SOURCE PARAMETERS STUDY OF LOCAL EARTHQUAKES IN THE GARHWAL HIMALAYA REGION BASED ON THE DIGITAL BROADBAND DATA

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SUMMARY

This paper presents an analysis of 15 local earthquakes which occurred in the Garhwal Himalaya region during the period September 1997 to December 1997. These events were recorded by a network of two triaxial broadband seismographs deployed at Narendranagar and Rudraprayag in the Lesser Himalaya. The source parameters viz.,seismic moment, source radius and stress drop of the events are computed. The source parameters are computed following Brune's theory by using the corner frequency and the low frequency asymptote estimated from the spectral method. The seismic moment ranges between 2.89×10^{18} to 3.90×10^{20} dyne-cm for seismic events with magnitudes between 2.44 to 3.32. The stress drops computed are less than 100 bars with minimum as 2.97 bars and maximum as 83.42 bars. The stress drop values show increasing trend with the magnitudes of the earthquakes but are independent of the size of the source. The empirical relationships between the source parameters and the magnitude are computed for this region which would need upgradation when more data becomes available. In order to examine variability of spectral shape and to find an independent stress parameter, the Hanks or dynamic stress drop σ_H, which is related to root mean square acceleration, is also computed using the method given by Andrews (1986). Scatter diagrams showing ratio of Brune to Hanks stress drop versus corner frequency, ratio of Brune to Hanks stress drop versus Brune stress drop, and Brune stress drop versus corner frequency are plotted. The scatter diagrams show that the three parameters are independent.

INTRODUCTION

Brune (1970) developed a powerful theory describing the nature of seismic spectrum radiated from the seismic source by considering the physical process of the energy release. The source model relates the corner frequency and low frequency asymptote to source dimension, seismic moment and stress drop. In several studies stress drops and other source parameters have been computed based on this model (e.g. Tucker and Brune, 1977; Fletcher, 1980; Archuleta et al., 1982; Hanks and Boore 1984; O'Neill, 1984; Andrews,1986; Sharma and Wason, 1994; Bansal,1998). A general result of these investigations is that the scaling behaviour of small events (M< 3) differs from that of larger events, which implies a dissimilarity in the rupture process (Frankel and Wennerberg, 1989). Specifically, the corner frequencies of the smaller events are observed to either increase very slowly or remain unchanged with decrease in seismic moment. This is interpreted to signify that the faulting dimensions of small events are relatively uniform as seismic moment falls below 10^{20} dynes-cm so that stress drop decreases with decreasing moment (Archuleta et al., 1982; Papageorgiou and Aki, 1983; Aki, 1984). In contrast, studies of the spectra of larger events with 3.5 <M <6 report constant stress drop with decrease in seismic moment (Thatcher and Hanks, 1973).

The Brune's method has been used for estimation of seismic moment, source radius and stress drop for the 15 local earthquakes in the Garhwal Himalaya region which occurred during the period Sept. 1997 to Dec. 1997. The dynamic stress drop or the Hanks stress drop is also computed using the method given by Andrews (1986).

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Logarithmic plots of Brune stress drop against corner frequency, ratio of Hanks to Brune stress drop against corner frequency as well as Brune stress drop are made.

The seismic activity in the Garhwal Himalaya region is largely concentrated in a relatively narrow belt , in the near vicinity of the surface trace of the Main Central Thrust. Most of these earthquakes have focal depths in the upper 20 km of the crust. Majority of the earthquakes are located between part of Lesser Himalaya and immediate south of Higher Himalaya extending from Nepal through Kumaun and Garhwal and western Himachal Pradesh.

SEISMOTECTONICS OF THE REGION

The Himalaya is regarded as having been formed by the collision of Indian and Eurasian Plates. Different models have been proposed by various research workers to explain the origin of the Himalaya (e.g. Gansser, 1966; Dewey and Bird, 1970; Molnar and Tapponnier, 1975; Valdiya, 1980; Seeber and Armbruster, 1981). The collision has also resulted into large scale thrusting and the same is progressed southward forming the Main Central Thrust (MCT) and Main Boundary Thrust (MBT) (Molnar et. al., 1977). The Indus-Tsangpo Suture (ITS) located about 250 km. north of MCT marks the pre-collision boundary along which the Indian plate subducted below the Eurasian plate and the subduction ended in Eocene times (Gansser, 1964, 1980). Along the MCT, the Higher Himalaya overthrusted the Lesser Himalaya and along MBT, the Lesser Himalaya thrusted over the Siwaliks. The Main Frontal Thrust (MFT) along the southren margin of the Sub-Himalayan Siwalik foothills is considered as the present boundary between the Indian and Eurasian plates (Nakata et al.,1990). In a widely accepted tectonic model proposed by Seeber and Armbruster (1981), a detachment fault is taken to represent the top surface of the northward underthrusting Indian plate. The Lesser Himalaya is characterized by northwardly dipping thrust zone and the rocks are highly folded and faulted. The broadband seismograph stations at Narendranagar and Rudraprayag, are located in this region.

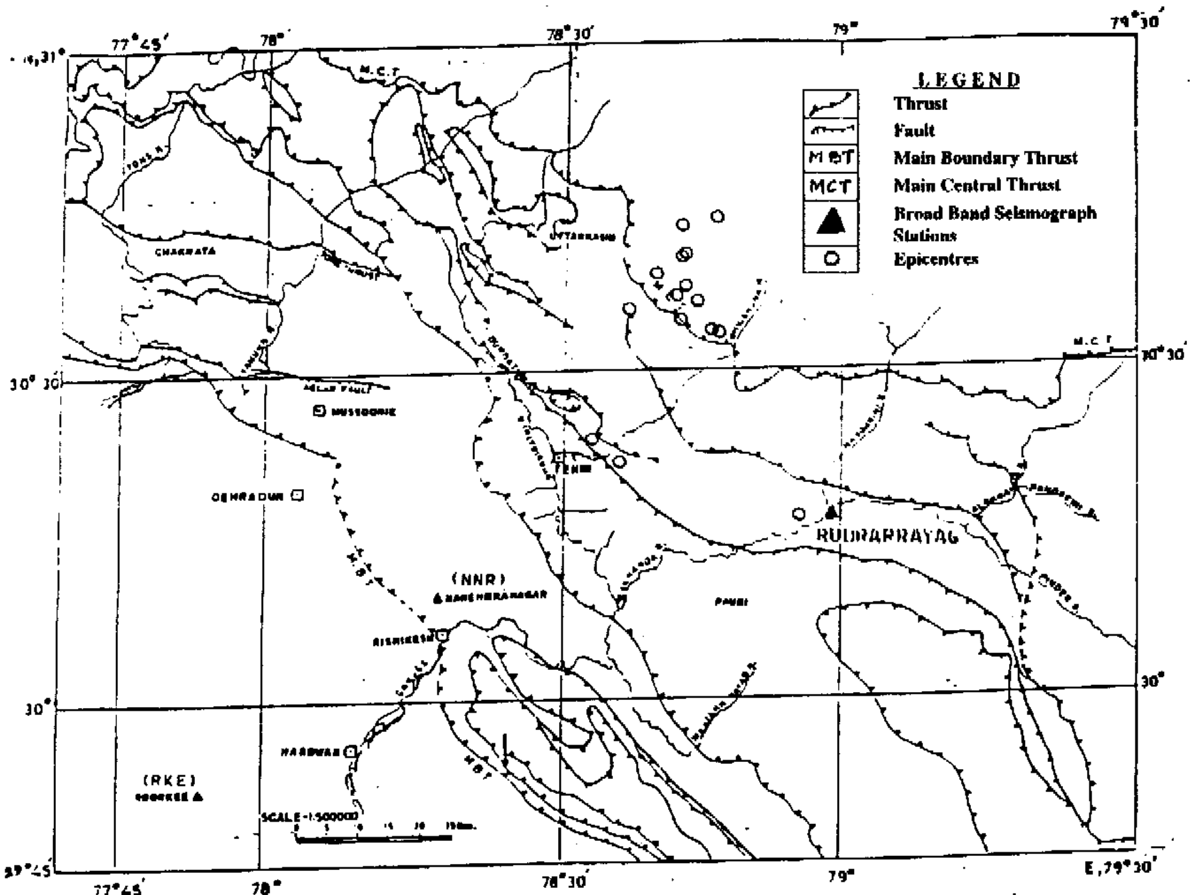

Fig. 1 Tectonic map (after Fuchs and Sinha, 1978) of the area showing epicentres of the seismic events and locations of Broadband Stations.

COMPUTATION OF SOURCE PARAMETERS

The data set used in the present study consists of the data acquired during Sept. - Dec. 1997 by two triaxial broadband seismographs installed at Narendranagar (Lat.30° 09.00´N, Long.78° 18.80´E) and Rudraprayag (Lat.30° 16.80´N , Long.78° 58.80´E) in the Garhwal Lesser Himalaya region. The events have been recorded in continuous as well as triggered mode. Each station is equipped with a 3-component CMG-40T broadband sensor, a 24-bit digitizer and a GPS clock. The frequency response of the sensor used is 20 sec to 50 Hz . The events analysed were mostly recorded at Narendranagar station. The coda magnitudes of the events are between 2.44 to 3.32. The location of the events are marked in Fig. 1 and their magnitudes are listed in Table 1.

Source parameters viz., seismic moment, source radius and stress drop of 15 local events which occurred in Garhwal Himalaya region during the period Sept 1997 to Dec. 1997 have been estimated by analyzing the P-wave spectra of the events. A data window length of 5.12 sec is used for all the events. This length is sufficient to resolve corner frequencies above 0.4 Hz. After removing the DC bias the sample window is cosine tapered with a 10% taper at both ends. The Fast Fourier Transform (FFT) algorithm of Cooley and Tukey is applied to compute the signal spectrum. The source parameters have been computed from the spectral analysis of the recorded digital waveforms using the formulations :- $M_0 = 4\pi\rho V^3 D\Omega_0 / R_{\theta\varphi}$; $r = V/(\pi f_0)$; $\Delta\sigma = 7M_0/(16r^3)$; and $E = \Delta\sigma M_0/(2\mu)$ where M_0, r, $\Delta\sigma$, D, Ω_0 , f_0 and $R_{\theta\varphi}$ denote seismic moment, source radius, stress drop, epicentral distance, low frequency asymptote, corner frequency and radiation pattern respectively. The crustal P-wave velocity and density are assumed to be 6.00 km/s and 2.7 gm/cm^3 respectively. The coefficient of radiation pattern $R_{\theta\varphi}$ for P-wave is taken as 0.63. The source parameters thus computed are listed in Table 1. The seismic moment ranges between 2.89x10^{18} to 3.90x10^{20} dyne-cm for events with coda magnitudes ranging between 2.44 to 3.32. The stress drops computed are less than 100 bars with minimum as 2.97 bars and maximum as 83.42 bars. The values of M_0, $\Delta\sigma$, r and E are plotted against magnitude on a semi-log scale. These plots alongwith corresponding straight line fits are shown in Figs. 2-5. The empirical relationships between the source parameters and the magnitude based on the earthquakes considered in this study are as follows:

$$\log(M_0) = (1.326 \pm 0.537)M_D + (10.585 \pm 1.507) \quad (1)$$

$$\log(\Delta\sigma) = (1.019 \pm 0.420)M_D - (1.436 \pm 1.180) \quad (2)$$

$$\log(r) = (0.101 \pm 0.072)M_D + (1.643 \pm 0.202) \quad (3)$$

$$\log(E) = (2.358 \pm 0.941)M_D + (8.613 \pm 2.639) \quad (4)$$

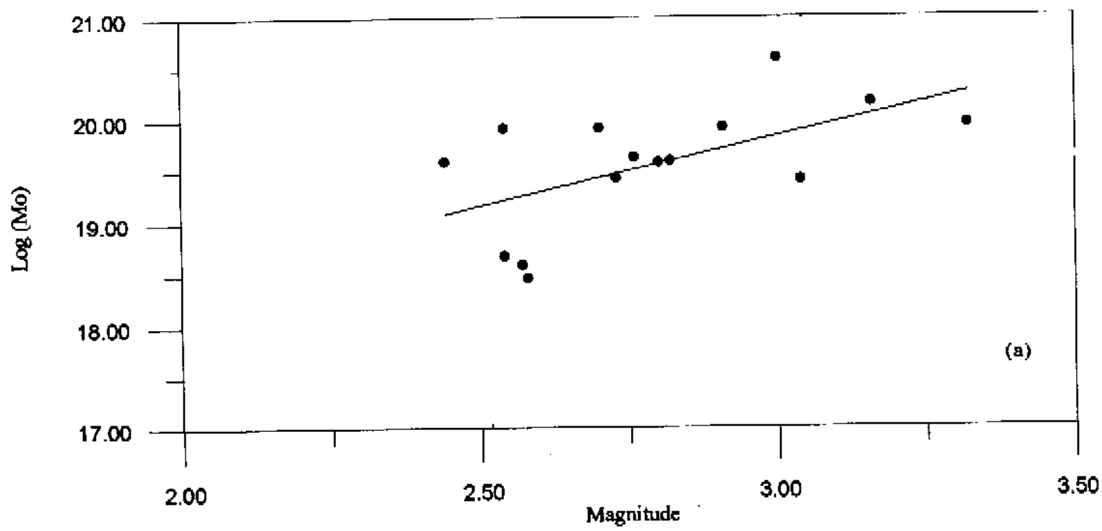

Fig. 2. Plot of Magnitude versus Log (Mo)

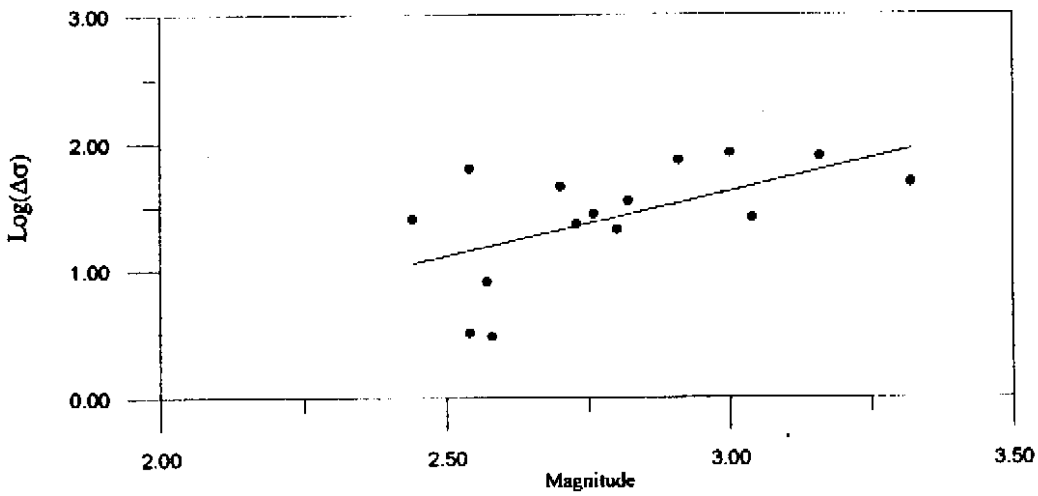

Fig. 3. Plot of Magnitude versus Log (Δσ)

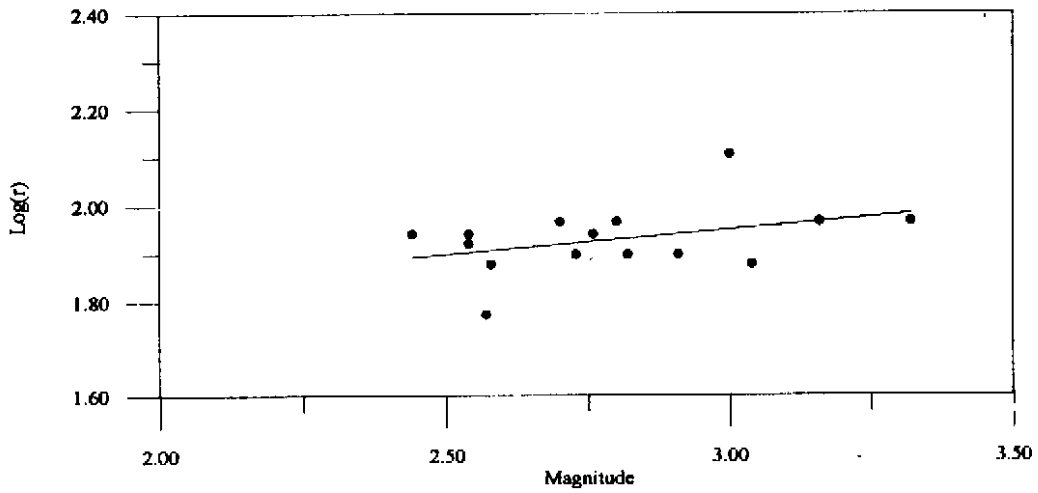

Fig. 4. Plot of Magnitude versus Log (r)

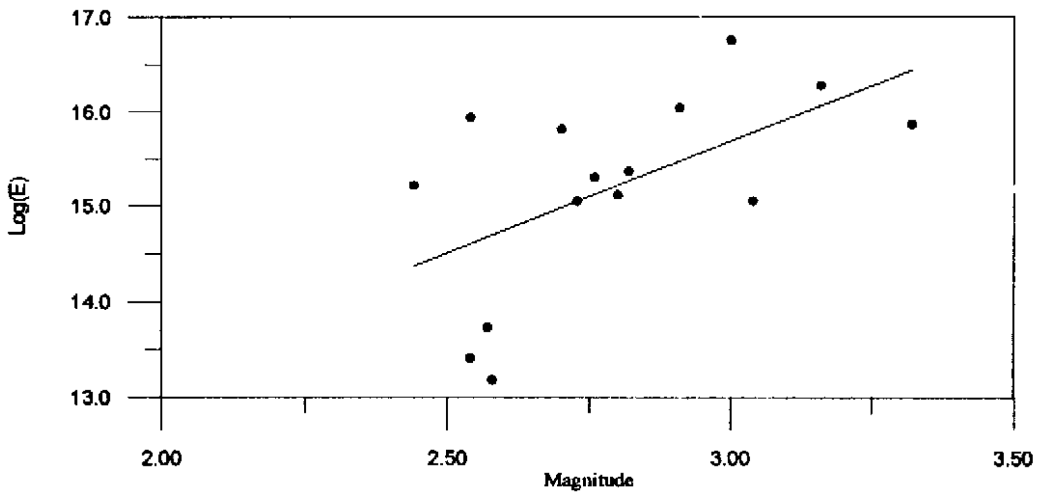

Fig. .5. Plot of Magnitude versus Log (E)

Table 1

Serial No.	Date	Mag.	Seismic moment (Dyne-cm)	Source radius (m)	Stress drop (bars)	Energy (ergs)
1	15-09-97	2.44	3.82E+19	87.12	25.26	1.6E+15
2	18-09-97	2.57	3.82E+18	59.11	08.08	5.3E+13
3	19-09-97	2.82	3.90E+19	78.82	35.17	2.3E+15
4	21-09-97	2.54	4.70E+18	87.12	03.13	2.5E+13
5	17-10-97	3.32	8.59E+19	91.96	48.32	7.2E+15
6	18-10-97	2.58	2.89E+18	75.24	02.97	1.5E+13
7	19-10-97	2.54	8.11E+19	82.76	62.60	8.7E+15
8	23-10-97	2.73	2.62E+19	78.82	23.44	1.1E+15
9	30-10-97	3.04	2.50E+19	75.24	25.73	1.1E+15
10	31-10-97	3.16	1.40E+20	91.96	78.51	1.9E+16
11	01-11-97	2.70	8.11E+19	91.96	45.63	6.4E+15
12	28-11-97	2.76	4.17E+19	87.12	27.62	2.0E+15
13	14-12-97	2.80	3.70E+19	91.96	20.80	1.3E+15
14	15-12-97	2.91	8.10E+19	78.82	72.46	1.1E+16
15	17-12-97	3.00	3.90E+20	127.32	83.42	5.6E+16

The scatter in the plots of source parameters vs magnitude (Figs. 2 - 5) and the level of uncertainities in the coefficients of the straight line fits do not show a strong correlation. This is mainly on account of approximations done in computation of coda lengths, azimuths of the epicentres and the hypocentral distances and the small data set taken.

Brune's and Hanks stress drops are also calculated by following the method given by Andrews (1986). The velocity power spectrum of each record is further multiplied by the hypocentral distance squared to correct for geometrical spreading . Note that this effect of geometrical spreading has been taken into account by considering the D (Hypocentral distance) term in the computation of M_0 (Brune, 1970). The corrected velocity power spectrum, $V^2(f)$, and the displacement spectrum, $D^2(f) = V^2(f)/(2\pi f)^2$ of each event have been used to estimate the source parameters. A brief description of the method given by Andrews (1986) is as given below.

The corrected displacement power spectrum, $D^2(f)$, and the corrected velocity power spectrum, $V^2(f)$ are used to define the following integrals

$$S_{D2} = 2\int D^2(f)df \quad \text{and} \quad S_{V2} = 2\int V^2(f)df \tag{5}$$

The Brune' stress drop is then computed using the following expression:

$$\sigma_B = \frac{2\rho S_{V2}^{5/4}}{2.34 R S_{D2}^{3/4}} \tag{6}$$

Hanks or dynamic stress drop σ_H which is related to root mean square acceleration (Hanks and Mcguire, 1981)is also computed in order to examine variability of spectral shape and to find an independent stress parameter. This source parameter can be estimated using the relationship proposed by Boatwright (1982). Acceleration power spectra $A^2(f) = (2\pi f)^2 V^2(f)$ is used to compute the following integrals:

$$s_{A2} = \int_0^{f_m} A^2(f)df \quad \text{and} \quad s_{A4} = \int_0^{f_m} A^4(f)df \tag{7}$$

where f_m is the upper limit and is greater than f_c. The power spectral acceleration level is taken as:

$$\langle A^2 \rangle = [S_{A4} / S_{A2}] \tag{8}$$

The above formulation is not sensitive to the choice of f_m. The Hanks stress drop can be written as:

$$\sigma_H = [2\pi f_c \rho / 2.34 R_{\theta\varphi}]\sqrt{\langle A^2 \rangle} \tag{9}$$

The advantage of this method is that in addition to the two independent parameters i.e., corner frequency and low frequency asymptote in the first case (Brune's model), we now have a third independent parameter, the Hanks stress drop. To check the independency of the third parameter with respect to the other two, the ratio of Brune stress drop to the Hanks or dynamic stress drop is plotted against corner frequency. The scatter as seen in Fig 6. shows that the three parameters are independent and the method to compute these (Andrews, 1986) is stable and is independent of the shape of the spectra. The ratio of the two stress drops is also plotted against Brune stress drop and the same conclusion is drawn based on the scatter of the points as shown in Fig. 7. No correlation could be seen while plotting the Brune stress drop with respect to corner frequency as shown in Fig. 8.

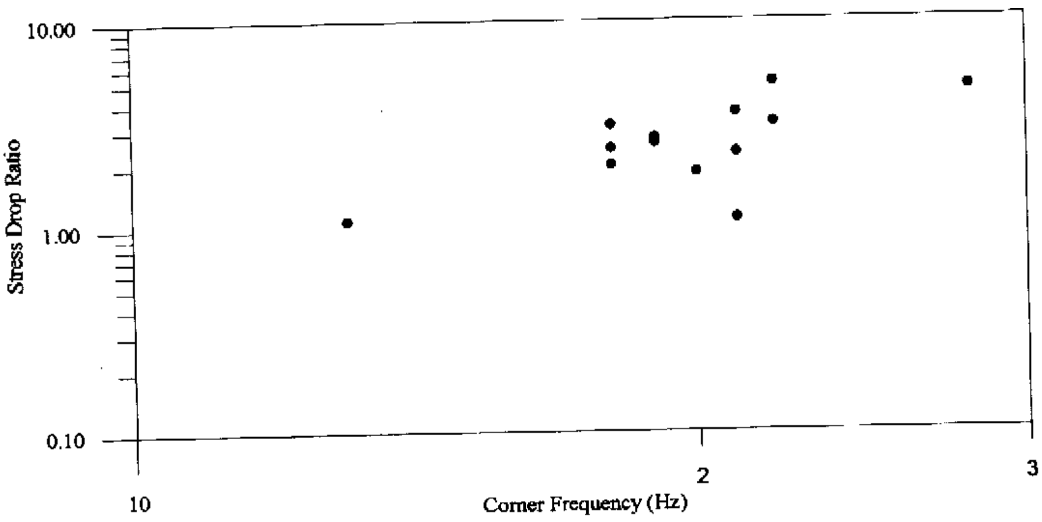

Fig. 6. Plot of Hanks to Brune Stress Drop Ratio vs Corner Frequency

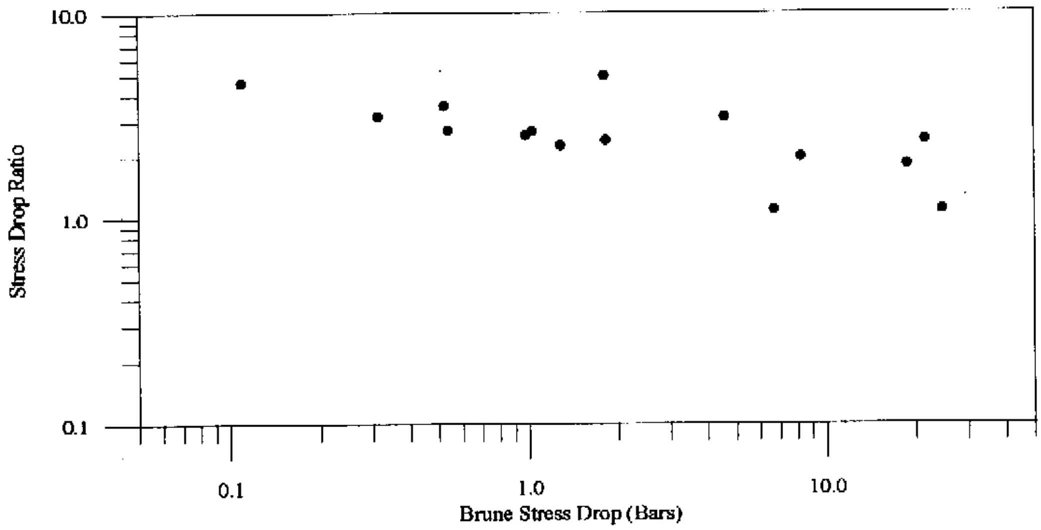

Fig. 7. Plot of Hanks to Brune Stress Drop Ratio Vs Brune Stress Drop

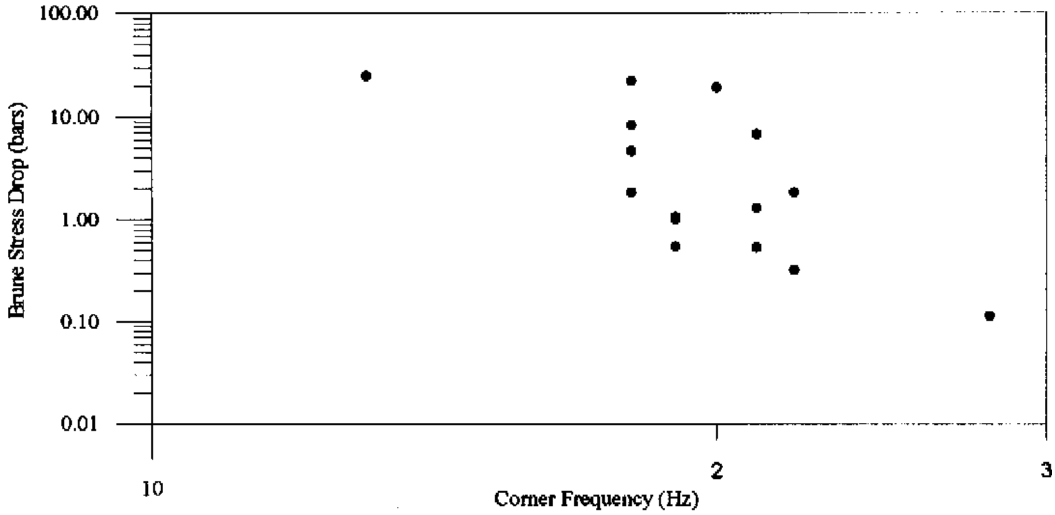

Fig. 8. Plot of Brune Stress Drop vs Corner Frequency

CONCLUSIONS

The source parameters are computed for 15 local events recorded on Broadband staions in the Lesser Garhwal Himalaya region. The source parameters are computed using Brune's theory by estimating the corner frequency and the low frequency asymptote from the spectral method. The seismic moment ranges between 2.89×10^{18} to 3.90×10^{20} dyne-cm for events with magnitudes between 2.44 to 3.32. The stress drops computed are less than 100 bars with minimum as 2.97 bars and maximum as 83.42 bars. The empirical relationship between the source parameters and the magnitude are also proposed for this region which would need upgradation when more data becomes available. The uncertainities in the coefficients of the straight line fits are mainly on account of approximations done in computation of coda lengths, azimuths of the epicentres and the hypocentral distances as well as the small data set taken. An independent spectral measure, i.e., Hanks stress drop is also computed in order to examine variability of spectral shape and to find an independent stress parameter. Scatter diagrams showing ratio of Brune to Hanks stress drop versus corner frequency, ratio of Brune to Hanks stress drop versus Brune stress drop, and Brune stress drop versus corner frequency are plotted. The scatter diagrams show that the three parameters are independent.

ACKNOWLEDGEMENTS

This study is carried out under a research project funded by Department of Science and Technology, Govt. of India . The authors are thankful to Mr. Kamal Kapoor, Ms. Dinesh Nandini, Mr. Vipin Kara and Mr. P. K. Khan for assisting in the data acquisition and processing work.

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