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LAPSE-TIME DEPENDENCE OF Q_c IN THE GARHWAL HIMALAYA

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ABSTRACT

Digital data of local earthquakes, obtained in the region of the Garhwal Himalaya employing Digital Telemetered Seismic Array, has been analysed for the three lapse time windows of 20, 30 and 40 sec duration to estimate coda Q (Q_c) as a function of lapse time window length. It is found that the Q_c values increases with increasing window length. The frequency dependence Q_c relationships for these three time windows are obtained as $Q_c = 69f^{1.15}$, $Q_c = 125f^{0.96}$ and $Q_C = 148f^{0.94}$ respectively. The approximate radius and area sampled by the coda waves with respect to their window lengths are 70 &15,400, 80 & 20,000 and 90 km & 25,500 km^2 respectively. The increase in Q_c with increasing window length, in the region, is interpreted to increase in Q_c with depth which means that the coda waves in the longer part of the seismogram is sampled by larger area from the deeper part of the earth's crust or upper mantle which is considered to be less heterogeneous as compared to the shallow crust.

INTRODUCTION

Coda waves of small local earthquakes are considered to be the superposition of backscattered S-waves generated when primary S-waves encounter numerous structural heterogeneities present in the earth's crust and upper mantle (e.g., Aki, 1969; Aki and Chouet, 1975; Sato, 1977 a, b and Aki, 1980 a, b). Therefore, these waves represent the inhomogeneities in the medium and provide the information about the average attenuation properties of the medium through which they propagate. The earthquake source and medium properties of a seismic region, from the decay rate of coda waves, were determined first by Aki (1969). Subsequently various authors have used coda waves to determine the attenuation laws for different seismic regions of the world (e.g., Aki and Chouet, 1975; Sato, 1977 a, b; Tsujiura, 1978; Roecker, 1982; Pulli, 1984; Reha, 1984; Herraiz and Espinosa, 1986; Ibanez et al., 1990; Nishigami et al., 1990 and Kanao and Ito, 1991, 1992). Frequency dependence attenuation law for the region of Garhwal Himalaya has also been determined by Gupta et al., (1995) from the study of quality factor of coda waves (Q_c), using digitally recorded local earthquakes in the region. It has also been observed that the Q_c is dependent on lapse time window and increases with increasing window length (e. g., Roecker, 1982, Pulli, 1984; Rovelli, 1984; Lee et al., 1986; Kvamme and Havskov, 1989; Ibanez et al., 1990 and Woodgold, 1994).

In the earlier study of frequency dependence Q_c by Gupta et al., (1995), the coda waves amplitude decay with lapse time was analysed at central frequencies 1.5 to 18 Hz using 13 seismograms of local earthquakes recorded digitally in the region. The single backscattering model given by Aki and Chouet (1975) was used and only the single coda (lapse time) window of 30 sec duration was analysed. However, in the present study, three lapse time windows of 20, 30 and 40 sec duration for each seismogram have been analysed using the similar data set and the procedure. It is observed that Q_c increases as window length increases in the region. This indicates that the deeper part of the earth's crust or upper mantle below the region is less heterogeneous as compared to the shallower part of the earth's crust.

DATA AND ANALYSIS

Seven local earthquakes used in the study are listed in (Table-1). These earthquakes were recorded digitally during the period from 29.03.89 to 12.06.89 (six earthquakes) and 18.12.90 (single earthquake) in the region of Garhwal Himalaya employing Digital Telemetered Seismic Array (DTSA). The locations of events along with the seismological recording stations are shown in Fig. 1. The same data set was used for the study of frequency dependent Q_c in the Garhwal Himalaya (Gupta et al., 1995).

Table-1 **List of selected events used in Q_c analysis. Origin times of events are local times.**

Sl. No.	Date	Origin Time Hr.	Mn.	Sec.	Location Lat.°N	Long.°E	M_L	Focal Depth (Km)	No. of stations for Loct.	Q_c
1.	890329	10	59	08.57	30.72	78.86	2.41	2.40	4	1
2.	890402	10	38	59.13	30.31	79.21	3.16	3.15	4	2
3.	890412	17	39	21.62	30.74	78.33	3.03	3.00	4	2
4.	890419	04	39	01.92	30.18	78.65	2.92	2.90	4	3
5.	890612	12	43	48.21	30.87	78.13	3.08	3.10	4	2
6.	890612	19	50	05.04	30.16	78.72	2.89	2.90	4	2
7.	901218	08	07	33.93	30.44	78.91	4.85	4.85	4	1

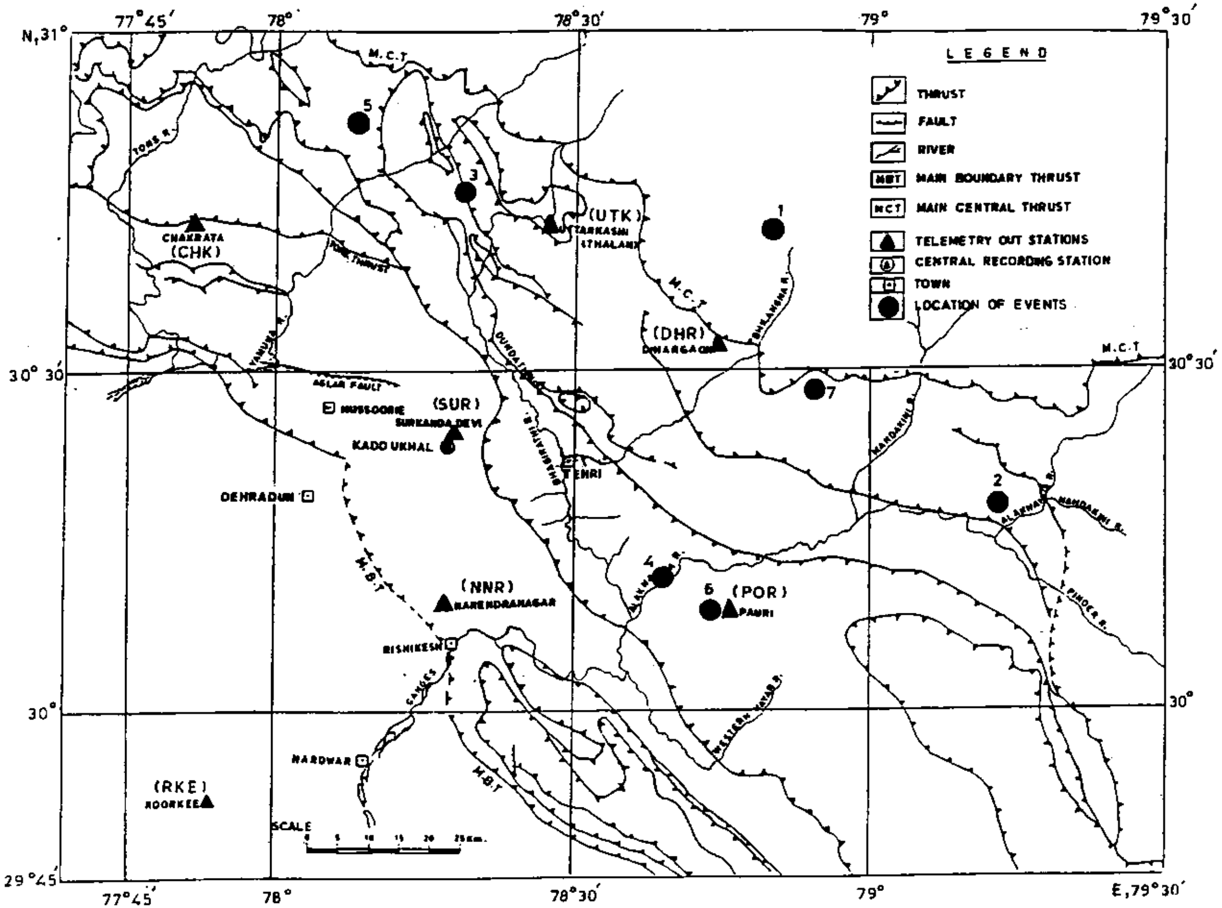


Fig. 1 Tectonic map of the Garhwal Himalaya along with the locations of events selected for the study. Seismometer stations of DTSA are also shown (Tectonics after Fuchs and Sinha, 1978).

Single backscattering model given Aki and Chouet (1975) has been used to analyse the coda waves in the seismograms for Q_c estimation. According to this model, the coda waves are considered as superposition of backscattered body waves generated from numerous heterogeneities present randomly but uniformly in the earth's crust and upper mantle. The model is based on the following assumptions:

i) scattering is a weak process and does not produce any secondary (multiple) scattering when it encounters another scatter. This is the so called *Born approximation*, which violates the energy conservation law but has been accepted in various physical problems and used successfully in high frequency seismic waves analysis.

ii) as the coda waves arrive long time after the arrival of all direct waves (P, S and Surface waves) the source and receiver are assumed to be placed at one point (or coincident).

Under the above assumptions, coda-waves amplitude, $A(f,t)$ in a seismogram can be expressed, for a central frequency f over a narrow bandwidth signal, as a function of the lapse time t, measured from origin time of the seismic event.

$$A(f,t) = S(f)t^{-a} \exp(-\pi f t / Q_C) \qquad ....(1)$$

where $S(f)$ represents the source function at frequency f, and is considered to be a constant for a narrow band pass filtered signal as it is independent of factors like time and radiation pattern which are responsible for energy loss in the medium; 'a' is the geometrical spreading factor taken as 1 for single scattering body waves. Q_c is the quality factor of coda waves representing the average attenuation in a medium. Equation (1) can be simplified as:

$$\ln[A(f,t)\cdot t] = C - b\cdot t \qquad ....(2)$$

where $C = \ln S(f)$ and $b = \pi f / Q_C$

From the slope of linear equation (2) between $\ln[A(f,t)\cdot t]$ and t the estimation of Q_c can be obtained as a function of frequency. In order to determine Q_c at different central frequencies (f_c), seismograms are filtered over narrow bandwidths of $0.67 f_c$ using an 8-pole Butterworth bandpass filter. The filter parameters used are given in the Table-2 and the number of frequency bands selected in this study are ten as compared to the five used in earlier study by Gupta et al., (1995). Filtered seismograms are used for the study of Q_c as a function of frequency and lapse time window length. The average time intervals for three lapse time windows of 20, 30 and 40 sec used for coda wave analysis of a seismogram are taken as 30-50, 30-60 and 30-70 sec respectively (Fig.-2). These time intervals start from $2t_s$ where t_s is the travel time of S-waves measured from earthquake origin time (Rautian and Khalturian, 1978). Only seismograms having $2t_s \geq 30$ sec are used in this study. The same lapse time window (i.e., 20, 30 and 40 sec) is selected for all the stations so that there should not be any variation in Q_c estimation due to distance while averaging is done. The filtered coda waves amplitude in different time windows from lapse time 30 sec onwards are smoothed using a root-mean-square (RMS) technique which calculates the RMS values of coda amplitude of the filtered seismograms in a time window of 5.12 sec for (1, 1.5 & 2 Hz) and 2.56 sec for (3, 4, 6, 8, 12, 16 & 18 Hz) with a sliding window in steps of half i.e., 2.56 sec and 1.28 sec respectively. RMS values of coda amplitude obtained by this approach constitute a smoother envelope of the coda. Fig. 3a & 3b (Gupta et al., 1995) show an example of a filtered and smoothed logarithmic amplitude of the coda part of seismogram along with estimated Q_C values at various central frequencies.

Table-2. Parameters of bandpass filters showing central frequencies and their low and high cut off frequencies.

Low Cutoff	Central Frequency Hz	High Cutoff
0.67	1.0	1.33
1.00	1.5	2.00
1.33	2.0	2.67
2.00	3.0	4.00
2.67	4.0	5.33
4.00	6.0	8.00
5.33	8.0	10.67
8.00	12.0	16.00
10.67	16.0	21.33
12.00	18.0	24.00

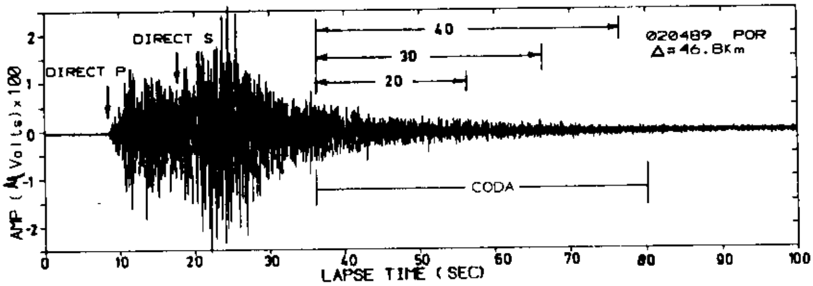
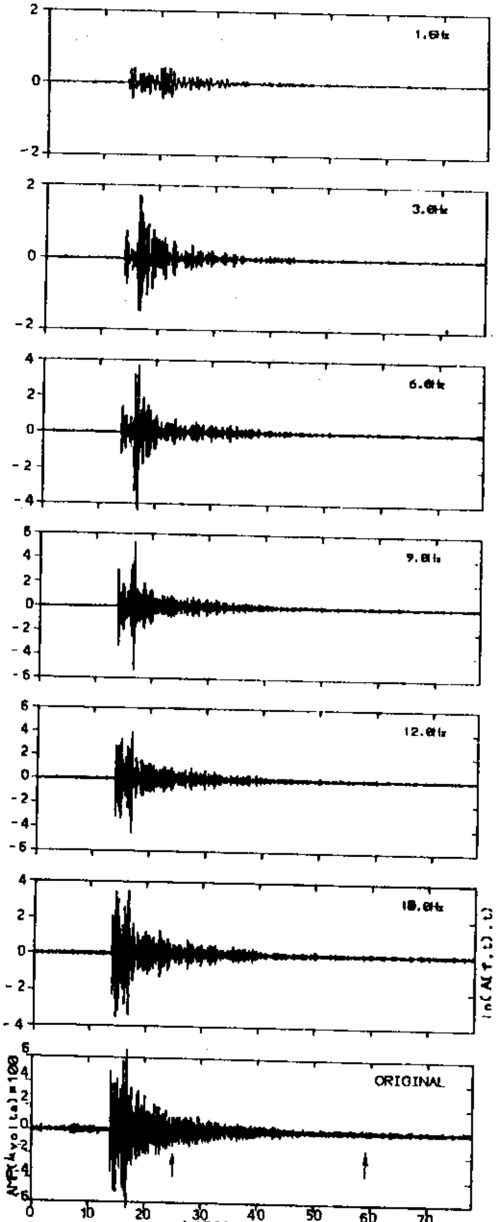


Fig. 2. An example of a seismogram, event no. 2 in Table-1, showing direct P and S-phases and different portion of coda (lapse time) windows selected for analysis.



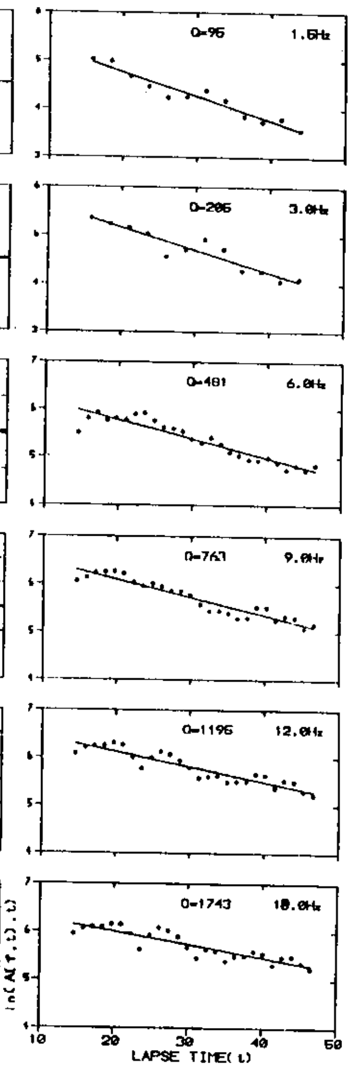


Fig. 3a. An example of original (bottom) and band pass filtered coda wave forms of seismogram from station POR for earthquake recorded on 19.04.89. The analysis interval for Q_c estimation is indicated by arrows (↑).

3b. Corrected and smoothed logarithmic coda amplitude using RMS approach for the portion shown by arrows in 3a. The straight line is fitted in the least square sense. The estimated Q_c value for each frequency component is also shown.

RESULTS AND DISCUSSION

Coda Q (Q_c) for three lapse time windows of 20, 30 and 40 sec duration have been computed in the frequency range of 1.0 to 18 Hz from the seven local earthquakes recorded digitally in the region of Garhwal Himalaya employing DTSA.

The estimated mean values of Q_c for these three lapse time windows in the frequency range 1.0 to 18 Hz are shown in Table-3 and the frequency dependent Q_c relationships of the form $Q_c = Q_0 f^n$ are obtained as, $Q_c = 69 f^{1.15}$, $Q_c = 125 f^{0.96}$ and $Q_C = 148 f^{0.94}$ respectively for the three time windows, as shown in Fig. 4. The general characteristics of frequency dependence of Q_c, as obtained by Gupta et al., (1995), is maintained for all time windows, however, Q_c becomes less frequency dependent as window length increases.

Table-3 **Estimated mean of Q_C for different lapse time windows. The standard error from mean for each central frequency is also given. N is number of observations made.**

f (Hz)	Lapse Time Window					
	20 sec		30 sec		40 sec	
	Q_c	N	Q_c	N	Q_c	N
1.0	67±7.00	8	141±20.81	11	137±20.03	8
1.5	123±12.33	9	182±26.00	7	226±37.05	7
2.0	164±13.33	9	253±29.18	8	301±32.72	7
3.0	236±29.39	6	359±18.39	8	475±33.26	7
4.0	308±33.58	8	390±17.33	9	508±17.68	8
6.0	511±37.33	9	649±46.89	11	732±44.88	9
8.0	723±55.56	9	935±69.49	12	1040±63.16	11
12.0	1162±65.00	9	1421±49.36	12	1495±70.71	11
16.0	1746±96.00	11	1882±77.06	12	2090±78.74	10
18.0	2080±140.46	8	2085±74.47	11	2368±100.00	11

A comparison of mean value of Q_c for all three time windows is given in Fig. 5a which shows that Q_c increases as the window length increases. The significant variation in mean value of Q_c can be seen if time windows of 20 and 40 sec are only considered (Fig. 5b).

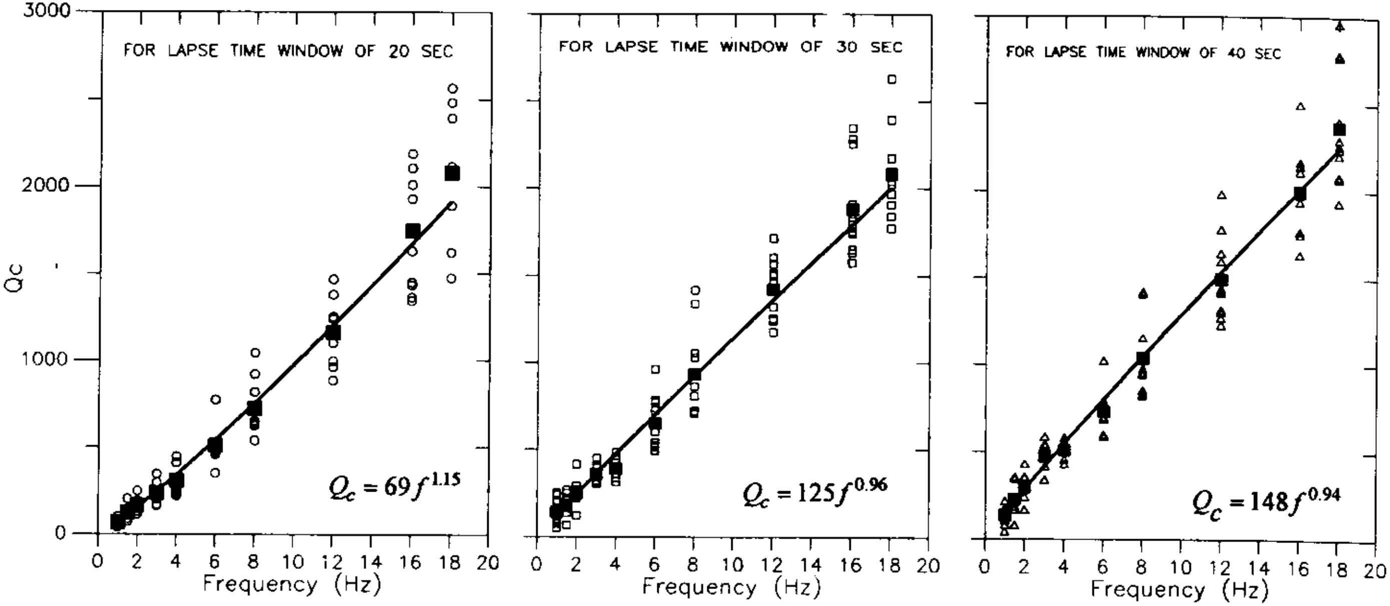


Fig.4. Plots of all values of Q_c as a function of frequency estimated for three lapse time windows of 20, 30 and 40 sec duration. Mean value of Q_c calculated for each central frequency, is shown by solid square. The frequency dependence Q_c relationship of the form $Q_c=Q_0f^n$ obtained for each lapse time window is also shown.

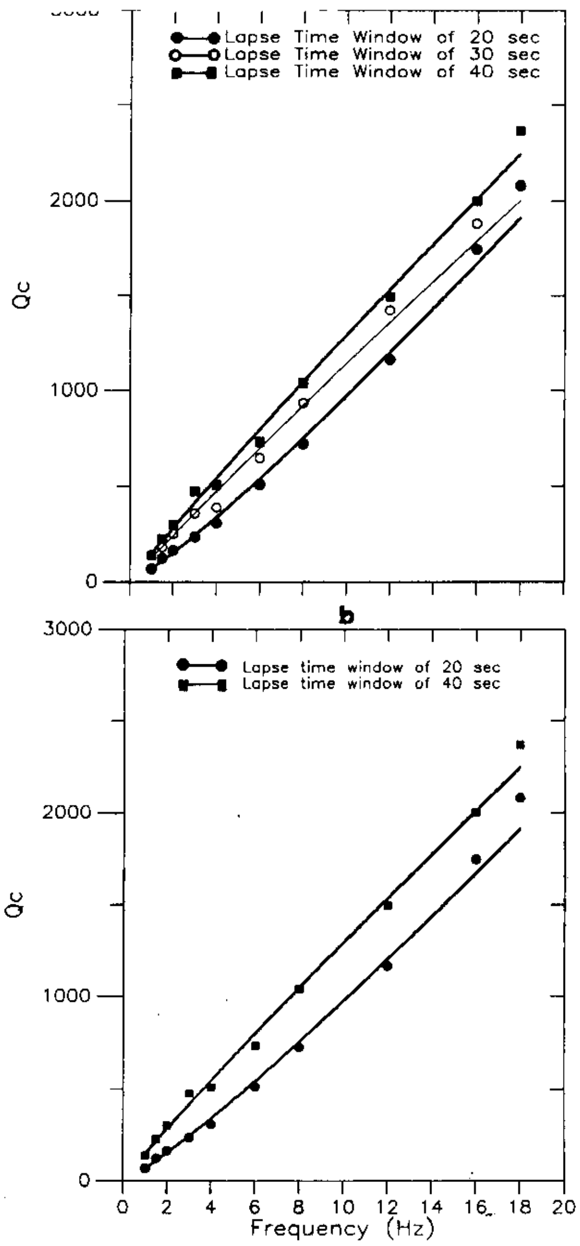


Fig.5a. Comparison of mean values of Q_c as a function of frequency obtained from lapse time window of 20, 30 and 40 sec duration for the region of Garhwal Himalaya.

5b. Comparison of mean values of Q_c as a function of frequency obtained from lapse time window of 20 and 40 sec duration.

The area sampled by the coda waves is represented by an ellipsoid (Pulli, 1984) and surface projection of this ellipsoid for a surface source in circular shape can be defined as:

$$\frac{x^2}{(vt/2)^2}+\frac{y^2}{((vt/2)^2-R^2/4)}=1 \qquad ....(3)$$

where R, v and t are the source-receiver distance, average velocity of S-waves and the average lapse time respectively. In this study, R, v and t are taken as 0 (source-receiver coincident), 3.5 km/sec and 40, 45 & 50 sec (mid point of lapse time windows) respectively. The maximum `coda generating area' in circular shape along with radius for three time windows is shown in Table-4.

Table-4 Coda generating area and corresponding radius covered by the coda waves for each lapse time window.

Lapse time window Duration (sec)	from	Mid point of Lapse time window (sec)	Approximate radius (Km)	Coda generating area (Km^2)
20	30-50	40	70	15,400
30	30-60	45	80	20,000
40	30-70	50	90	25,500

The increase in mean value of Q_c with window length for various frequency bands (Table-3) reflects that Q_c is a function of depth as coda waves observed with longer window length sampled from larger area (Table-4) covering the deeper part of the earth's crust or the upper mantle. The high Q_c values (or low attenuation) with increasing window length (or depth) indicates the increase of homogeneity with depth and hence the deeper part of the earth's crust or upper mantle may be considered as less heterogeneous compared to the upper part of the earth's crust in the region of the Garhwal Himalaya. A similar interpretation has been given by Roecker et al.(1982) for Hindukush, Pulli (1984) for New England, Rovelli (1984) for Montenegro (Yugoslavia) and Ibanez et al. (1990) for Granada (Spain).

CONCLUSIONS

Estimates of coda Q (Q_c), in the frequency range 1.0 to 18 Hz, have been made for three lapse time windows of 20, 30 & 40 sec duration in the region of Garhwal Himalaya using seven local earthquakes recorded digitally employing DTSA.

The mean values of Q_c estimated for these three time windows are 67±7, 141±21 and 137±20. at frequency 1.0 Hz whereas the values are 2080±140, 2085±75 and 2368±100 at 18 Hz respectively. The frequency dependence Q_c relationships, for these three time windows, are obtained as $Q_c = 69f^{1.15}$, $Q_c = 125f^{0.96}$ and $Q_C = 148f^{0.94}$ respectively whereas the approximate radius and area sampled by the coda waves with respect to their window lengths are 70 &15,400, 80 & 20,000 and 90 km & 25,500 km^2 respectively.

It is found that Q_c increases as lapse time window length increases in the region of Garhwal Himalaya. The increase of Q_c with increasing lapse time window is attributed to increase in Q_c with depth because the coda waves observed in the longer part of seismogram are thought to be sampled from the larger area (Table-4) covering the deeper part of the earth's crust or upper mantle. High Q_c values at greater depths indicate the increase of homogeneity and it seems that the deeper part of the earth's crust or upper mantle in the region of Garhwal Himalaya is less heterogeneous as compared to the shallower part of the earth's crust. Therefore, it is concluded that the average attenuation in Garhwal Himalaya is a function of lapse time window and show a decreasing trend with depth.

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