Earthquake sequence in Kerala during December 2000 and January 2001

S. N. Bhattacharya* and R. S. Dattatrayam

India Meteorological Department, Lodi Road, New Delhi 110 003, India

An earthquake of magnitude (M_L) 5.0 occurred on 12 December 2000 in the bordering regions of Idukki and Kottayam districts of Kerala followed by a series of aftershocks. After a brief lull, another earthquake of magnitude (M_L) 4.8 occurred in the same region on 7 January 2001, which was also followed by a series of aftershocks for a short spell. These events were monitored by permanent seismological observatories in the region as well as by operating temporary field observatories. The waveforms of broadband digital seismographs at two stations located approximately 98 and 128 km from the epicentre show that both the main events indicate similar focal mechanisms. *P*-wave first motion data and waveform inversion yield a focal mechanism solution with one nodal plane trending along NW direction and the other along ENE direction with predominant strike–slip component. The epicentral distribution indicates a cluster in a N–S direction passing through Erratupetta (Kottayam District). The association of the activity with subsurface faults needs to be corroborated through detailed geological/geophysical investigations.

TWO earthquakes of magnitudes 5.0 and 4.8 occurred on 12 December 2000 and 7 January 2001 respectively, in the bordering regions of Idukki and Kottayam districts of Kerala, both of which were followed by aftershocks. India Meteorological Department (IMD) monitored the earthquake sequence through its national network of seismological observatories as well as by the temporary field observatories established in the epicentral area. In addition, data from the seismological observatories operated by Kerala State Electricity Board (KSEB) and Centre for Earth Science Studies (CESS) were also collected. The broadband data, particularly those from stations close to the epicentre are very useful in constraining the source characteristics. A detailed seismological analysis of this earthquake sequence is presented here.

Regional seismicity since historic times and major faults in this part of south India (south of 12°N) are shown in Figure 1 (ref. 1). The detailed tectonic features very close to the epicentral zone of the present earthquake sequence are shown in Figure 2. The region has witnessed several slight to moderate magnitude earthquakes in the past. Amongst the past earthquakes, the most significant one is the Coimbatore earthquake (M: 6.0) of 8 February 1900 located at latitude 10.7°N and longitude 76.7°E in the close proximity to an east-west trending fault. The earthquake had produced a maximum intensity of VII on modified Mercalli scale[2]. A sequence of earthquakes occurred at around latitude 9.81°N and longitude 77.21°E during 7–8 June 1988 in which three events had magnitude between 3.5 and 4.5. The composite fault plane solution of a few earthquakes in this sequence indicated nodal planes trending in northwest and northeast directions[3]; these directions respectively correspond to NW–SE trending Periyar fault and NE–SW trending lineament passing close to the locations of these earthquakes. On 2 December 1994 another earthquake of magnitude 3.8 occurred at latitude 10.75°N and longitude 76.25°E in Wadakkancheri region of Thrissur district, which is slightly north of the region of the present earthquake activity (Figure 1). This earthquake which was also followed by a few aftershocks, created much alarm among the residents of Wadakkancheri[4,5]. The region has thus witnessed earthquake sequences of slight to moderate magnitudes on three occasions (1988, 1994 and 2000–01) at regular intervals of about six years.

An earthquake of magnitude 5.0 on the Richter scale occurred in the morning of 12 December 2000 in the bordering regions of Idukki and Kottayam districts of Kerala. This earthquake was felt widely in Kerala and adjoining parts of Tamil Nadu. No major damage was reported; however, cracks appeared in some houses in the epicentral area. This earthquake was followed by a series of aftershocks of lesser magnitude, some of which were felt locally. The phase data from the stations of the local and national network were used to obtain the epicentral location, which are shown in

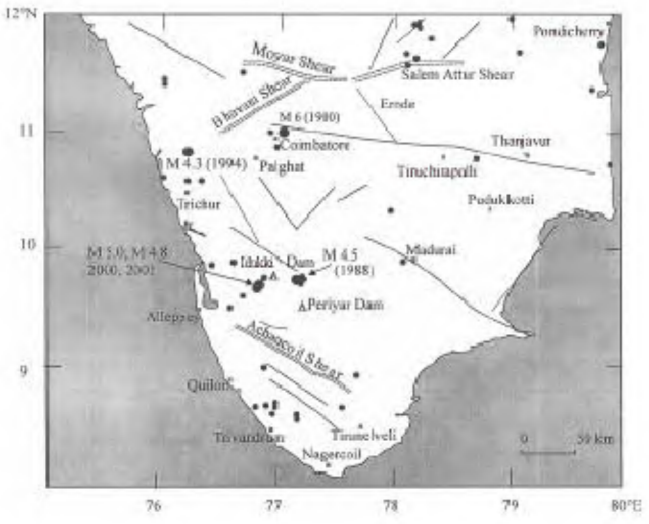

Figure 1. Tectonic features and past earthquakes in the region of the present earthquake sequence (modified from GSI, 2000).

*For correspondence. (e-mail: sn_bhattacharya@hotmail.com)

Table 1. Hypocentral parameters of the two main earthquakes

Date	Origin time IST	Latitude °N (Deg : Min)	Longitude °E (Deg : Min)	Depth (km)	Magnitude M_L	Magnitude M_W
12 December 2000	06 : 53 : 59.3	9 : 39.2	76 : 44.4	7	5.0	4.7
7 January 2001	08 : 25 : 59.9	9 : 37.8	76 : 46.7	8	4.8	4.6

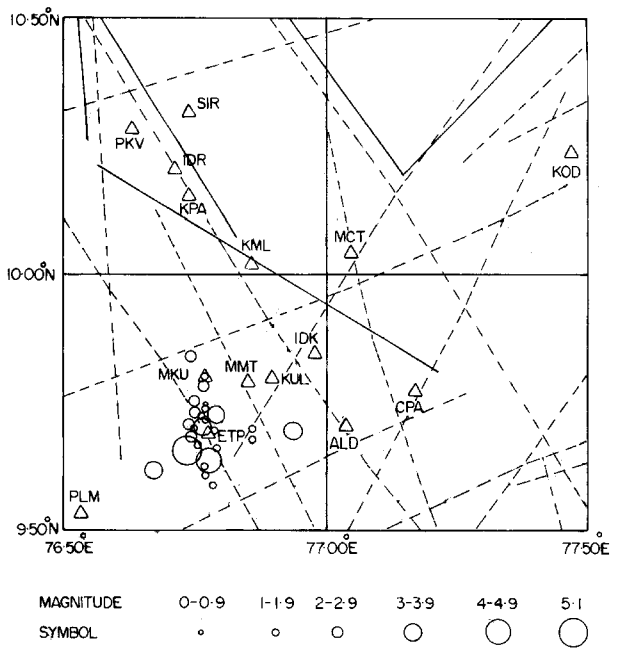

Figure 2. Detailed tectonic features very close to the epicentral zone of the present earthquake sequence. Lineaments are shown by dashed lines and faults are shown by continuous lines (GSI, 2000). Locations of the two main earthquakes, aftershocks and the seismological observatories are shown. Important locations are Kodaikanal (KOD), Idukki (IDK) and Moolamattom (MMT).

Table 1 and Figure 2. We used the crustal structure IP11 obtained for the Indian peninsula[6].

In addition to monitoring this sequence through the national network of seismological observatories, a team of scientists from IMD rushed to the affected area after the occurrence of this earthquake and set-up temporary field observatories at Melukavu (MKU, Figure 2) on 15 December 2000 and at Moolamattom (MMT, Figure 2) on 18 December 2000 by installing high gain analogue seismographs. These observatories continued to operate till the first week of February 2001. Locations of these observatories along with seismograph stations operated by KSEB at Idukki and Idamalyar areas are also shown in Figure 2.

Phase data from all these observatories were collected and analysed. A histogram depicting the daily frequency of tremors is shown in Figure 3 along with the daily maximum magnitude shown on the top of each bar for those events with magnitude 2.0 or more. There were 46 aftershocks of magnitude 0.1 and above recorded till 28 December 2000, of which two events with magnitude exceeding 3.5 occurred on 12 December 2000 at 17:37 (M : 3.7) and 16 December (M : 3.9).

Subsequent to the 12 December 2000 earthquake another one of magnitude 4.8 on the Richter scale occurred in the morning of 7 January 2001 nearly at the same location (Table 1 and Figure 2). A few more scientists from IMD joined the team working in the field and installed one more observatory at Erratupetta (ETP, Figure 2) on 11 January 2001. A field survey conducted in the affected area showed that a few buildings in Melukavu region of Kottayam District developed cracks. The Sacred Heart Convent building of concrete-type construction located about 3.5 km south of Melukavu developed hairline cracks in the walls. Cracks in buildings were also noticed in Pala, Kottayam District. The 64-year-old St. Gregory's Church in Kizhaparayar area of Pala suffered damage in the form of ground-cracks and cracks in the floor and walls. It was also noted that a statue of Mary resting on the top of the church building fell towards the south. In the same area, a 'cross' resting on a small, round structure on the ground fell towards the north. The predominant ground motion in this area appears to be oriented approximately in a north-south direction. Damages caused during this earthquake appeared to be more than those in the previous one of 12 December 2000; it appears that the cracks developed in buildings during the previous earthquake gave way for the damages noticed in this earthquake.

The 7 January 2001 earthquake was also followed by a series of aftershocks, with thirty-two of them occurring on 7 and 8 January 2001 alone followed by 10 more till the end of January 2001. The daily frequency of tremors of this sequence is also shown in Figure 3. The maximum magnitude of aftershocks during this part of the sequence was 2.7.

Both the main events were well-recorded by the broadband seismographs being operated at Peechi (PCH) and Thiruvananthapuram (TRD), which are located at epicentral distances of approximately 98 and 128 km, respectively. The ground displacement waveforms at PCH and TRD are shown in Figure 4 *a* and *b*, respectively which were obtained with a high-cut filter at 1 Hz to avoid contamination of high-frequency scattered waves due to shallow lateral heterogeneity. The similarity of the observed waveforms (Figure 4) for

these events clearly indicates that both have similar focal mechanism.

First motion data of *P*-waves collected from local and regional networks for these two events are plotted in Figure 5 as a projection of lower focal hemisphere, to get a composite fault plane solution. However, the available *P*-wave first motion data do not offer well-constrained nodal planes. To work out a unique solution, we have further inverted the seismograms from PCH and TRD. Synthetic seismograms were generated using the wave number or slowness integration method[7,8] for different focal mechanism solutions; we used a triangular shape far-field source time function with base length of 0.8 s. A comparison of synthetic seismograms with the observed ones is shown in Figure 4 *a* and *b* for PCH and TRD, respectively. However, while comparing the arrival times of *P*- and *S*-waves, it was seen that the velocity structure of the first layer (granitic layer) needs to be slightly modified from IP11 (ref. 6). In IP11, the *P*- and *S*-wave velocities in the first layer are 5.78 and 3.53 km/s, respectively. These velocities were revised to 6.10 and 3.52 km/s, respectively along the wave path from the epicentre to TRD and 6.20 and 3.44 km/s, respectively along epicentre to PCH. It is to be noted that the wave path from the epicentre to TRD is mostly along plain coastal land, while the same from the epicentre to PCH cuts across hilly region.

The fault plane solution thus obtained from inversion is shown in Figure 5 and given below:

NP1: Strike 309°, dip 56°, slip 143°
NP2: Strike 62°, dip 60°, slip 40°

The seismic moment used for generating synthetic seismograms is 10×10^{22} dyne-cm and the amplitude of synthetic seismograms has been so selected to match the recorded amplitudes of the earthquake of 12 December 2001. The amplitude of the observed waveform for the

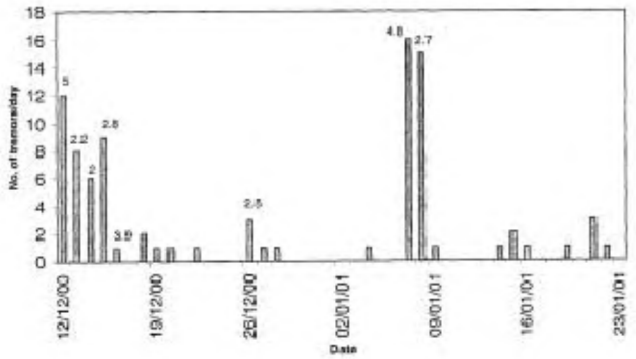

Figure 3. Histogram showing the daily frequency of aftershocks. The daily maximum magnitude is shown at the top of the bar for events with $M \geq 2.0$.

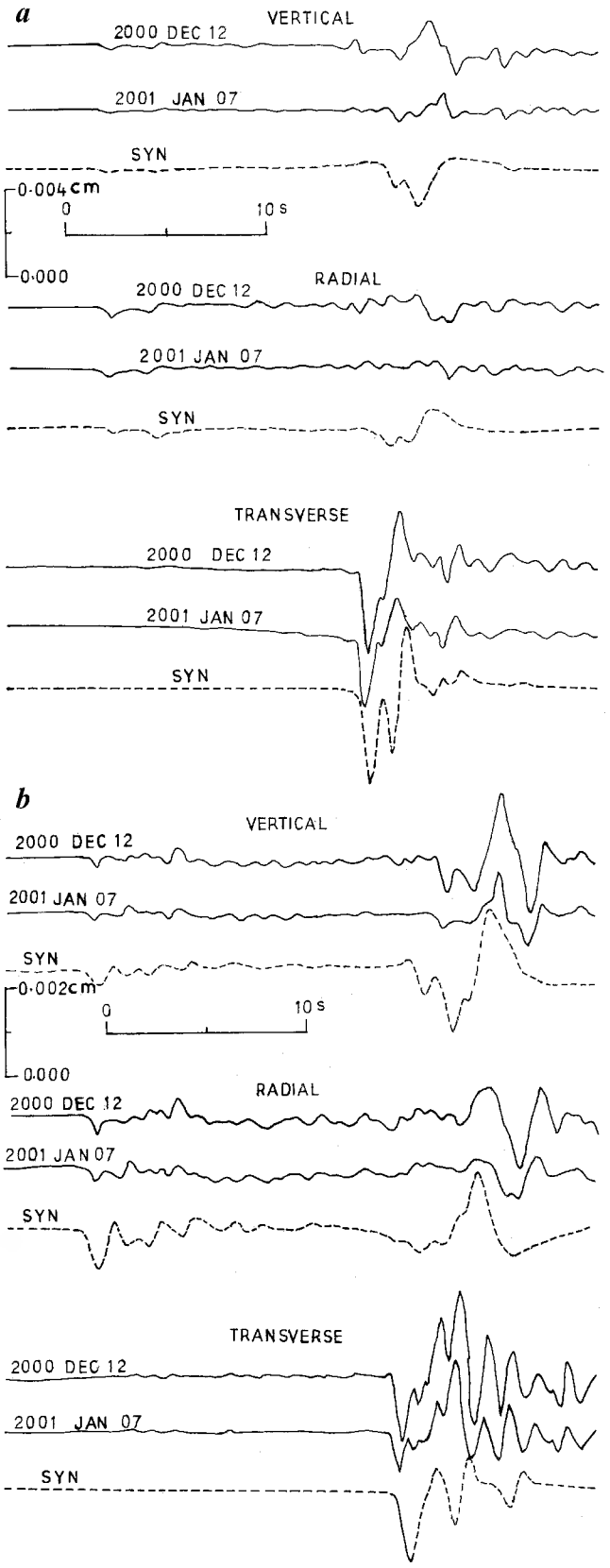

Figure 4. Vertical, radial and transverse components of observed seismograms of 12 December 2000 and 7 January 2001 events recorded at *a*, Peechi (PCH); and *b*, Thiruvananthapuram (TRD). The corresponding synthetic seismograms are drawn for focal mechanism solution shown in Figure 5.

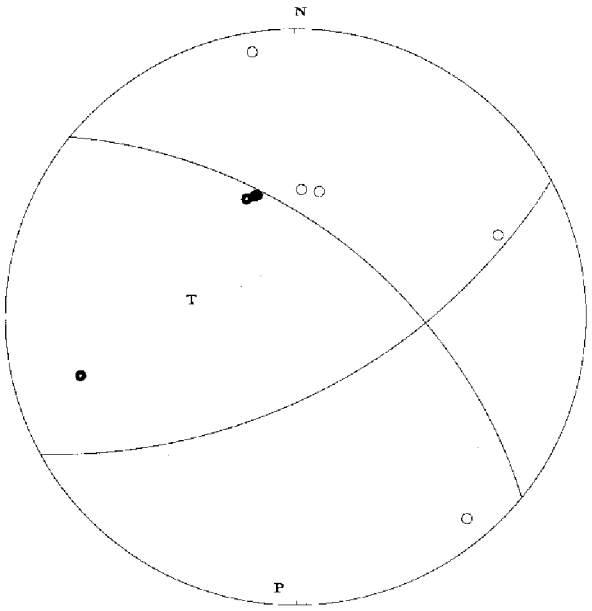

Figure 5. Observed *P*-wave first motions for the two earthquakes of 12 December 2000 and 7 January 2001 shown on the projection of lower focal hemisphere. The fault plane solution obtained from inversion is also shown.

earthquake of 7 January 2001 is relatively less, and we had to consider a seismic moment of 7×10^{22} dyne-cm. The seismic moments thus obtained through inversion of synthetic seismograms give the moment magnitude (M_W) as 4.7 and 4.6 respectively for the first and second events.

The aftershocks recorded by three or more observatories have been located and epicentral locations of 40 events, including the two main shocks are plotted in Figure 2. It may be seen from Figure 2 that the current seismic activity is aligned more or less in a north-south direction passing through Melukavu (MKU) and Erratupetta (ETP). The focal depths of majority of these events lie within 12 km.

The alignment of the aftershocks does not give any direct indication of its association with the mapped lineaments in the region. However, the composite fault plane solution obtained from inversion of waveforms for the two main events yields one of the nodal planes (NP1), trending almost parallel to NW–SE-oriented lineament passing very close to the epicentre of the 7 January 2001 event.

In summary, an earthquake of magnitude 5.0 occurred in the morning of 12 December 2000 in the bordering region of Idukki and Kottayam districts of Kerala. This earthquake was followed by a series of aftershocks with maximum magnitude 3.9 on 16 December 2000. The aftershock activity nearly ceased on 28 December 2000. After a brief lull, another earthquake of magnitude 4.8 occurred in the morning of 7 January 2001. This event was also followed by aftershocks with a maximum magnitude of 2.7. Most of the aftershocks in this sequence occurred on 7 and 8 January 2001. The two main shocks of 12 December 2000 and 7 January 2001 are located 5–6 km southwest and south of Erratupetta, respectively. The epicentres of the present earthquake sequence are aligned more or less in a north-south direction passing through Melukavu and Erratupetta, with majority of the events having focal depths less than 12 km. The composite fault plane solution obtained from inversion of waveforms for the two main events yields one of the nodal planes (NP1), trending almost parallel to NW–SE-oriented lineament passing very close to the epicentre of the 7 January 2001 event. However, a more detailed geological and geophysical mapping in the region is expected to throw more light on the association of the current seismic activity with possible seismogenic sources in the region.

1. *Seismotectonic Atlas of India and its Environs*, Geological Survey of India, 2000.
2. Basu, K. L., *Indian J. Meteorol. Geophys.*, 1964, **15**, 281–286.
3. Rastogi, B. K., *Curr. Sci.*, 1992, **62**, 101–108.
4. Report, India Meteorological Department, 1995.
5. Rajendran, C. P. and Rajendran, K., *Curr. Sci.*, 1996, **70**, 304–307.
6. Bhattacharya, S. N., *Curr. Sci.*, 1992, **62**, 94–100.
7. Kind, R., *J. Geophys.*, 1979, **45**, 373–380.
8. Bhattacharya, S. N., *Geophys. J. Int.*, 1992, **111**, 79–90; *Mausam*, 1992, **43**, 51–58.

ACKNOWLEDGEMENTS. We thank the Director General of Meteorology for permission to publish this paper. We acknowledge the constant encouragement and useful reviews of Dr Kusala Rajendran in the preparation of this manuscript.

Received 30 March 2001; revised accepted 28 January 2002