Seismic wave attenuation characteristics of three Indian regions: A comparative study

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Study of seismic wave attenuation characteristics of three Indian regions, namely Garhwal Himalaya, Koyna region and northeast India showed that part of northeast India is tectonically more active compared to Garhwal Himalaya and Koyna region. The Garhwal Himalaya and the Koyna region exhibit similar levels of tectonic activity.

THREE regions of India, namely Garhwal Himalaya, Koyna region and northeast India are seismically active. These regions are also important from the engineering point of view, as many hydroelectric projects are either in operation or under advance stage of planning and construction. Many seismological and strong motion networks have been deployed in these regions for collecting the data of local earthquakes as well as strong motion records of moderate to large-sized earthquakes. These data sets allowed the study of seismic wave attenuation characteristics of the three regions mentioned above. For Garhwal Himalaya and Koyna region, Q_c estimates have been obtained using the coda waves of local earthquakes[1–4] and for northeast India, Q_c estimates have been obtained using the coda waves of strong motion records of 6 August 1988 earthquake ($m_b = 6.8$) (refs 3 and 5). The single backscattering model given by Aki and Chouet[6], has been used to analyse the coda waves of local earthquakes and strong motion records.

In the present study, the seismic wave attenuation characteristics of three Indian regions have been compared and correlated with their tectonic set-up.

Study regions

Three regions, namely Garhwal Himalaya, Koyna region and northeast India, considered for the study, are marked as 1, 2 and 3, respectively on the map of India (Figure 1). The Garhwal Himalaya forms the northwestern part of the Himalaya, the Koyna region is located in the western margin of the Indian Peninsula, and the Shillong plateau is located in the northeastern part of India. All these three regions are seismically active and located in different geotectonic environments.

Data used

The following data sets of local earthquakes and strong motion records of moderate earthquakes have been used to study the seismic wave attenuation characteristics of the three regions.

For Garhwal Himalaya and Koyna region, Q_c estimates have been made using the coda waves of digitally recorded local earthquakes[1–4] and for northeast India, the coda waves observed on strong motion records have been used to estimate Q_c (refs 3 and 5). Typical examples of local earthquake records from Garhwal Himalaya and Koyna region and strong motion records of 6 August 1988 earthquake ($m_b = 6.8$) collected from the northeast region are shown in Figure 2.

Methodology

The single backscattering model[6] has been adopted to analyse the coda wave part of local earthquakes and strong motion records of moderate-sized earthquakes. The method is as follows:

According to the single backscattering model, the coda wave amplitude, $A(f, t)$, for a narrow bandwidth signal centred at frequency f and at lapse time t, is described as $A(f, t) = S(f)t^{-a} \exp(-\pi ft/Q_c)$, where $S(f)$ represents the source function at frequency f and is considered as constant, a is the geometrical spreading factor and taken as unity for body waves, and Q_c is the quality factor representing the average attenuation characteristics of the medium. Q_c is estimated from the slope ($= b$) of the equation after rewriting the above equation in the form $\ln[A(f, t)t] = C - bt$, where $C = \ln S(f)$ and $b = \pi f/Q_c$. Normally, lapse time t is taken as twice the S-wave travel time[7], but in case of strong motion records, t is taken from the point where regular decay of coda waves on the strong motion records starts. To estimate Q_c at different frequency bands, the coda waves of local earthquakes and strong motion records are filtered at a number of frequency bands[1–4] using eight-pole Butterworth bandpass filter.

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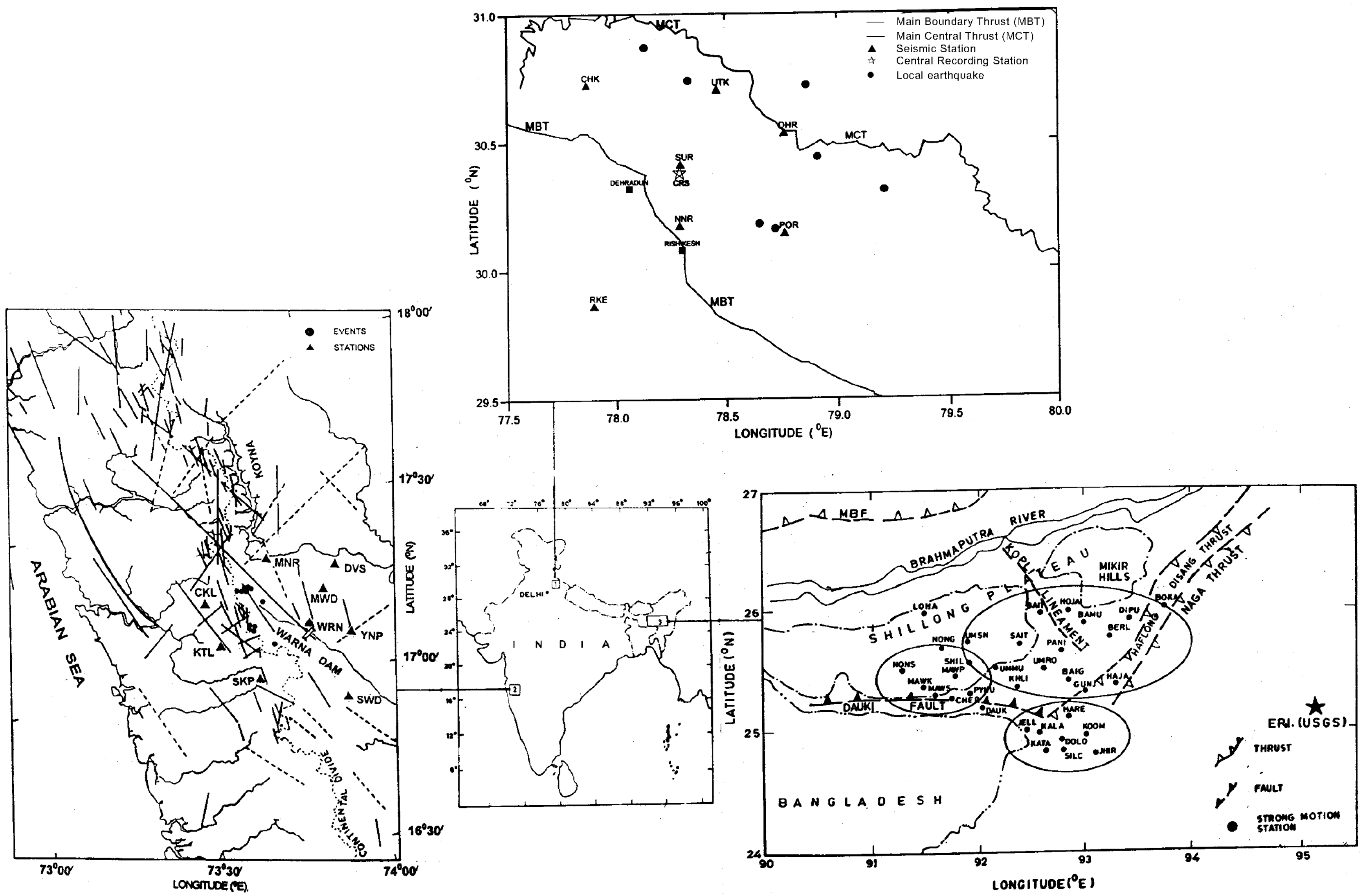

Figure 1. Map showing tectonics, recording stations and events considered for the three regions studied and their locations.

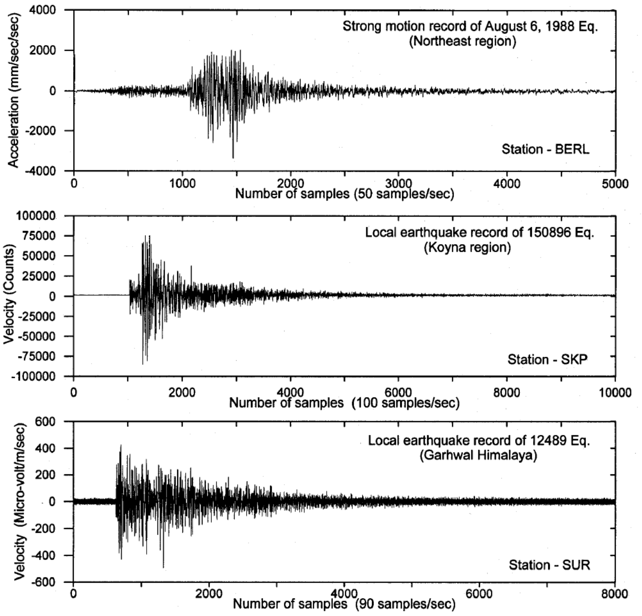

Figure 2. Typical examples of local earthquake records from Garhwal Himalaya and Koyna region and strong motion record from northeast India.

Table 1. Q_c estimate as a function of frequency for three regions

	Q_c estimate		
f (Hz)	Garhwal Himalaya	Koyna region	Northeast India
1.0	104 ± 16.09	–	–
1.5	174 ± 24.60	148 ± 13.5	122 ± 10.52
2.0	249 ± 30.25	178 ± 17.3	181 ± 14.49
3.0	362 ± 17.90	335 ± 26.3	254 ± 20.12
4.0	394 ± 16.45	443 ± 23.9	358 ± 33.46
6.0	651 ± 46.44	768 ± 29.8	584 ± 53.38
8.0	936 ± 66.86	1014 ± 39.2	729 ± 50.05
12.0	1429 ± 47.01	1539 ± 44.7	1067 ± 68.16
16.0	1900 ± 76.50	1956 ± 41.8	1356 ± 74.36
18.0	2168 ± 95.02	–	–
24.0	–	2703 ± 38.8	–

'–', Q_c values have not been estimated.

Results

Using the data sets of local earthquakes and strong motion records and adopting the single backscattering model, the following results of Q_c estimates have been obtained.

For Garhwal Himalaya, Q_c estimates vary from 104 ± 16.09 at 1.0 Hz to 2168 ± 95.02 at 18.0 Hz (Table 1) and follow the frequency-dependent relationship as $Q_c = (110 \pm 5.15)f^{(1.02 \pm 0.025)}$ (using 30 s coda window length) (Figure 3 *a*)[1–3]. Q_c values have also been computed using three lapse time coda window lengths of 20, 30 and 40 s duration of local earthquake data. It was found that Q_c is a function of lapse time window length. Q_c value increases as window length increases[2]. Mean value of Q_c, frequency-dependent Q_c relationships and the area coverage for these three window lengths are given in Table 2.

For Koyna region, Q_c estimates vary from 148 ± 13.5 at 1.5 Hz to 2703 ± 38.8 at 24.0 Hz (Table 1) and frequency-dependent Q_c relationship (using 30 s coda window length) is obtained as $Q_c = (97 \pm 7.18)f^{(1.09 \pm 0.036)}$ (Figure 3 *a*)[3,4]. This relationship provides the average attenuation characteristics of the medium underneath a localized zone around the Koyna region covering an area of about 11,500 km^2, with the lateral extent of about 120 km and depth extent of about 60 km (refs 3 and 4). Lapse time-dependent Q_c relationships obtained for the region using five lapse-time window lengths are given in Table 3.

For northeast India, Q_c estimates using the strong motion records vary from 122 ± 10.52 at 1.5 Hz to 1356 ± 74.36 at 16.0 Hz (Table 1) and the frequency-dependent Q_c relationship, $Q_c = (86 \pm 4.04)f^{(1.01 \pm 0.026)}$ is obtained for the region (Figure 3 *a*)[3]. This relationship provides the attenuation characteristics of the region, covering parts of the Shillong massif and the area lying between south of the Mikir hills and north of the Halflong–Disang thrust.

Discussion and conclusions

Q_c estimates for Garhwal Himalaya, Koyna region and northeast India are found to be a strong function of frequency in the high frequency range (from 1.0 Hz to 24.0 Hz) and follow a power law, $Q_c = Q_0 f^n$, where Q_0 is Q_c at 1 Hz, and n is the power of frequency dependence. Variations of Q_0 and n in the attenuation relationships for different tectonic regions have been the focus of many studies. Both these parameters appear to represent the level of tectonic activity of a seismic region. A positive correlation between low Q_0 at 1 Hz and the area of high tectonic activity has been brought out by many investigators[8–10]. From a synthesis of available results, Aki[11] showed that Q_c^{-1} increases systematically from tectonically stable to active regions in the frequency range of 0.1 to 25 Hz. He argued that Q_c can be used as a measure of tectonic intensity for a given region. Jin and Aki[12] interpreted Q_c as a tectonic parameter and the regions with high tectonic activity are characterized by low Q_c values. Further, a strong correlation between n and the level of tectonic activity of the region has been observed by several investigators[8–10,13,14]. In general, the regions having high n value are characterized by the tectonically active regions and tectonically stable regions show low n value. For example, for a tectonically stable region such as central United States, almost no frequency dependence ($Q_c = 1000f^{0.20}$) is observed in

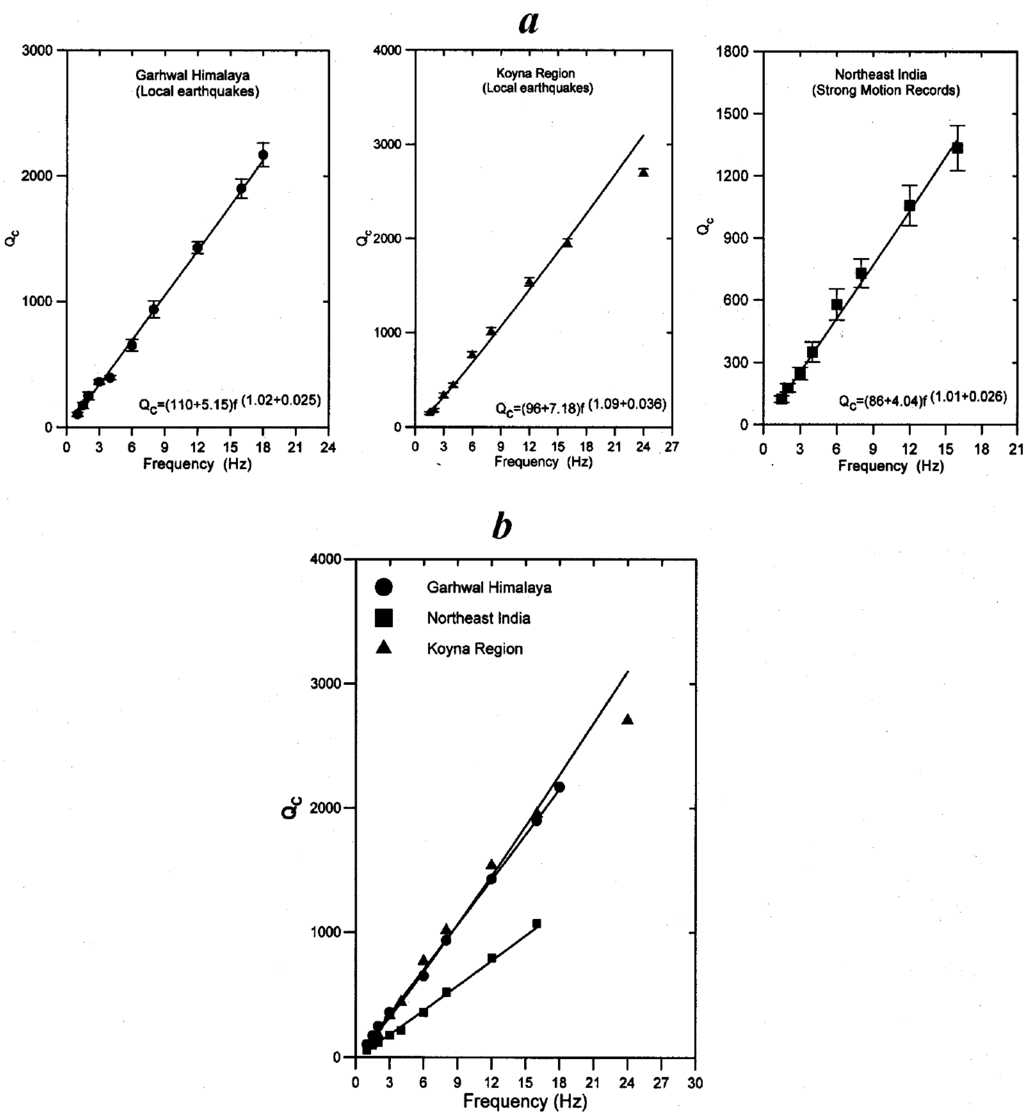

Figure 3. *a*, Mean value of Q_c estimates obtained for three regions. Bar shows standard error from mean at each frequency and power law for each data set is also mentioned; *b*, Comparison of Q_c as a function of frequency for the three regions.

Table 2. Mean Q_c, frequency-dependent Q_c relationship and area coverage for Garhwal Himalaya

Window length (s)	Mean value of Q_c at 1.0 Hz	Mean value of Q_c at 18.0 Hz	Empirical relationship	Area coverage: Area (km^2)	Area coverage: Depth (km)
20	61 ± 6.98	2116 ± 157.45	$Q_c = (66 \pm 3.67) f^{(1.18 \pm 0.03)}$	15,400	70
30	104 ± 16.09	2168 ± 95.02	$Q_c = (110 \pm 5.15) f^{(1.02 \pm 0.025)}$	20,000	80
40	136 ± 20.71	2359 ± 90.86	$Q_c = (149 \pm 5.90) f^{(0.95 \pm 0.021)}$	25,500	90

the frequency range of interest[15]. However, for a tectonically active region such as subduction zone of Japan, Q_c was found to be a strong function of n in the frequency range from 1.5 Hz to 25 Hz (ref. 6). On the basis of comparison of Q_c estimates in the Hindukush region with those in other regions, it has been shown that n correlates with the regional heterogeneity[9]. The finding also supports that Q_c is primarily influenced by scattering, and tectonic processes such as folding and faulting. These processes are instrumental in increasing the scattering effect.

Table 3. Lapse time-dependent Q_c relationship for Koyna region

Window length (s)	Mean value of Q_c at 1.5 Hz	Mean value of Q_c at 24.0 Hz	Empirical relationship	Area coverage: Area (km^2)	Area coverage: Depth (km)
20	105 ± 11.8	2229 ± 44.3	$Q_c = (66 \pm 7.06) f^{(1.16 \pm 0.051)}$	8,500	50
30	148 ± 13.5	2703 ± 38.8	$Q_c = (97 \pm 7.18) f^{(1.09 \pm 0.036)}$	11,500	60
40	187 ± 14.6	3002 ± 41.0	$Q_c = (131 \pm 13.42) f^{(1.04 \pm 0.049)}$	15,400	70
50	206 ± 13.2	3252 ± 48.2	$Q_c = (148 \pm 18.57) f^{(1.04 \pm 0.060)}$	20,000	80
60	233 ± 13.7	3531 ± 52.9	$Q_c = (182 \pm 26.75) f^{(1.02 \pm 0.069)}$	25,500	90

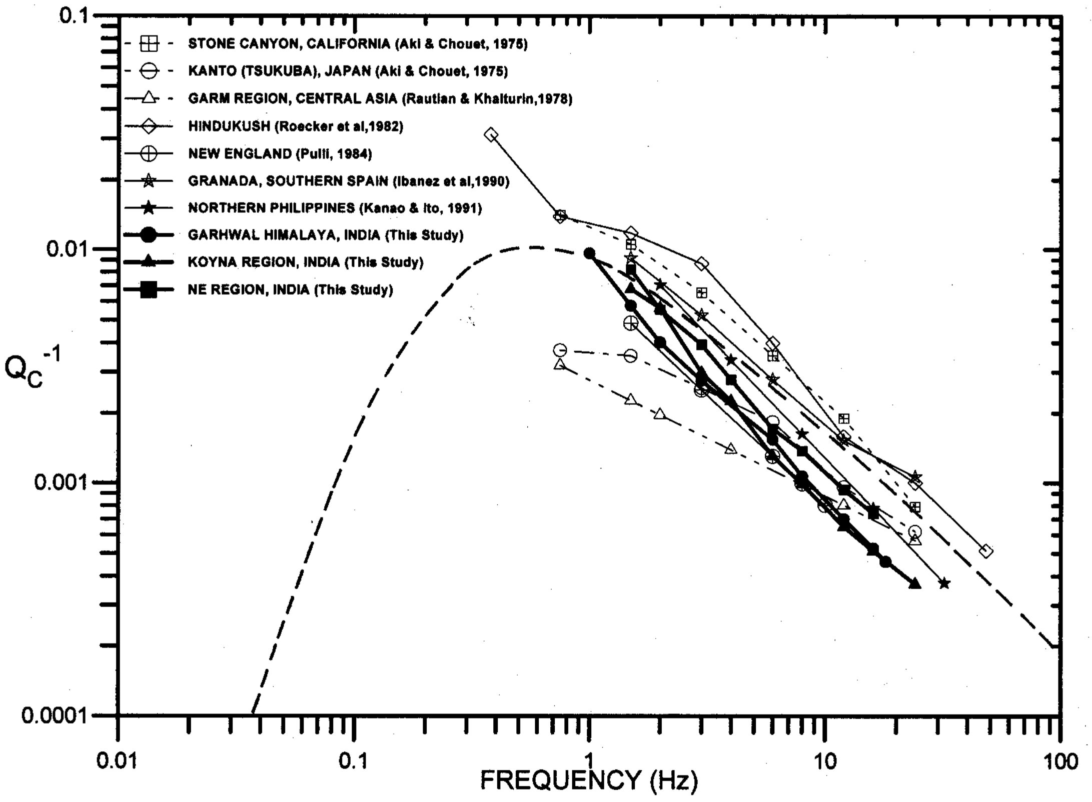

Figure 4. Q_c^{-1} as a function of frequency for the three regions studied along with other tectonic regions in the world. Sato's[16] theoretically predicted curve is shown by dotted line.

Strong frequency dependence of Q_c, brought out in this study, indicates that all the three Indian regions are tectonically active. A comparison of frequency-dependent Q_c relationships is shown in Figure 3 *b* and Table 4. Q_c values for a part of northeast India at higher frequencies, i.e. 8.0, 12.0 and 16.0 Hz, are significantly lower compared to Garhwal Himalaya and Koyna region. This difference minimizes and becomes indistinct at lower frequencies, i.e. 2.0, 1.5 and 1.0 Hz. This demonstrates that northeast India seems to be relatively more tectonically active compared to Garhwal Himalaya and Koyna region. Further, Q_c estimate curves obtained for Garhwal Himalaya and Koyna region are found to be by and large overlapping (Figure 3 *b*). However, Q_c-values for Koyna region at frequencies 1.5, 2.0 and 3.0 Hz, are marginally lower, and at frequencies 8.0, 12.0 and 16.0 Hz are slightly higher than Garhwal Himalaya. This shows a similar level of tectonic activity in these two regions.

Comparison of attenuation (Q_c^{-1}) relationships obtained for three Indian regions with the attenuation relationships observed for other tectonic regions of the world (Figure 4) showed that Q_c^{-1} relationships for all three Indian regions follow by and large a similar trend

Table 4. Frequency-dependent Q_c relationship for the three regions studied. Analysed coda window for each relationship is given in parenthesis

Q_c relationship		
Garhwal Himalaya	Koyna region	Northeast India
Local earthquake data (Frequency range 1.0 to 18 Hz)	Local earthquake data (Frequency range 1.5 to 24 Hz)	Strong motion data (Frequency range 1.5 to 16 Hz)
$Q_c = (66 \pm 3.67) f^{(1.18 \pm 0.03)}$ (20 s)	$Q_c = (66 \pm 7.06) f^{(1.16 \pm 0.051)}$ (20 s)	$Q_c = (86 \pm 4.04) f^{(1.02 \pm 0.026)}$ (29–32 s)
$Q_c = (110 \pm 5.15) f^{(1.02 \pm 0.025)}$ (30 s)	$Q_c = (97 \pm 7.18) f^{(1.09 \pm 0.036)}$ (30 s)	
$Q_c = (149 \pm 5.90) f^{(0.95 \pm 0.021)}$ (40 s)	$Q_c = (131 \pm 13.42) f^{(1.04 \pm 0.049)}$ (40 s)	
	$Q_c = (148 \pm 18.57) f^{(1.04 \pm 0.060)}$ (50 s)	
	$Q_c = (182 \pm 26.75) f^{(1.02 \pm 0.069)}$ (60 s)	

Table 5. Q_0, n and depth coverage for Garhwal Himalaya and the Koyna region for different lapse-time window lengths

Window (s)	Garhwal Himalaya				Koyna region			
	Duration (s)	Q_0	n	Depth (km)	Duration (s)	Q_0	n	Depth (km)
20	30–50	66	1.18	70	20–40	66	1.16	50
30	30–60	110	1.02	80	20–50	96	1.09	60
40	30–70	149	0.95	90	20–60	131	1.04	70
50	–	–	–	–	20–70	148	1.04	80
60	–	–	–	–	20–80	182	1.02	90

of other tectonic regions of the world. These relationships also follow the trend of theoretically predicted curve given by Sato[16].

Both for Garhwal Himalaya and Koyna region, lapse time-dependent Q_c shows that Q_c value increases as the coda window length increases. As the coda window length increases, the larger area of deeper crust and upper mantle is sampled by the coda waves. Therefore, the increase in Q_c value with increase of coda window length represents that for both the Garhwal Himalaya and Koyna region, the part of deeper crust and upper mantle is less heterogeneous (high Q) compared to the shallow crust that is highly heterogeneous (low Q). Rautian and Khalturian[7] observed this behaviour of coda waves for the first time for the Garm and Pamir region of Afghanistan. Since then many investigators have studied lapse time-dependence of Q_c for several tectonic regions.

As discussed earlier, the level of tectonic activity in a region can be correlated with the degree of frequency dependence n (refs 9, 10, 13 and 14). Higher n value is observed for tectonically active regions compared to tectonically stable regions. Roecker *et al.*[9] noticed for Central Asia that, while Q_c increases with depth, the frequency dependence decreases from $\sim f^{1.0}$ (for depth about 100 km) to $\sim f^{0.75}$ (for depth about 400 km) to $\sim f^{0.50}$ (for depth about 1000 km). Pulli[17] investigated lapse time-dependence of Q_c for New England from the data set having depth from surface to 500 km and observed as $n = 0.95$ (for lapse time < 100 s) and $n = 0.40$ (for lapse time > 100 s). Results from both these regions provide information for a wider area with large depth extent. For tectonically active regions and short coda window length, Q_0 is often small (≈ 100) and n may be up to 1 (refs 15 and 18). Therefore, for a localized region having shorter lapse-time window lengths, stationary n at a number of window lengths has been observed in several investigations; Kvamme and Havskov[19] for Southern Norway; Ibanez *et al.*[20] for Granada basin, South Spain and Akinci *et al.*[14] for Western Anatolia region, Turkey.

For Garhwal Himalaya and Koyna region, degree of frequency dependence, n, and Q_0 for different lapse-time window lengths are listed in Table 5. n remains relatively stationary with increasing window length, while Q_0 increases significantly. This showed that the scattering in the medium is considered a dominant contributor to the degree of frequency dependence n, and is due to medium heterogeneities, whereas Q_0 represents intrinsic attenuation of the medium. Therefore, from the data given in Table 5, it can be interpreted that the scattering effect shows a decreasing trend with depth up to 90 km. This may occur due to decrease in heterogeneities (density variation, fractures, folding and faulting, etc.) of the medium with depth. It is attributed to increase of pressure as well as elimination of small-scale heterogeneities due to increase of temperature with depth. The significant increase in Q_0 from 66 to 149 (for Garhwal Himalaya) and from 66 to 182 (for Koyna region) demonstrates that the effect of intrinsic attenuation dominates in the depth ranging from 70 to 90 km for Garhwal Himalaya and from 50 to 90 for Koyna region.

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The recording of traditional knowledge: Will it prevent 'bio-piracy'?

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Traditional knowledge is not protected within the patent system as it stands today. The turmeric case highlights the problems faced by India in preventing bio-piracy. The recording of traditional knowledge seeks to reduce the possibility of bio-piracy, but looks to future legislation to effectively protect the rights of the people. Some important structural changes based on a sound legal footing are proposed, which can be easily incorporated within the present databases, and would go a long way in preventing bio-piracy and protecting the interests of the knowledge-holders.

THE turmeric case, in which India succeeded in overturning a patent granted by the United States Patent and Trademark Office on turmeric powder, was a landmark in the battle against 'bio-piracy'. It was the first case in which a Third World country succeeded in its objection to a foreign patent on the grounds that it was based on traditional knowledge known to the country for generations. By this, the attempt to secure a monopoly on turmeric powder for use in wound healing was defeated. This case threw into prominence some of the main issues concerning the position of traditional knowledge of scientific importance under the patents regime, and also highlighted the difficulty in protecting knowledge that was known for centuries, but which was not articulated in a form found within Western cultural paradigms.

A number of consequences have followed from this case, one of which has been the effort to record the traditional knowledge of India, in an attempt to ensure that similar patents are not granted again anywhere in the world. This article seeks to analyse the effect within the patent system of such recording of traditional knowledge, and whether it will in fact, achieve the aims of its proponents. Certain problems are pointed out, and possible solutions suggested. In particular, the use of contractual provisions to overcome the flaws in the patent system might point a way to prevent cases of 'bio-piracy' in the future.

This article is restricted to the recording of traditional knowledge relating to plants, animals, microorganisms and other forms of life. The actual biological material,

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