Attenuation of seismic waves in the northern Appalachians of southeastern Canada

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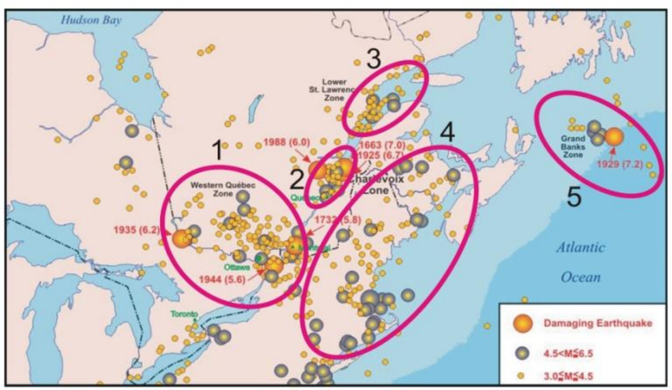
Abstract

We investigate seismic attenuation characteristics of the Canadian portion of the northern Appalachians. Coda Q is determined using 389 earthquakes (1.8 =< M =< 3.9) recorded on four stations of the Canadian National Seismic Network (CNSN) in New Brunswick from 1985 to 2020. For comparison, we divide the study area into northern and southern portions, each with two seismic stations and 162 and 227 events, respectively. At lapse times of 12 to 60 seconds, coda Q at 1 Hz (Q0) at the two seismic stations in the region of northern New Brunswick that is closer to the seismically active Charlevoix seismic zone (including a M7 event in 1663) is 82 +/- 5 on average. In contrast, the two stations in southern New Brunswick have an average Q0 of 114 +/- 3. The lower Q0 value in the north in comparison with the southern part of the region is in agreement with Jin and Aki's (1988) finding that Q0 is lower in the vicinity of large earthquakes. Ongoing mapping of coda Q in the area using the CNSN stations is planned in order to contribute to the ongoing development of more accurate seismic hazard models.

Introduction

Attenuation of seismic waves during propagation, which is typically described in terms of the seismic quality factor Q, refers to decay in amplitudes of seismic waves during the passage from source to the receiver site. A region with high Q value is generally supposed to be a stable region whereas low Q value represents seismically active region. In general, the main factors responsible for attenuation are geometrical spreading, transformation of seismic energy into heat and redistribution of energy due to heterogeneities in the medium. Q is an essential parameter for better understanding of the Earth's interior structure and for quantitative prediction of strong ground motion in order to build ground-motion prediction equations (GMPEs) or ground-motion models (GMMs) for the seismic-hazard assessment.

Earthquakes in southeastern Canada



Original map: Courtesy of Lamontagne et al., 2004

Earthquakes occur throughout southeastern Canada, but years of recordings have identified five zones with greater earthquake activity: 1. West Quebec, 2. Charlevoix-Kamouraska, 3. Lower St. Lawrence, 4. Northern Appalachians, and 5. Laurentian Slope (Grand Banks).

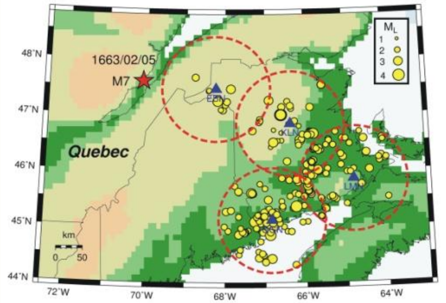
Located some 100 km downstream from Quebec City, the Charlevoix Seismic Zone is the most seismically active region of eastern Canada. Historically, the zone has been subject to five earthquakes of magnitude 6 or larger: in 1663 (M 7); 1791 (M 6); 1860 (M 6); 1870 (M 6.5); and 1925 (Ms 6.2 ± 0.3).

Unlike the Charlevoix Seismic Zone, no large earthquake has ever been reported or recorded in the Lower St. Lawrence zone and only two events are known to have exceeded magnitude 5.0.

The Northern Appalachians Seismic Zone includes most of New Brunswick and extends into New England down to Boston. The zone witnesses a continuing low level of seismic activity including many larger historic earthquakes in New Brunswick.

The largest recorded earthquake in eastern Canada occurred in 1929 (M 7.2) in the Laurentian slope seismic zone that comprises an area off Canada's southeast coast, which includes the Grand Banks of Newfoundland.

Data and Analysis



To study the coda Q, or Q_c in the Canadian portion of the northern Appalachians, 389 earthquakes (1.8 =< M =< 3.9) in New Brunswick between 1985 to 2020 were selected within 100 km of four stations of the CNSN. For comparison, we divide the study area into northern and southern portions, each with two seismic stations (EBN, KLN in the north and GGN, LMN in the south) and 162 and 227 events, respectively.

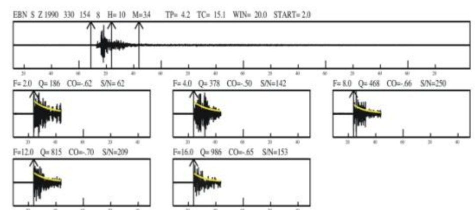
We determine Q_c, using the single backscattering approximation, which assumes that the *S* coda waves comprise secondary *S* waves produced by heterogeneities inside the propagation medium (Aki, 1969; Aki and Chouet, 1975). The coda wave amplitude *A* at frequency *f*, and lapse time *t* (time from the event origin) is described by:

$$A(f, t) = S(f) t^{-\beta} e^{-\pi f t / Q_c} \qquad (1)$$

where *S(f)* is the source factor, which is related to the earthquake source spectrum and includes station site, backscattering, and source effects, and β is a geometrical spreading parameter. Equation (1) assumes that the source and receiver are at the same point, which is only a good approximation for signals at a lapse time, *t*, greater than twice the *S*-wave travel time, t_S. For body-waves (this study) β= 1 and equation (1) can be written as:

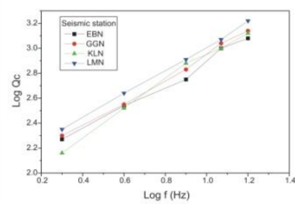
$$\ln(A(f,t)) + \ln(t) = \ln(S(f)) \;\; \pi f t / Q_c \qquad (2)$$

Plotting the envelope of *ln(A(f,t))+ln(t)* as a function of *t* for a given frequency (by band pass filtering the signal), gives a straight line with slope $\pi f/Q_c$ and Q_c can be determined (Havskov and Ottemöller, 2010). By calculating the Q_c values for different frequencies, the frequency dependence of this quantity can be expressed as $Q_c = Q_0 f^{\alpha}$ (Rautian and Khalturin, 1978) with Q_0 and α obtained by linear regression of log (Q_c) on log (*f*).



The first step in data processing is the selection of events with the highest signal to noise (S/N) ratio. The top trace is the original unfiltered waveform where the 3 vertical lines indicate (from left) origin time, start and end of coda window. Above the seismogram is first the station code, origin time, depth (h), magnitude (ML), P-wave travel time (TP, s), start of coda window from the origin (TC, s), window length (WIN, s) and start of coda window in terms of S-wave travel time (t coda > ST*S-travel time). The amplitude decay corresponding to estimation parameters are shown by a curve in the five filtered segment. In this study we only consider Q values with C (correlation coefficient) >= 0.5 and S/N >= 5.

Results



Logarithmic plots of the overall average variation of coda Q with frequency for stations in north and south of the study area.

$Q=82f^{1.02}$ (North)

$Q=114f^{0.93}$ (South)

Conclusions

Q_c was calculated for the stations in the Canadian portion of the Appalachians. The lowest values were derived in the northern part with an average frequency relation of $Q_c = 82\, f^{1.02}$ in the vicinity of the seismically active Charlevoix zone. The highest values were observed in the southern part with an average frequency relation of $Q_c = 114\, f^{0.93}$ This is in agreement with Jin and Aki's (1988) finding that Q0 is lower in the vicinity of large earthquakes. The average frequency relation for this region is $Q_c = 99\, f^{0.96}$.

Refernces

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