Aftershock activity of Bhuj earthquake of January 26th, 2001

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Following a large-sized Bhuj earthquake ($M_s = 7.6$) of January 26th, 2001, a small aperture 4-station temporary local network was deployed, in the epicentral area, for a period of about three weeks and resulted in the recording of more than 1800 aftershocks ($-0.07 \leq M_L < 5.0$). Preliminary locations of epicenters of 297 aftershocks ($2.0 \leq M_L < 5.0$) have brought out a dense cluster of aftershock activity, the center of which falls 20 km NW of Bhachau. Epicentral locations of aftershocks encompass a surface area of about $50 \times 40\,\text{km}^2$ that seems to indicate the surface projection of the rupture area associated with the earthquake. The distribution of aftershock activity above magnitude 3, shows that aftershocks are nonuniformly distributed and are aligned in the north, northwest and northeast directions. The epicenter of the mainshock falls on the southern edge of the delineated zone of aftershock activity and the maximum clustering of activity occurs in close proximity of the mainshock. Well-constrained focal depths of 122 aftershocks show that 89% of the aftershocks occurred at depths ranging between 6 and 25 km and only 7% and 4% aftershocks occur at depths less than 5 and more than 25 km respectively. The Gutenberg-Richter (GR) relationship, $\log N = 4.52 - 0.89M_L$, is fitted to the aftershock data ($1.0 \leq M_L < 5.0$) and the b-value of 0.89 has been estimated for the aftershock activity.

1. Introduction

The Kachchh basin extends for about 250 km in the eastwest direction and 150 km in the north-south direction and is bounded by two major faults namely, the Nagar Parker fault in the north and the Kathiawar fault in the south. The basin is marked by the presence of several other eastwest trending tectonic features viz., Katrol Hill Fault, Vigodi Fault, Kachchh Mainland Fault, Banni Fault, Wagad Fault, Island Belt Fault and Allah Bund Fault. Throughout the Cenozoic period the region has experienced several episodes of tectonic deformations along the major eastwest trending faults. These deformations have contributed both to the evolution of the present day landscape and accentuated the structural pattern of the region (Biswas 1971; Malik *et al* 1999).

Many devastating earthquakes have occurred in the region in the past. Notable among these are the Samaji town (25°N, 68°E) earthquake of May 1668 (maximum MMI intensity X), the Rann of Kachchh earthquake of June 16th, 1819 (MMI intensity XI and M_w 7.8), the Lakpat earthquake of April 19th, 1845 (MMI intensity VIII) and the Anjar earthquake of July 21st, 1956 (MMI intensity IX and M_w 6.0) (Tandon 1959; Chandra 1977; Chung and Gao 1995). The great Kachchh earthquake produced the first evidence of faulting in the form of eighty kilometers long scarp with a maximum height of about 6 m (Richter 1958).

The Bhuj earthquake of January 26th, 2001 was followed by intense aftershock activity that spans the magnitude range from less than zero to 5.7. The India Meteorological Department (IMD) reported 458 aftershocks having a magnitude three and above up to February 28th, 2001. To monitor the aftershock activity associated with this earthquake, the Department of Earthquake Engineering installed a small aperture 4-station temporary

Keywords. Bhuj earthquake; aftershocks; local network; temporal distribution; b-value.

Proc. Indian Acad. Sci. (Earth Planet. Sci.), **112**, No. 3, September 2003, pp. 391–395

Table 1. *Geographical coordinates of recording stations and duration of recording.*

Sl. no.	Station name	Station code	Location Lat. (°N)	Long. (°E)	Recording duration
1.	Maliya	MLY	23.10	70.78	8 days (February 4th–11th)
2.	Samakhyari	SHM	23.30	70.50	18 days (February 11th–28th)
3.	Pragpar	PRG	22.90	69.71	24 days (February 5th–28th)
4.	Deshalpar	DLP	23.19	69.45	23 days (February 6th–28th)
5.	Khavda	KVD	23.83	69.74	21 days (February 8th–28th)

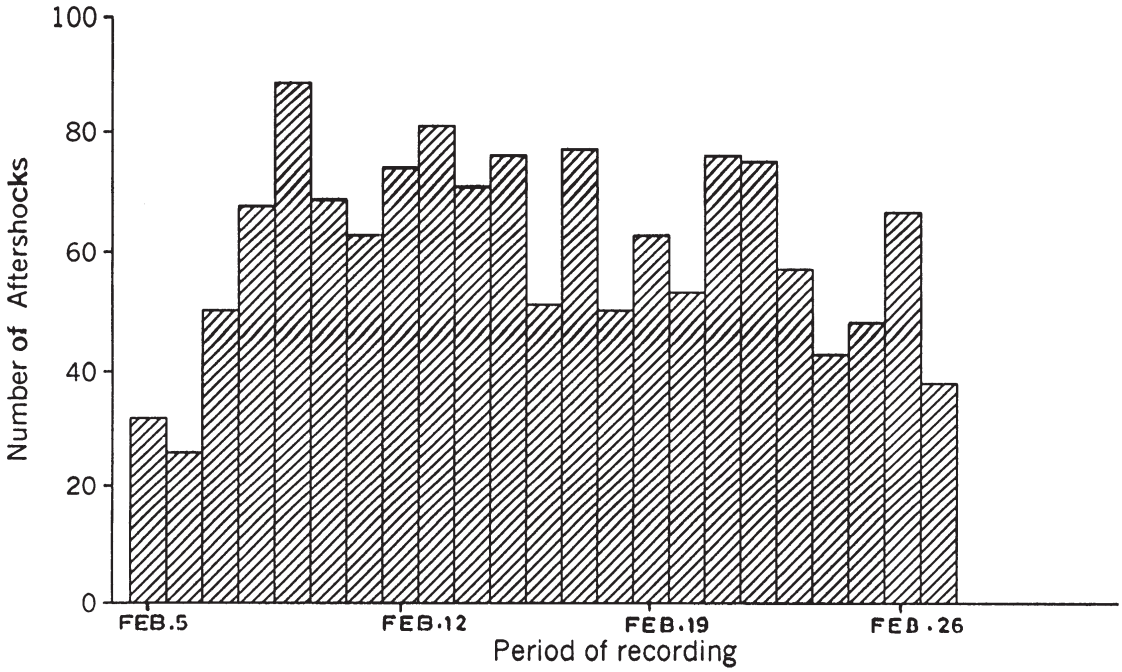

Figure 1. Daily frequency of aftershocks ($M_L \geq 1$) from February 5th to February 27th, 2001.

local network around the epicentral area. The network stations were operated for a period of 25 days from February 4th to February 28th, 2001 at five locations namely, Maliya (MLY), Pragpar (PRG), Deshalpar (DLP), Khavda (KVD) and Samakhyari (SHM). However, simultaneous recording at four stations was conducted for a period of three weeks (table 1). The equipment used for recording consisted of microearthquake recorders (MEQ-800B) coupled to short period vertical component seismometers. The recording was carried out at a speed of 120 mm/min and 202 seismograms were obtained. Scanning of seismograms resulted in the identification of more than 1800 aftershocks ($-0.07 \leq M_L < 5.0$). The present study describes the preliminary results obtained on the basis of analysis of the aftershock data.

2. Temporal distribution of aftershock activity

Out of 1800 aftershocks in the magnitude (M_L) range between −0.07 and 5.0, about 1400 aftershocks fall in the magnitude range between 1.0 and 5.0. A histogram of daily frequency of occurrence of aftershock activity ($M_L \geq 1$) recorded for a period of 23 days is shown in figure 1. From February 5th to February 27th the recording was done continuously whereas, on February 4th and February 28th the recording was done for a few hours only. During this period the frequency of aftershocks ($M_L \geq 1$) varies from 27 events per day to about 89 events per day and activity does not show decay with time. There were more than 1000 events having $1 \leq M_L < 2$, about 323 events between magnitude 2 and 3, and 71 events having $M_L \geq 3$.

3. Locations of aftershocks

Hypocenter parameters of aftershocks were estimated employing HYPO71PC computer program and using the two layers crustal velocity model (Tandon and Chaudhury 1968; Lee & Lahr 1975). Due to 4-station network, *S*-phase arrival time data was also used in addition to *P*-phase arrival time

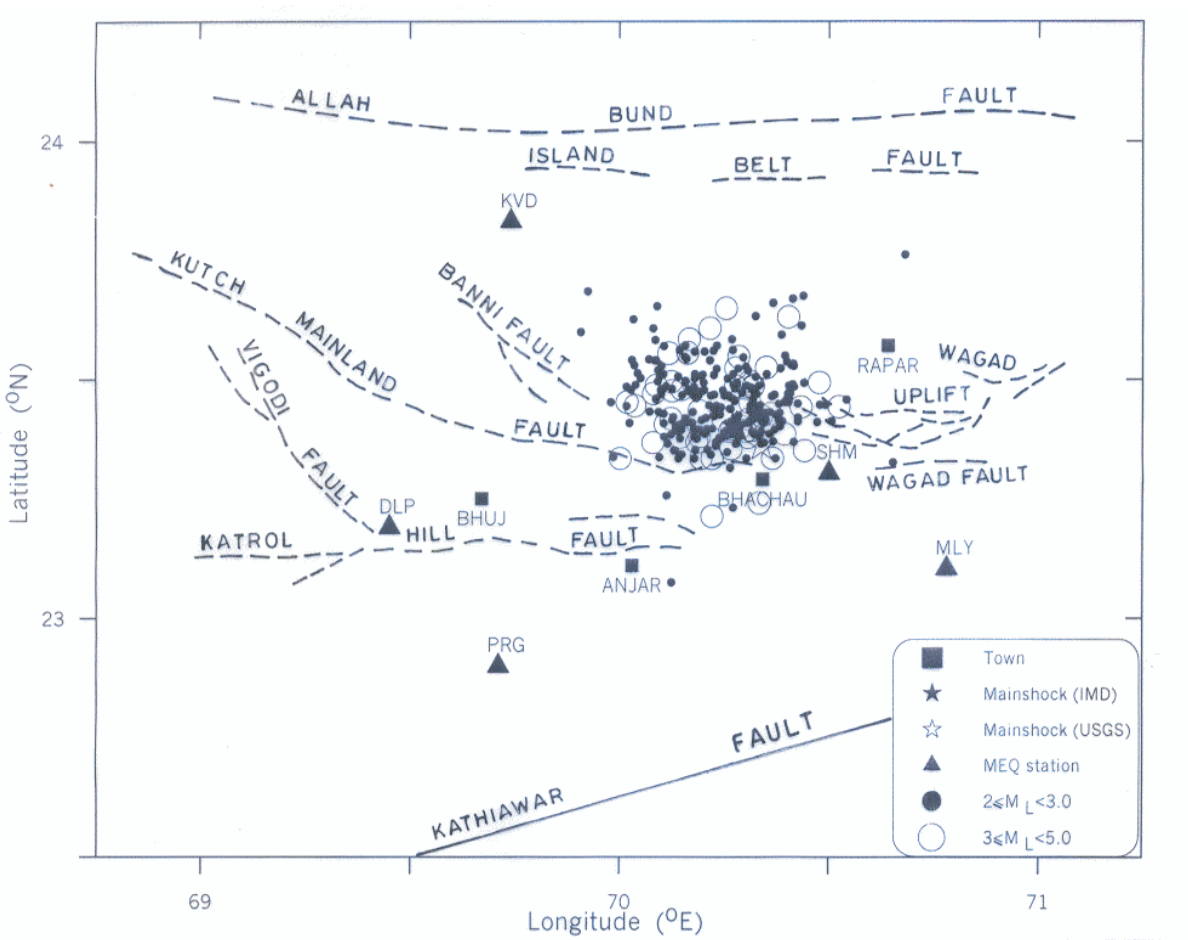

Figure 2(a). Epicenters of aftershocks ($M_L \geq 2$) of Bhuj earthquake, January 26th, 2001.

data to allow estimation of standard errors in the hypocenter parameters. Preliminary locations of epicenters of 297 aftershocks ($2 \leq M_L < 5.0$) have brought out a dense cluster of activity in the close proximity of the mainshock epicenter. The center of the cluster falls 20 km NW of Bhachau (figure 2a). The epicenters of aftershocks encompass a surface area with dimensions of about $50 \times 40\,\text{km}^2$ that seems to indicate the surface projection of the rupture area associated with the earthquake. The distribution of activity with $M_L \geq 3$, as shown in figure 2(b), is nonuniform in nature and primarily defines two main zones of aftershocks aligned in the north and northwest directions. The zone aligned in the north direction is about 25 km in length and the aftershocks aligned in the northwest direction over a length of about 30 km. In addition there are two weak zones of aftershocks aligned in the northeast direction. The surface area of $50 \times 40\,\text{km}^2$ is by and large in agreement with the fault area of $1661\,\text{km}^2$ (Bhattacharaya *et al* 2001). The epicenters of aftershocks obtained in this study, are comparable with those reported by Rastogi *et al* (2001) and by CERI, Memphis, USA (2001).

The clusters of epicenters of aftershocks seem to indicate the secondary redistribution of stresses due to primary failure on the fault (Mendoza and Hartzell 1988). The distribution of aftershocks shows NP2-strike 60°, dip 58°, slip 56° (Bhattacharaya *et al* 2001) as the most likely fault plane.

4. Focal depth distribution

The focal depth distribution of 122 aftershocks ($2 \leq M_L < 5.0$) with well constrained focal depths having standard errors in focal depth ≤ 5 km shows that about 89% of aftershocks occur at depths between 6 and 25 km and only 7% and 4% aftershocks occur in the depth range up to 5 km and above 25 km respectively. The focal depths obtained in this study are shallow in comparison to those reported in other studies (Rastogi *et al* 2001; CERI, Memphis, USA 2001). The observed

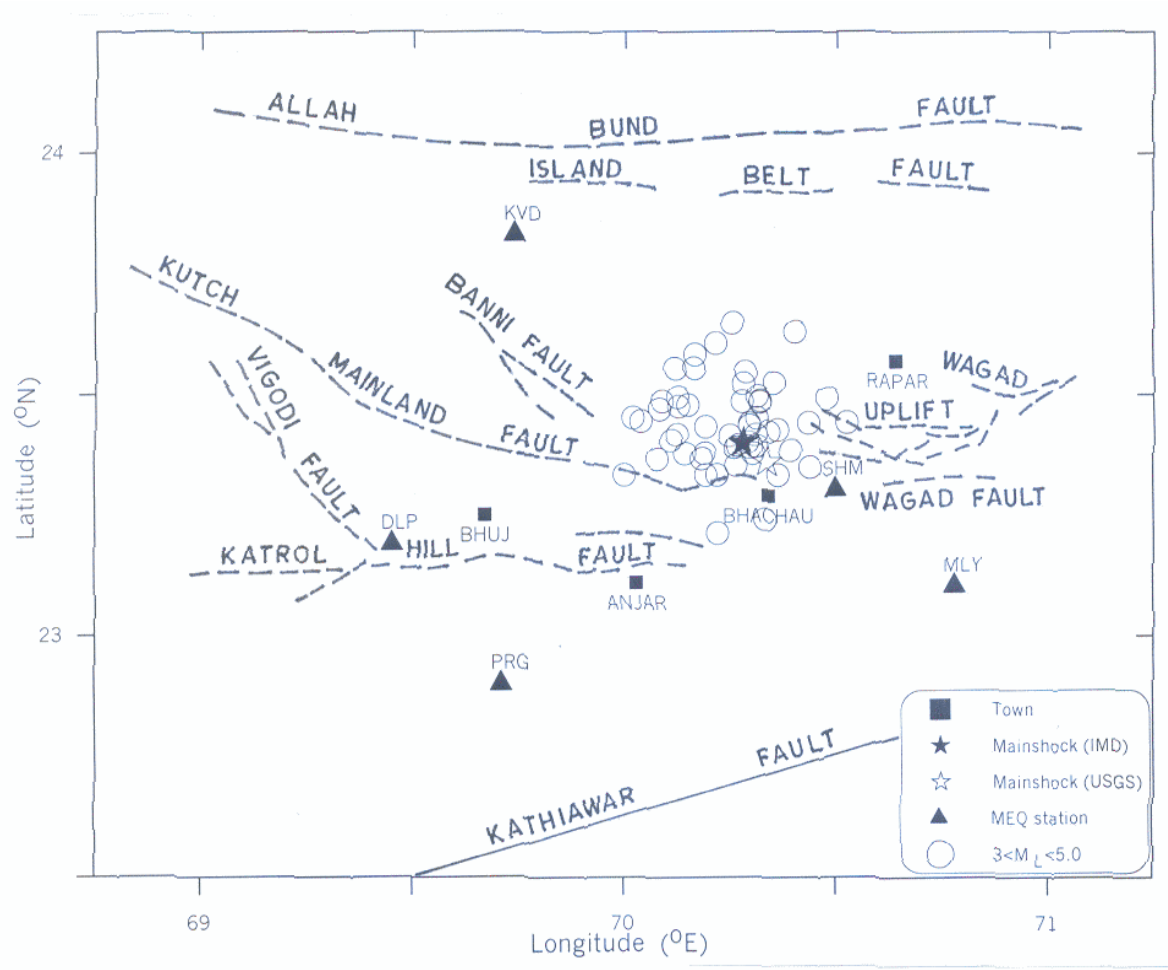

Figure 2(b). Epicenters of aftershocks ($M_L \geq 3$) of Bhuj earthquake, January 26th, 2001.

difference in focal depths may be due to different velocity models and other factors influencing the estimation of hypocenter parameters including the period of recording.

5. Frequency-magnitude relationship

A histogram, giving the frequency distribution of aftershocks ($M_L \geq 1$) with magnitudes, is drawn by grouping events in the magnitude class interval of 0.4 (figure 3a). The plot depicts that the frequency of aftershocks decreases as magnitude increases and about 95% aftershocks occur in the magnitude range of $1.0 \leq M_L < 3.0$. Only 5% of aftershocks occur above magnitude 3. Considering this data set ($1.0 \leq M_L < 5.0$), a Gutenberg-Richter (GR) recurrence relationship, $\log N = 4.52 - 0.89 M_L$, (figure 3b) is fitted employing least-square technique and the b-value of 0.89 has been estimated for the aftershock activity.

6. Conclusions

The following broad conclusions are drawn from this study:

- The Bhuj earthquake of January 26th, 2001 was followed by intense aftershock activity and more than 1800 aftershocks ($-0.07 \leq M_L < 5.0$) were recorded for a period of 25 days from February 4th to February 28th, 2001. Temporal distribution does not show decay of aftershock activity with time during the period of observation.
- The epicenters of 297 aftershocks ($2 \leq M_L < 5.0$) encompass a surface area of $50 \times 40\,\text{km}^2$. This seems to be the surface projection of fault rupture area associated with the earthquake. The locations of aftershocks ($M_L \geq 3$) have brought out two prominent alignments of cluster in the north and northwest of the epicenter of the mainshock having a length of 25 km and 30 km respectively.
- Well constrained focal depths of 122 aftershocks ($2 \leq M_L < 5.0$) show that about 89% after-

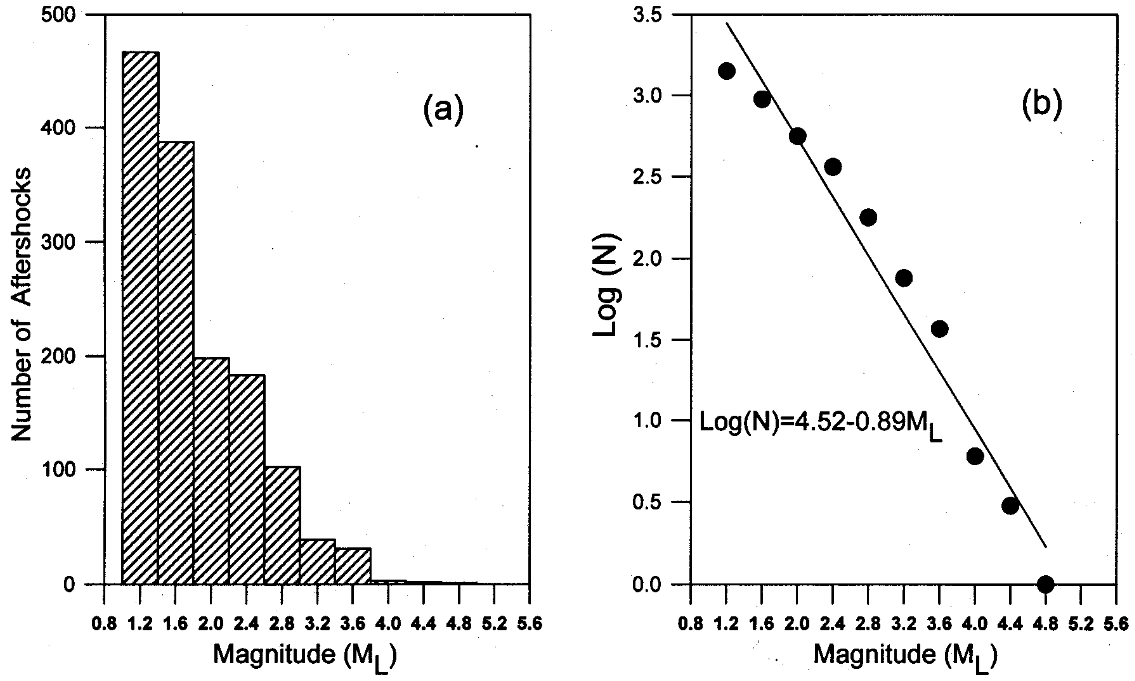

Figure 3. **(a)** Frequency distribution of aftershock activity with magnitude and **(b)** Gutenberg-Richter recurrence curve for the aftershock activity.

shocks occur at depths between 6 and 25 km. The b-value of 0.89 has been estimated for the aftershock activity.

Acknowledgements

Financial support to carry out the study became available from the Department of Science and Technology, Seismology Division, New Delhi. Authors are thankful to the Head, Department of Earthquake Engineering, for extending facilities to carry out the study.

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