listed in Table 5.

Table 5: Events recorded at Gauribidanur Seismic Array (GBA)

No	Date	P- arrival time (GMT) hr: min: sec
1.	2.12.94	10 : 36 : 51.00
2.	2.12.94	11 : 46 : 32.00
3.	3.12.94	18 : 08 : 07.00
4.	4.12.94	00 : 07 : 26.00

iv. Aftershock Studies by India Meteorological Department (IMD)

Observations presented in the following session are summarized from the IMD report (1995) entitled, "Report of the microearthquake survey in Thrissur District of Kerala".

Two temporary stations were established by the IMD on 17.12.94 at Varavur and Kulapully (Fig 5). The station at Kulapully has been in operation up to 2.1.95. The Varavur seismic station is still in operation. A total of 20 microtremors were recorded by these stations, out of which 13 could be located (Table 6). The locations of these tremors are shown in Figure 5. The largest of these tremors (M 2.5) occurred on January 1, 1995. All the 20 tremors recorded by the IMD stations were within an epicentral distance of about 13 km from the station at Varavur. Most tremors including the largest aftershock located by IMD stations had epicentral coordinates close to 10.72N, 76.23E (10° 43.2' N; 76° 13.8). Since these are located using stations very close to the epicentre, they are considered the most reliable instrumental location. IMD computed epicentral location of the main shock as 10.75°N and 76.25°E (10° 45' N and 76° 15' E) (see Table 3).

Table 6: The events recorded by IMD

Sl. No.	Date	Origin Time hr min sec	Lat (°N)	Long (°E)	Distance (km) from Varavur Obs.	Mag (Rich- ter)
1.	18.12.94	11 27 24.90	-	-	7.2	-0.5
2.	18.12.94	12 24 36.90	10.67	76.16	9.1	0.3
3.	19.12.94	11 17 47.30	10.70	76.23	20.0	0.6
4.	20.12.94	18 08 06.30	10.73	76.15	8.5	0.1
5.	20.12.94	23 28 13.10	10.72	76.23	0.3	0.2
6.	21.12.94	06 48 14.80	-	-	8.0	0.1
7.	21.12.94	12 15 38.80	-	-	7.2	0.1
8.	25.12.94	03 35 17.20	10.68	76.28	6.0	0.7
9.	25.12.94	05 43 12.10	10.72	76.23	0.3	0.5
10.	25.12.94	12 45 45.90	10.72	76.23	0.3	-0.5
11.	25.12.94	12 46 19.50	10.63	76.29	12.2	-0.5
12.	25.12.94	18 32 15.20	10.72	76.21	2.0	0.2

Table 6 (Contd.)

13.	28.12.94	15 47 22.80	-	-	6.4	0.05
14.	28.12.94	21 03 00.30	10.78	76.32	12.3	0.9
15.	29.12.94	18 35 00.40	10.78	76.32	2.5	0.5
16.	01.01.95	01 16 32.60	10.65	76.19	8.2	1.0
17.	01.01.95	05 31 37.10	10.72	76.23	0.3	2.5
18.	04.01.95	15 50 03.10	-	-	8.1	0.1
19.	05.01.95	13 26 20.90	-	-	9.0	1.0
20.	05.01.95	19 05 13.40	-	-	8.1	0.1

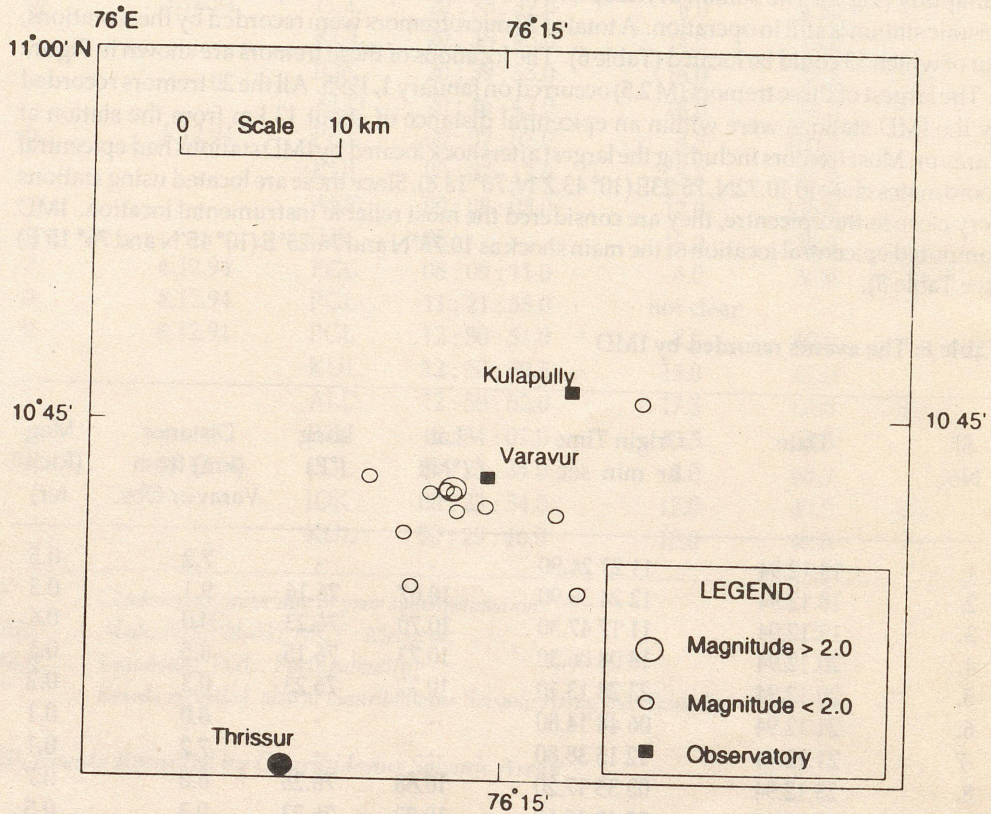


Figure 5. Epicentral coordinates of earthquakes from 18.12.94 to 05.01.95 (modified from IMD Report, 1995)

IV. SEISMIC ACTIVITY IN KERALA AND THE NEIGHBOURING AREAS

i. Background

Moderate tremors have been reported from different parts of Kerala from historic past, the earliest one dating back to 1341, a tremor felt in Malabar. In one of the earliest reports on seismic phenomena in British India (Ballore, 1900), this event is mentioned as a "severe earthquake", as a consequence of which Vypin (referred in the reports as Waypi) Island was raised above the sea level.

Seismicity of Kerala and that of the west coast of India has been the subject of several studies over the past three decades (Gubin, 1968,1969; Karunakaran and Mahadevan, 1971; Tilak, 1980, Krishnabrahmam, 1993). In general, these studies suggested that the tremors in the west coast are the result of adjustments on old preexisting faults in the region. The largest instrumentally recorded earthquake in Kerala ($M_L = 4.5$) has occurred at Nedumkandam, about 25 km west of Idukki.

During the last decade (1984-94), there have been isolated occurrences of earthquakes in different parts of the state (Fig. 6) These have been investigated and the results are presented in various reports (Rastogi et al., 1989; Singh et al., 1988; 1989, Singh and Santosh, 1993; Singh and Rajendran, 1993; Rajendran and Rajendran, 1994, for example). Observations made in these reports have generally been constrained by the lack of instrumentally recorded data. The existing seismic stations at Trivandrum (operated by IMD) and the stations of KSEB at Idukki and Idamalayar are insufficient to locate small tremors occurring at large distances from these stations. The need for a more systematic monitoring of microseismicity of Kerala is imperative, particularly in view of the increasing number of tremors.

ii. Previous Seismicity in Thrissur District

There have been reports of small tremors from some parts of Thrissur since 1989. A small tremor of magnitude ≈ 3.0 occurred at Panagattukara, close to Wadakkancheri on March 15, 1989. This tremor was accompanied by rumbling sound but it was felt only in a small area of about 30 km² (Singh and Raghavan, 1989). Tremors were also reported from Chavakkad and Wadakkancheri during February 25-26, 1993. The February 25 tremor was located close to Chavakkad and the tremor on February 26 was located near Kalazhi, south of Wadakkancheri. Severe shaking of the ground accompanied by sound comparable to passing of heavy trucks were reported during both these tremors. These have been assigned a magnitude of 3.6, and are discussed in detail by Singh and Santosh (1993).

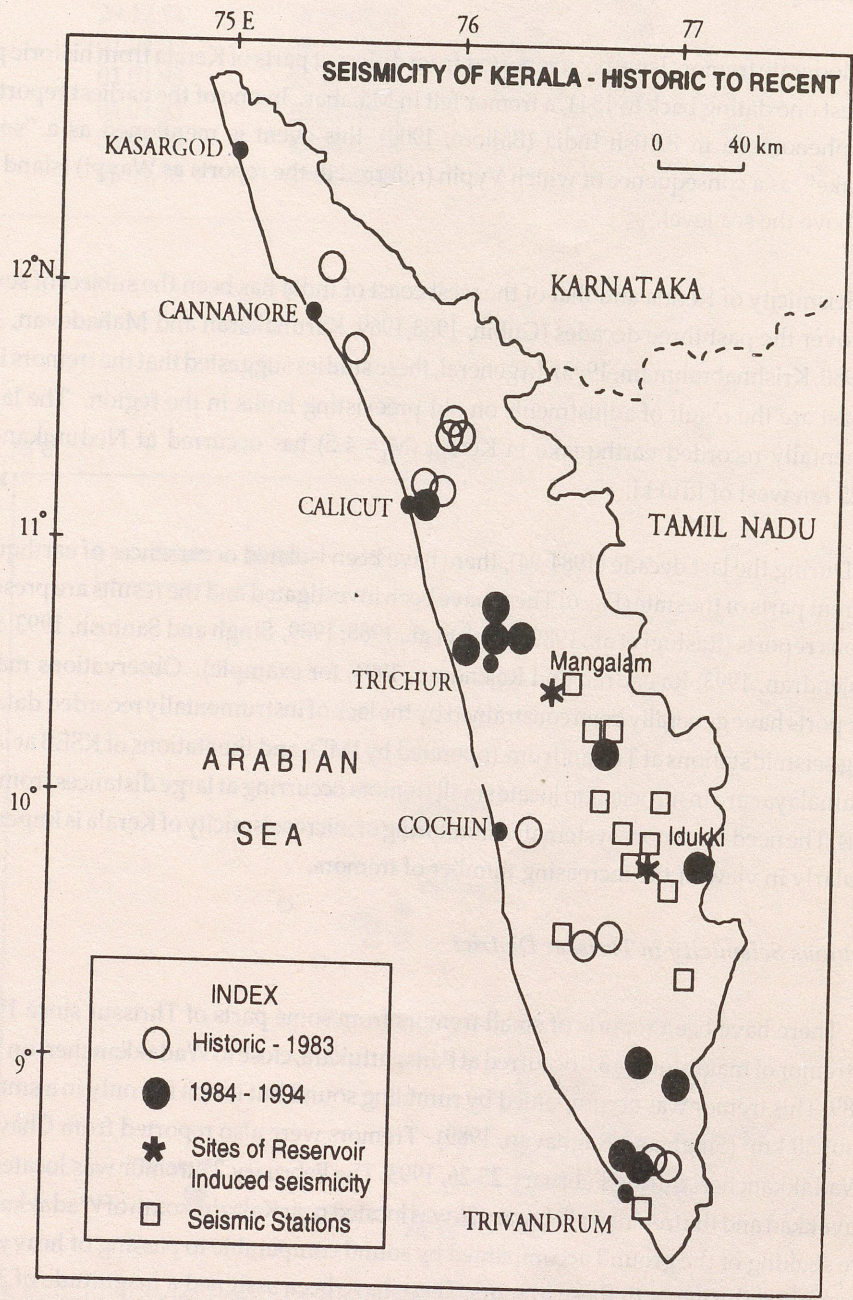


Figure 6. Seismicity of Kerala from historic to recent times.

A small tremor was reported from Varavur on June 8, 1994. This tremor was also accompanied by thundering sound and was felt only in a small area (report by *Mathrubhoomi Daily*, June 9, 1994).

During the field work in the area we talked to senior citizens to know if there were any past occurrences of tremors that they could recall. There was mention of a small tremor in 1954. A feature on Wadakkancheri earthquake by *The Malayala Manorama* (dated February 19, 1995) reported how another elderly citizen (100 years old) recalled experiencing tremor some seventy years ago. But for these reports, we could not obtain any evidence about the historic seismicity of the region.

iii. The Wadakkancheri Earthquake - Association with Structures

The regions around Wadakkancheri have not been the site of any larger earthquakes in the historic past. The available data do not suggest high level seismicity in the region. The largest regional earthquake that occurred in the area within 100 km radius is the magnitude 6.0 earthquake at Coimbatore on February 8, 1900. This is also the largest earthquake to have occurred in this part of south India, during the historic past. Another earthquake of $M 5$ occurred near Coimbatore on July 29, 1972. (Fig 7).

The 1994 earthquake occurred in the vicinity of the rectangular turn of the Bharathapuzha river, near Desamangalam. The E-W trend of the river takes WNW swing beyond this point. The E-W course is resumed further west (Figure 8).

Zones of fault intersections, jogs and bends act as regions of stress concentration in several fault zones. Such structures may manifest on the surface, possibly as geomorphological anomalies. Occurrence of several intraplate earthquakes in the vicinity of structural/geomorphic features indicate their higher seismogenic potential.

The occurrence of Wadakkancheri earthquake in the close proximity of a structural bend suggest that the stress accumulation in the area was probably higher. We believe that the zone defined by a sharp turn of the river has been the site of some previous deformation in the past, may be thousands of years ago.

The local data are quite insufficient to obtain a focal mechanism of the earthquake. There has not been much field evidences to constrain the direction of movement of the fault. From the few evidences available, we suggest that the faulting occurred on an east-west trending right lateral strike-slip fault (Fig. 3). At this point, we are not able to estimate if there is any component of thrust faulting. The sense of fault movement inferred by IMD agrees with our interpretation (IMD report, 1995). Any case, this interpretation is rather qualitative.

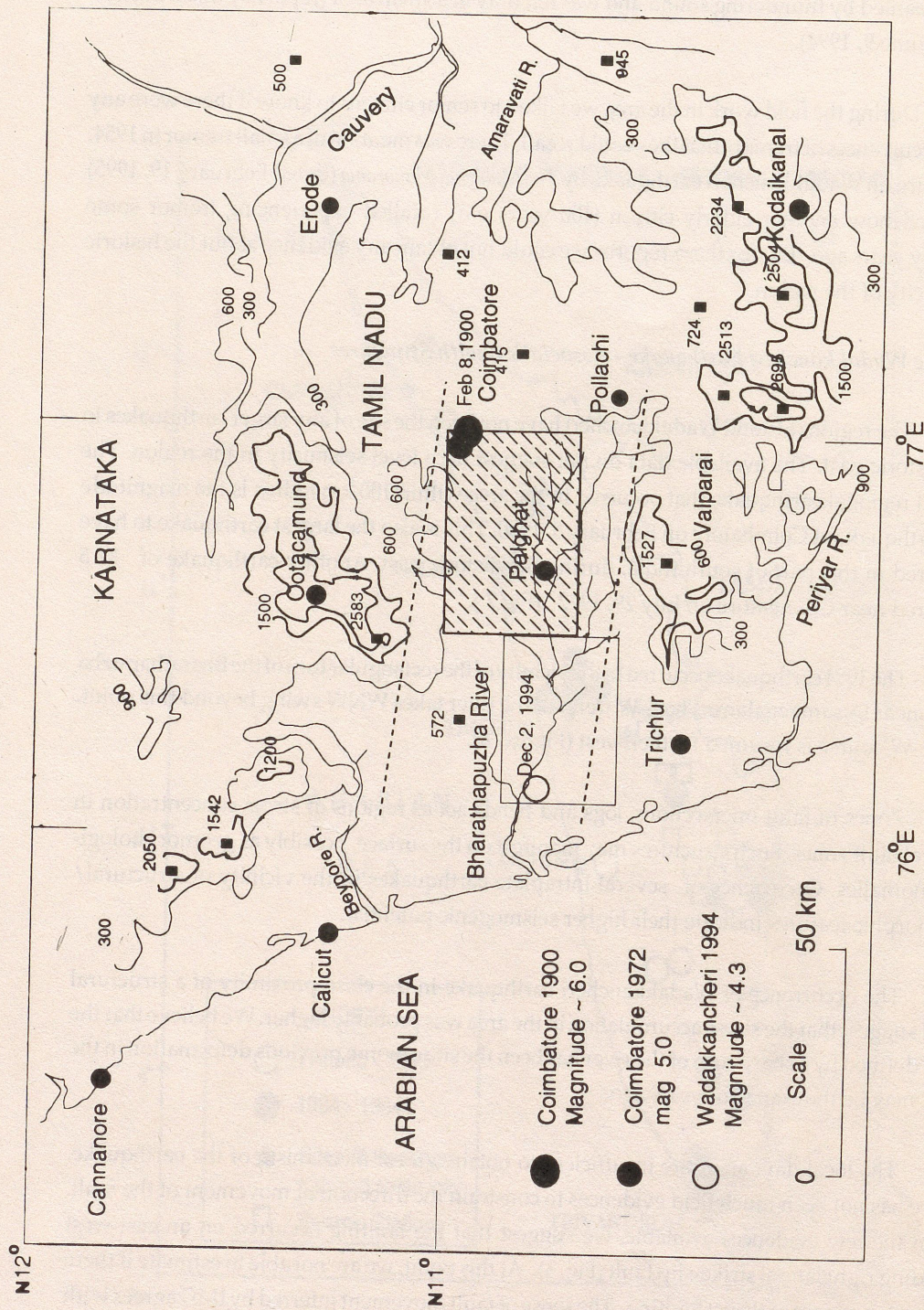


Figure 7. Regional physiographic map showing the prominent contours. Dashed lines mark the approximate extend of the Palghat Gap. Sites of notable earthquakes from the area are indicated. Shaded area indicates region of microseismic activity recorded by GBA. The area marked by the rectangle is blown up in Figure 8 (physiographic features modified from Subramanian and Muralidharan, 1985).

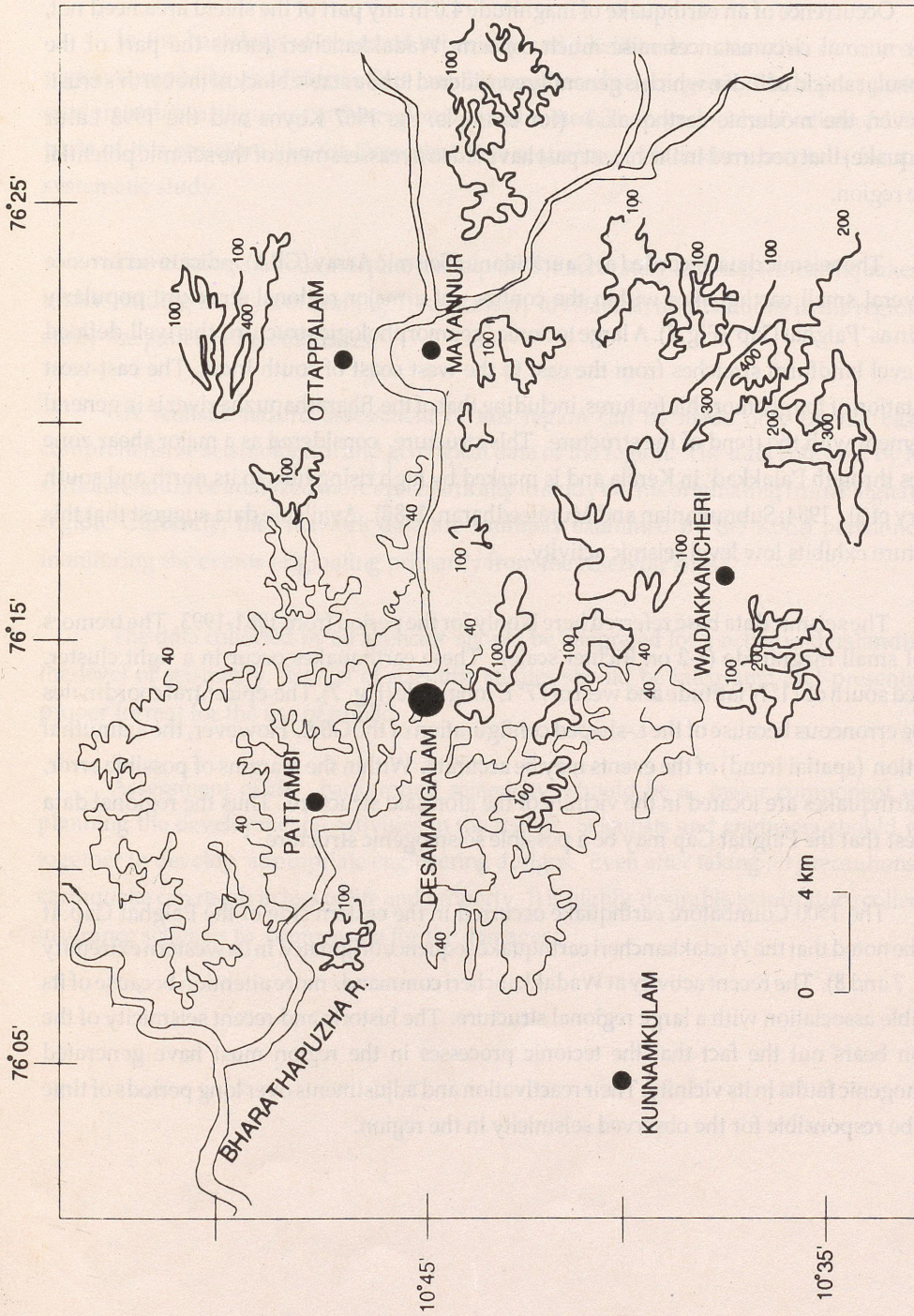


Figure 8. Physiographic map of the area around the Dec. 2, 1994 earthquake.

iv. Implications of Wadakkancheri Earthquake

Occurrence of an earthquake of magnitude 4.0 in any part of the shield area need not, under normal circumstances raise much concern. Wadakkancheri forms the part of the peninsular shield of India, which is generally considered to be a stable block of the earth's crust. However, the moderate earthquakes (for example: the 1967 Koyna and the 1993 Latur earthquake) that occurred in the recent past have led to a reassessment of the seismic potential of the region.

The seismic data recorded at Gauribidanur Seismic Array (GBA) indicate occurrence of several small earthquakes within the confines of a major regional structure popularly known as 'Palghat Gap' (Fig. 7). A large tectonic/geomorphologic structure, this well-defined low-level landform stretches from the east to the west coast of south India. The east-west orientation of the geomorphic features, including that of the Bharathapuzha river is in general agreement with the trend of the structure. This structure, considered as a major shear zone passes through Palakkad in Kerala and is marked by high rising hills to its north and south (Drury et al., 1984; Subramanian and Muraleedharan, 1985). Available data suggest that this structure exhibits low level seismic activity.

The seismic data base referred here is only for the period from 1981-1993. The tremors are of small magnitude (1-2 on Richter scale). These earthquakes occur in a tight cluster, located south of 11° N latitude and west of 77° E longitude (Fig. 7). The epicentral coordinates can be erroneous because of the L-shaped configuration of the GBA. However, the azimuthal direction (spatial trend) of the events may be accurate. Within the margins of possible error, the earthquakes are located in the vicinity of the aforesaid structure. Thus the regional data suggest that the Palghat Gap may be a possible seismogenic structure.

The 1900 Coimbatore earthquake occurred in the eastern side of the Palghat Gap. It may be noted that the Wadakkancheri earthquake sequence originated in its western extremity (Figs. 7 and 8). The recent activity at Wadakkancheri commands more attention because of its possible association with a large regional structure. The historic and recent seismicity of the region bears out the fact that the tectonic processes in the region must have generated seismogenic faults in its vicinity. Their reactivation and adjustments over long periods of time may be responsible for the observed seismicity in the region.

V. RECOMMENDATIONS AND SUGGESTIONS

In the backdrop of observed seismicity and likelihood of causative structures, the region comprising the Palghat Gap may be considered seismogenic. The repeat period of moderate size earthquakes in this region is not estimated. The occasional activation of different parts of this structure like the December 1994 sequence at Wadakkancheri calls for a more systematic study.

The existing stations are quite inadequate for accurately locating the earthquakes and understanding the style of faulting. It is necessary to establish more stations in the region and study the pattern of earthquakes.

A realistic hazard assessment of this region can be made only on the basis of comprehensive seismological and geological data of the region. The data collected by KSEB stations should be analyzed more systematically to study events originating from Palghat Gap region. Currently, the network data are routinely examined by the KSEB personnel for monitoring the events originating primarily from the reservoir sites.

The data collected by all agencies should be integrated for a better understanding of the level of seismicity. Results of scientific studies should be integrated and presented in proper format for the use of public.

Assessment of the background seismicity should be a major component while planning the developmental activities in the region. Scientists and engineers should work together to develop appropriate engineering designs. Even after taking all precautions, an earthquake can result in loss of life and property. It is highly desirable to introduce collective insurance schemes to compensate for the damages.

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Instrumentally recorded data for the tremors were provided by the Kerala State Electricity Board (KSEB), India Meteorological Department (IMD), National Geophysical Research Institute (NGRI) and Bhabha Atomic Research Centre (BARC).

The people of Wadakkancheri were very cooperative with our investigations. Without their help this work would not have been possible. We thank them for their help. Information gathered by journalists have been very useful in the investigations. Efforts of Mr. N.H. Vajid, Wadakkancheri correspondent of *Malayala Manorama* needs a special mention. His help in collecting details, particularly in documenting the numerous aftershocks, is gratefully acknowledged.

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Appendix I

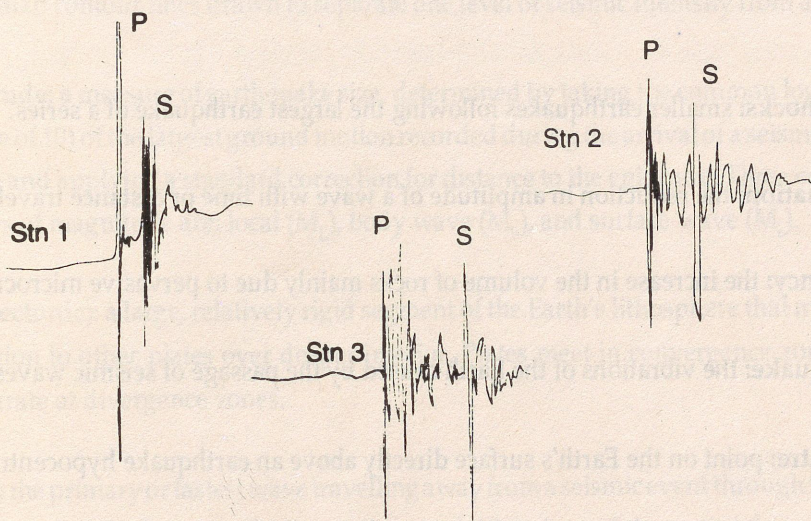
MODIFIED MERCALLI INTENSITY SCALE OF 1931

(Abridged; Wood and Neumann)

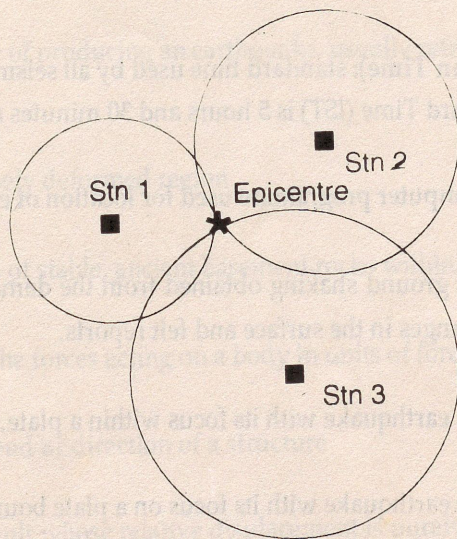
- I. Not felt except by a very few under especially favourable circumstances.
- II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
- III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
- IV. During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
- V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects some time noticed. Pendulum clocks may stop.
- VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
- VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
- VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.

- IX. Damages considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
- X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Shifted sand and mud. Water splashed (slopped) over banks.
- XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
- XII. Damage total. Waves seen on the ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Appendix II



A Schematic figure showing how stations at various distances record the same earthquake. The differences in the arrivals of P and S waves at various stations are used to calculate the approximate distance to the epicentre. In the example, Stn 1 is closest to the epicentre. Using three or more such arrivals, an earthquake can be located by taking the point of concurrence of arcs drawn from each station, with radii proportional to the distance (time). 1 second is approximately equal to 8 km.



Appendix III

Glossary

Aftershocks: smaller earthquakes following the largest earthquake of a series.

Attenuation: the reduction in amplitude of a wave with time or distance travelled.

Dilatancy: the increase in the volume of rocks mainly due to pervasive microcracking.

Earthquake: the vibrations of the Earth caused by the passage of seismic waves.

Epicentre: point on the Earth's surface directly above an earthquake hypocentre

Fault: a fracture along which there has been an observable amount of displacement.

Focal mechanism: geometry of faulting obtained from seismograms at various distances.

Focus (hypocentre): the point below the earth's surface where the earthquake originates

Foreshocks: smaller earthquakes preceding the largest earthquake of a series.

GMT (Greenwich Mean Time): standard time used by all seismic observatories of the world. Indian standard Time (IST) is 5 hours and 30 minutes ahead.

Hypo 71: a common computer programme used for location of earthquakes

Intensity: a measure of ground shaking obtained from the damage done to structures built by humans, changes in the surface and felt reports.

Intraplate earthquake: earthquake with its focus within a plate.

Interplate earthquake: earthquake with its focus on a plate boundary.

Isoseismal: contour lines drawn to separate one level of seismic intensity from another.

Magnitude: a measure of earthquake size, determined by taking the common logarithm (base of 10) of the largest ground motion recorded during the arrival of a seismic wave type and applying a standard correction for distance to the epicentre. Three common types of magnitude are: local (M_L), body wave (M_b), and surface wave (M_s).

Plate (tectonic): a large, relatively rigid segment of the Earth's lithosphere that moves in relation to other plates over deeper interior. Plates meet in convergence zones and separate at divergence zones.

P wave: the primary or fastest wave travelling away from a seismic event through the rock and consisting of a train of compressions and dilatations of the material.

Repeat time: the average interval of time between the occurrence of earthquakes in a particular region.

Right-lateral fault: a strike-slip fault on which the displacement of the far block is to the right when viewed from either side.

Seismogenic: capable of producing an earthquake, usually referring to a fault or part of a fault

Shear zone: an intensely deformed region

Shield: a large region of stable, ancient basement rocks within a continent.

Stress: a measure of the forces acting on a body in units of force per unit area.

Strike: the general trend or direction of a structure

Strike-slip fault: a fault whose relative displacement is purely horizontal.

S wave: the secondary seismic wave, travelling more slowly than the P wave and consisting of elastic vibrations transverse to the direction of travel. It cannot propagate in a liquid.

Tectonics: large scale deformation of the outer part of the Earth resulting from forces in the Earth.

