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Q FACTOR ESTIMATION FROM THE AFTERSHOCK SEQUENCE OF THE 13 MAY 1995 KOZANI EARTHQUAKE

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Abstract—The single isotropic scattering model has been applied for the estimation of coda Q values for a number of small aftershocks of the Kozani–Grevena 1995 earthquake. The events were recorded by the telemetric network of the Geodynamic Institute of National Observatory of Athens. Coda Q_c estimations were made for three frequency bands centered at 1 Hz, 2 Hz, and 4 Hz, and for lapse time windows $2t_s$ to 100 sec every 20 sec. The coda Q values obtained show a clear dependence of the form $Q_c = Q_0 f^n$, while Q_0 and n depend on the lapse time window. Q_0 was found to range from 50 to 160, and increases as lapse time increases. On the contrary, n decreases as lapse time increases and its values range from 1.02 to 0.76 with a tendency to be stable over 80 sec. This lapse time dependence is interpreted as being due to a depth-dependent attenuation. The temporal variation of Q_c was also examined within a month time period, but although the results show a tendency of temporal variation at of Q_c at 1 Hz, the case needs more investigation. © 1998 Elsevier Science Ltd. All rights reserved

INTRODUCTION

Seismic hazard in an area depends on two factors, the nature of the earthquake source and the nature of the medium transmitting the seismic waves. There are two properties of the medium that are important, namely the velocity of wave propagation and the attenuation of energy transmission.

Several methods have been applied in order to estimate seismic wave attenuation. The single scattering model of Aki and Chouet (1975), later extended by Sato (1977) to a single isotropic scattering model, became a powerful tool for the estimation of some attenuation parameters (Herraiz and Espinoza, 1987). In this extended version, the separation distance between receiver and hypocenter has been taken in consideration. On the other hand the analysis of data from seismic coda waves has been widely used by many researchers and in many regions.

In this paper we present the results of coda Q estimation using aftershocks that occurred within the Kozani–Grevena area, Western Macedonia, Greece.

METHOD

The observed coda amplitude decay rate of small earthquakes is independent of the source and receiver location and the source orientation (Aki and Chouet, 1975). In the single isotropic scattering model, coda waves have been interpreted as scattered S wavelets due to heterogeneity of the lithosphere (Sato, 1977). According to this model, the energy density of coda waves can be written as:

$$E_{sis}(\omega,t) = C(\omega)K(\beta t/r)e^{-\omega t/Q} \tag{1}$$

where $C(\omega)$ depends on the source, the recording site and the scattering coefficient of the medium. Function K is Sato's geometrical spreading, which characterises the additional decay immediately after the S-wave's arrival. The mean energy density is approximated by the Root Mean Square of the coda waves amplitude

$$E_{sis} = |A|^2 \tag{2}$$

or

$$A \propto \frac{C(\omega)}{r}\sqrt{K\left(\frac{vt}{r}\right)e^{\frac{-\omega t}{2Q_c}}} \tag{2}$$

Taking the logarithm of this relation

$$\log_{10}A = C - \log_{10}t - 1/Q[\pi f \log_{10}e]t \tag{3}$$

from which we can estimate the Q factor, using the filtered coda waves amplitude by means of least square method.

DATA

The data used were obtained from the aftershocks sequence of the Kozani–Grevena earthquake of May 13th, 1996. These events have been recorded by the seismographic station of Kozani operated by the Geodynamic Institute of the National Observatory of Athens. The station is equipped with a vertical short period (S-13 Teledyne Geotech) seismometer. The signals from the station are transmitted via telephone line to the central station at Athens. Analogue to digital conversion is performed with a sampling rate of 60 sample/sec and an accuracy of 0.4%, or 8 bits. 80 small aftershocks were selected for the analysis. The map of Fig. 1 shows the distribution of epicentres in the Kozani and Grevena areas. The local magnitudes of these events are between 3.0 and 4.3, while the focal depths are less than 20 Km. Figure 2 (upper left corner) shows a typical digital seismogram recorded at the KZN station (Kozani). Clipped S-waves amplitudes do not affect the analysis of the selected data since this starts after the clipping. Seismograms were then filtered with an 8 pole band-pass filter in the frequency range of 0.5 to 8 Hz, and at 1 Hz, 2 Hz and 4 Hz, with a bandwidth of $0.5f_c$ around the center frequency, f_c. Analysis is performed for the lapse time of 20 to 100 second in an overlapping time window, increasing every 20 seconds. Figure 2 also shows an example of the filtered seismograms at each frequency band and

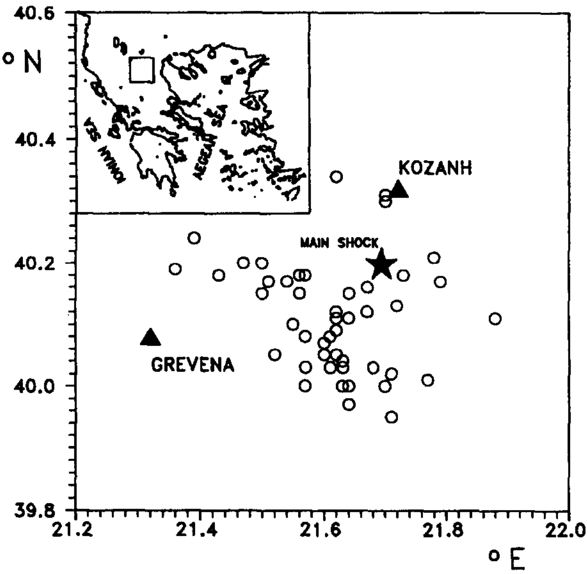

Fig. 1. Epicenter distribution of the events used in the analysis. The main shock is shown by a solid star. The cities of Kozani and Grevena are shown by solid triangles.

their respective $\log_{10}$RMS amplitude traces. Linear regression was applied according to Eqn. (3) and the coda Q values were estimated.

RESULTS

Figure 3 shows the plot of the mean Q_c and the standard deviation of the mean of each center frequency versus the lapse time window. The clear dependence of Q_c on the lapse time becomes apparent from this figure. The influence of the lapse time window on the coda Q_c has also been noted in several other studies. (Baskoutas and Sato, 1989; Steck *et al.*, 1989; Mayeda *et al.*, 1991; Ibanez *et al.*, 1990; Kosuga, 1992; Hatzidimitriou, 1993; Baskoutas, 1996). According to the single scattering model, the increases of Q_c probably reflect the increases of Q_s with depth (Sato, 1982b). Q_c at short lapse times is believed to depend more on the surface geology, while at longer lapse times, the deeper structure is the one that is more important.

The increase of Q_c value with frequency (Fig. 4), can be fitted according to the empirical power law of the form $Q_c = Q_0 f^n$, where f is the frequency in Hz, and exponent n indicates the degree of Q_c frequency dependence. Q_0 and n are obtained by using a least square method in the frequency range from 1 to 4 Hz. From this formula, Q_0 is equal to 130 and n is equal to 0.6. Low Q_0 and n values found in the present study are characteristics of an area with high seismicity.

Since, the area cannot be characterised as being of high seismicity—at least before the present seismic activity—this observation can be explained by the presence of numerous cracks due to the aftershock activity. It should be noted that the events used here are aftershocks that occured within a month after the main shock. Q_0 and n are also calculated

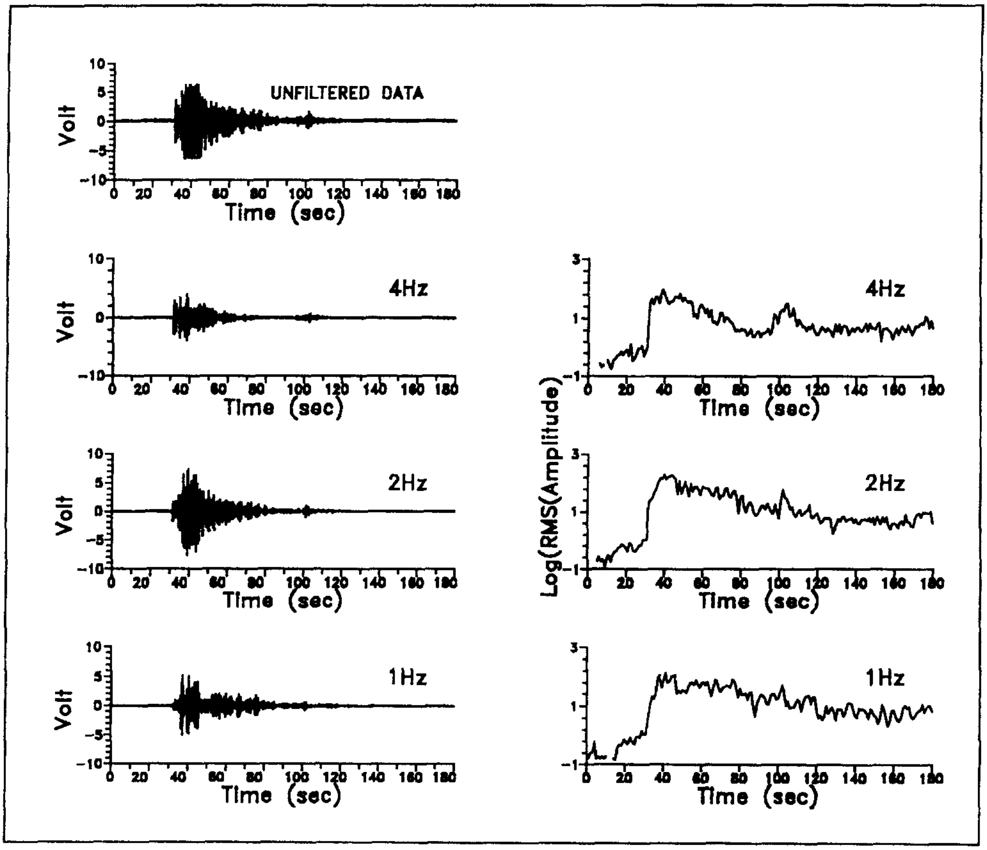

Fig. 2. Example of a typical event recorded at the Kozani station (upper left corner). Plot of the band-pass filtered seismograms and the quantity $\log_{10}(RMS(A))$ versus lapse time.

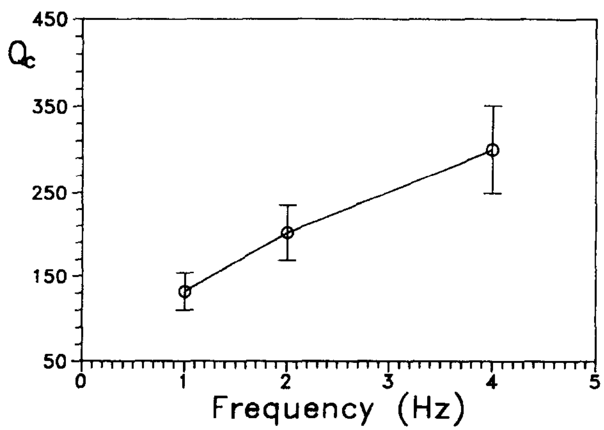

Fig. 3. Frequency dependence of *Qc*.

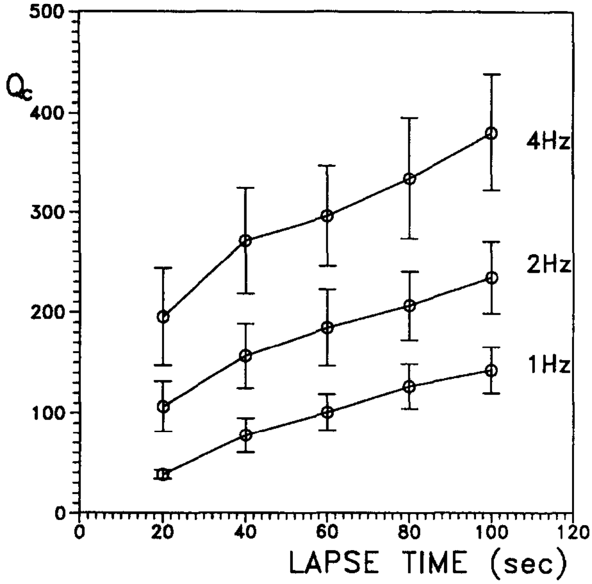

Fig. 4. Lapse time dependence of Qc.

for each lapse time window and they also show a similar dependence on frequency and lapse time.

The Q_0 values increase almost linearly with lapse time. The increase of Q_0 with lapse time has been also found in many studies (Roecker *et al.*, 1982; Herak, 1991; Baskoutas, 1996) and has been similarly interpreted as being due to an increase of Q with depth. Figure 5 shows the values of Q_0, for the range 50 to 160.

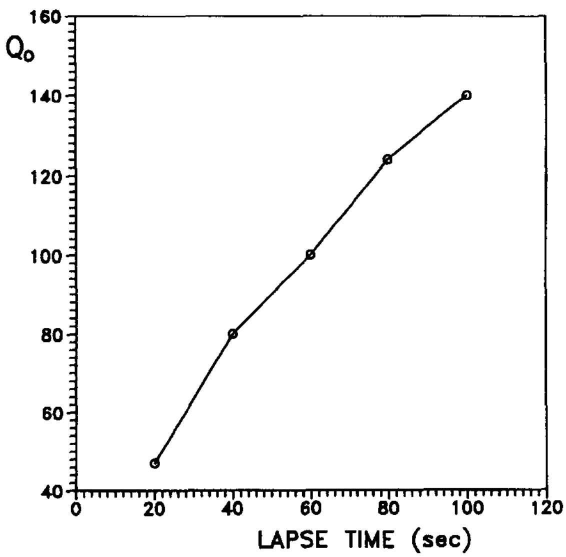

Fig. 5. Lapse time dependence of Q_0.

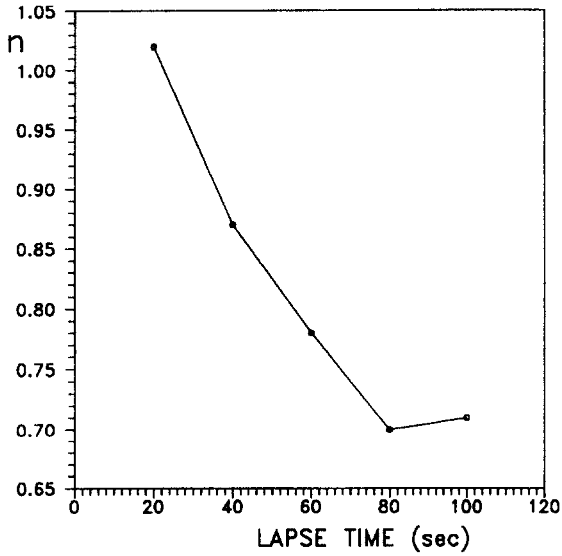

Fig. 6. Lapse time dependence of n.

The general decrease of n with lapse time has been also found in other regions. Herak (1991) found a linear decrease of n from 1.0 to 0.6 for time interval between 30 and 130 sec, for the Dinarides region, almost similar to the present study. Figure 6 shows the values of n which decrease from 1.02 to 0.70 for the time interval 20 to 80 sec and then becomes almost stable. According to single isotropic scattering model the general increase of Q_0 and

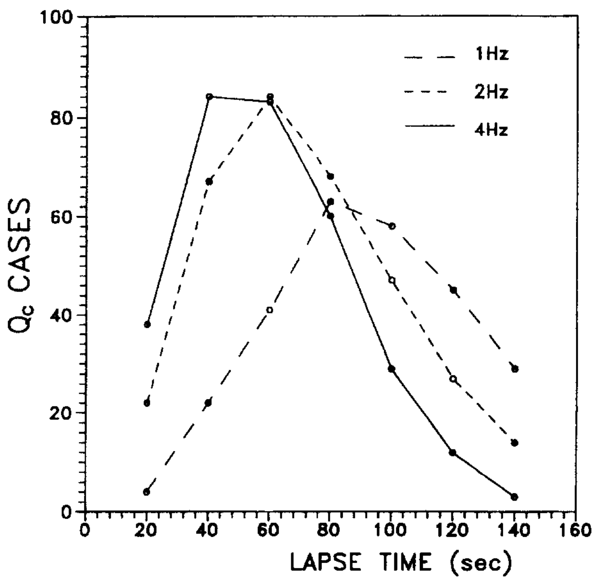

Fig. 7. Number of estimated Qc values at each frequency band versu. lapse time.

decrease of n, are interpreted as due to a depth dependent attenuation. Such a behaviour probably suggests a decrease of large scale inhomogeneities (Sato, 1984).

Figure 7 shows the number of Q_c values obtained with respect to lapse time window for each frequency band, which reflects the progressive loss of the high-frequency energy with time, as expected.

Several studies have shown significant temporal variations of mean Q (Jin and Aki, 1988; Sato, 1988). The formation of new cracks, the reopening and growing of existing cracks,

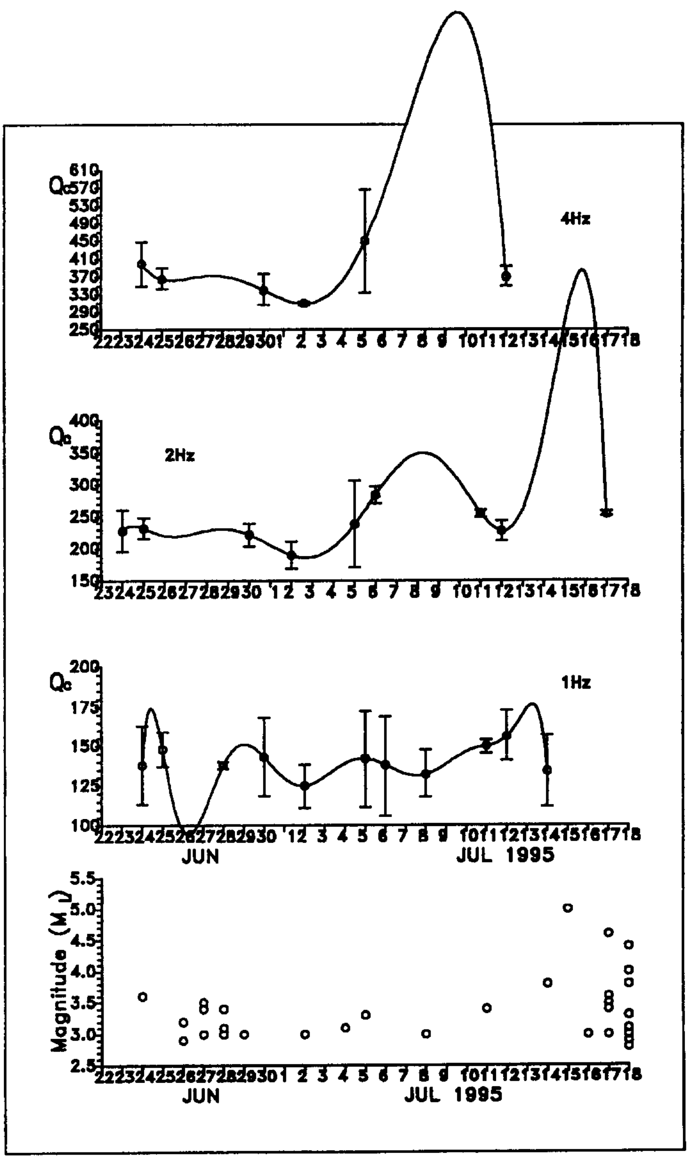

Fig. 8. Temporal variation of mean Qc values within a one-month time period and temporal distribution of the events in the same period.

the interaction of these cracks and the pore water movement through these cracks might correspond to such variations. In addition we may expect an inhomogeneous distribution of crack clusters in a fairly large aftershock region.

In this study, although the examined time period is very short (about a month), we examined the temporal variation using all the available data. We plotted mean Q_c value for each day and we performed polynomial regression according to the available data. Figure 8 shows a plot of the temporal mean Q_c distribution (for each day) at each frequency band, their respective errors and the line of regression. In the bottom of the same figure the plot shows the number of the events in the same time interval. From this figure we can observe at 1 Hz a step drop of the Q_c value before the cluster of events from the 16th to the 18th of July. Instead, the fitting in 2 and 4 Hz is very poor. The amount of data and the time of the examination period probably do not allow us to conclude a clearer correlation between the temporal variation of Q and seismic activity.

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