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STUDY OF SPATIAL DISTRIBUTION OF CODA Q WITH RESPECT TO THE SEISMICITY IN CENTRAL GREECE

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ABSTRACT

The spatial distribution of coda attenuation parameter Q_c was studied in the eastern part of central Greece. Attenuation parameters were estimated by applying the single isotropic scattering model to the time decay of coda waves. Analysis was performed as a function of lapse time and frequency. In order to investigate the regional distribution of Q_c values we separate the objective area into many grid points, homogeneously distributed. Then at each grid point we calculate the average of the observed Q_c values from each station-event pair. The smoothed spatial distribution of Q_c at low frequency range shows a remarkable correlation with seismically active areas, the main low Q_c spots appear on or very close to specific strong seismic sources. At the higher frequency band (8-12Hz), spatial Q_c distribution seem to be uncorrelated with seismicity. Such distribution may be controlled by the deeper structure of the examined area.

KEY WORDS: Coda Q, Greece, seismicity

1. INTRODUCTION

Recently there has been a growing interest in the study of seismic wave attenuation in the earth. The observations show both large and small scale regional differences of the attenuation properties. The desirability of using all available data to study those properties, makes models of coda excitation an important tool. Coda attenuation Q_c is a parameter which can be easily estimated by applying one of several coda scattering models. Estimation of the Q_c factor and its time and frequency dependence indicates how heterogeneous the areas under study are.

A widely accepted hypothesis on the nature of coda waves of local earthquakes was developed by Aki (1969), and Aki and Chouet (1975), and was later extended by Sato (1977). Thus coda is considered to be waves scattered by randomly distributed heterogeneities in the lithosphere and Q_c is a parameter which phenomenologically characterizes the coda amplitude decay gradient. Q_c is then assumed to be expressed in terms of scattering Q_{sc} and intrinsic Q_i in the form $Q_c^{-1} = Q_{sc}^{-1} + Q_i^{-1}$ (Dainty, 1981). In the single scattering model, however, we cannot separate Q_{sc} from Q_i. Separation of intrinsic from scattering attenuation was attempted by Fehler et al., (1992).

The mean value estimated from coda decay reflects an average Q_c within a certain volume which includes source and receiver.

It is well known local seismotectonic features can have a significant effect on the amplitude decay and the shape of locally recorded earthquakes. Many investigators have measured Q_c in a number of areas and correlated the results with the nature of geotectonic features (Aki and Chouet, 1975; Singh and Herrmann, 1983; Jin and Aki, 1988; Sato, 1984; Matsumoto and Hasegawa, 1989).

In the present study we estimated spatial distribution of Q_c values in the lithosphere in central Greece. Then we examined these results in terms of the shallow seismic activity within the extent of a local seismic

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network. For this purpose seismograms of local earthquakes were analyzed at short lapse time window after the S-wave arrival , and at frequency bands from 1 to 12Hz.

2. DATA

The area of study in the present analysis is covered by the extension of the digital VOLNET network. This network operated in the eastern part of central Greece.

Figure 1 shows the location of each station and the epicenter distribution of the events used. In this analysis we used 223 local events recorded during 1984. Parameters are taken from the monthly bulletin of the VOLNET network. Local magnitudes of events range from 1.2 to 3.9 and most of them (98%) are shallow events with depths of less than 20km. Figure 2 shows an example of a seismogram.

Stations are equipped with vertical component Willmore-MkIII velocity type seismometers. The transducer has a natural period of 1.5_s and a critical dumping of 0.7.

Data from all channels and time are recorded on magnetic tape, and the sampling rate of A/D conversion is 50Hz.

The criteria for the selection of the data are the following: the azimuthal distribution around stations; the quality of the signals (S/N ratio); and the time period which should not exceed a relatively long time period, since within the network there are two very active seismic regions with moderate earthquakes. It is noted that many researchers have observed temporal changes of Q_c before and after big earthquakes. These restraints reduce the amount of available data, but there is enough to assure the reliability of the analysis.

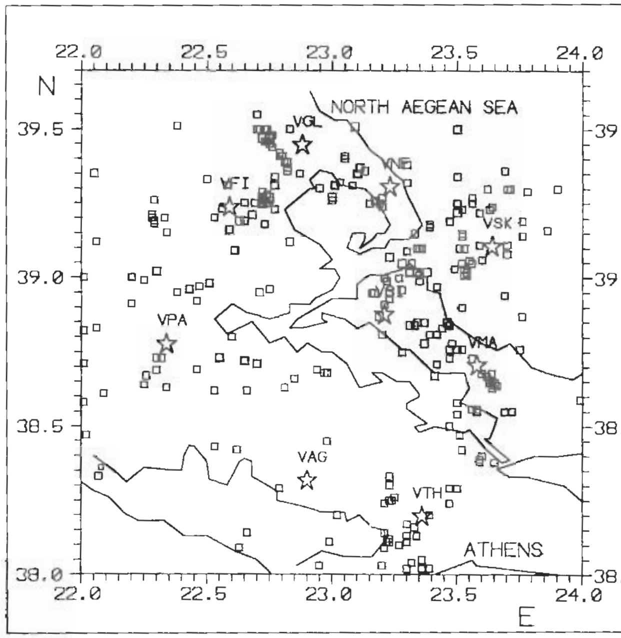

Fig. 1: Map showing event and stations (asterisks) used in the present sudy.

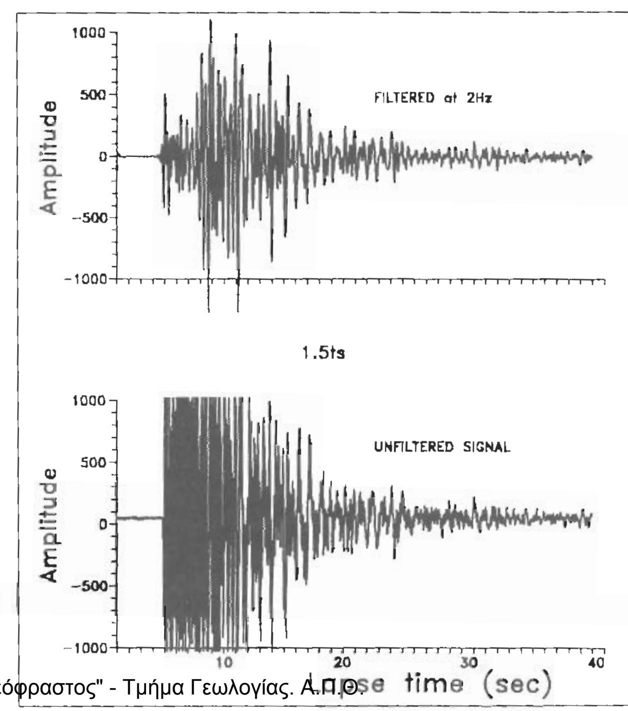

Fig. 2: Example of an unfiltered seismogram, (vertical component) and bandpass filt

3. ESTIMATION OF Q_c

In this study we use the single isotropic scattering model because our primary concern is to investigate Q_c for short lapse times, when the effect of multiple scattering is expected to be small for this specific area (Baskoutas et al., 1995).

For the analysis we used the equation for the coda envelope (Sato, 1977)

$$Z_i = \frac{X_i - X_m}{S} \qquad (1)$$

or

$$r = \frac{\sum_i (x_i - x_m)(y_i - y_m)}{\left[\sum (x_i - x_m)^2 \sum (y_i - y_m)^2\right]^{1/2}} \qquad (2)$$

when for $x>1$ (3)

We note that $C(\omega)$ is the coda source factor that includes the S-wave excitation strength and the scattering strength, and t_s is the S-wave travel time. Analysis was performed on Log(RMS) amplitude envelope using overlapping time window with an increment of 10s. This shifting gives in more detail, the dependence of Q_c with lapse time. The time window starts from $1.5t_S$, where t_s is the travel time of S-waves, till the noise level of the seismogram. Differences on the results due to the choice of start time, between $1.5t_s$ and $2t_S$, might show a little difference. On the other hand, the choice of the single isotropic scattering model give us the opportunity to examine Q_c for very short lapse times. Figure 2 shows an example of an unfiltered seismogram and the filtered one at 2Hz. The center frequencies f_c are defined as 1, 2 and 12Hz, and bandwidth as $0.5f_c$, except the last frequency band where it is $0.3f_c$.

4. SPATIAL DISTRIBUTION OF Qc VALUE

As the theory for the study of the attenuation of coda amplitude is not a linear problem it is very hard to estimate spatial distribution using common inverse technics. So we used a simple method in order to estimate this distribution quantitatively.

Q_c value was considered as the apparent Q_c for each station-epicenter pair and this value is assigned to the center of the epicentral distance between them (Peng et al., 1987). The area is divided into many grid points of equal spacing. At each grid point the mean value, which is calculated from adjacent Q values, is assigned. The equation used is:

$$K_s = \frac{Q_s}{5{,}5 \cdot r \cdot H}$$

where Z_i is the Q_c value of a nearest neighbor grid point d is distance and n in the number of Z elements. Weighting factor for the calculation of the mean interpolated value is the square of the inverse distance of each individual value from the grid point. Thus, the influence of a data point declines with distance from the point being estimated.

The single isotropic scattering model assumes that the scatterers are distributed homogeneously within an expanding ellipsoid, with foci the station and hypocenter. According to Pulli (1984) this volume is defined by a relation which includes the epicentral distance and the velocity of the seismic waves (3.5-4 km/s.). Approximately, as the time window used for analysis increases the scattered waves penetrate deeper and the volume under investigation increases. For example if we consider a lapse time of 10s, coda waves penetrate into a space with diameter of about 30km. Here we must note that as the volume increases the Q_c value represents the mean value within the volume.

In this study, we consider time windows of $1.5t_s$ to $1.5t_s$+10s. Most of the events used in this study have an S-wave travel time between 5 and 10s and very few have S-wave arrival times greater than this. In this way we restrain our consideration in the lithosphere. On the other hand the scale of these lapse time is smaller than the mean free time of 45s in Greece (Baskoutas et al., 1995), so the single scattering approximation is valid. Concerning the frequency band, we examine the lower center frequency 1 and 2Hz and the higher which is used in this study, i.e. 12Hz.

5. RESULTS AND DISCUSSION

It is well known that decreases of the amplitude in the later part after S-wave arrival is practically due to the presence of scatterers distributed in the medium. Thus Q_c is a parameter that represents the degree of heterogeneity in the lithosphere. Previous studies (Roecker et al., 1982; Gagnepain-Beyneix, J. 1987; Phillips et al., 1988; Ambeh and Fairhead, 1989; Havskov et al., 1989; Steck et al., 1989) have shown that Q_c shows regional variation often related to tectonic features and near-site geology. It is reasonable that some of the most important attenuation mechanisms are cracks, their density and geometry, fractures, fluid content and so on. It is expected that areas with significant seismic sources and with recent seismic activity have an enormous number of cracks and fractures. The analysis of short lapse time windows makes the correlation of the spatial distribution of Q_c with areas characterized by shallow seismic activity easier, since scattered seismic coda penetrates the shallow portion of the lithosphere.

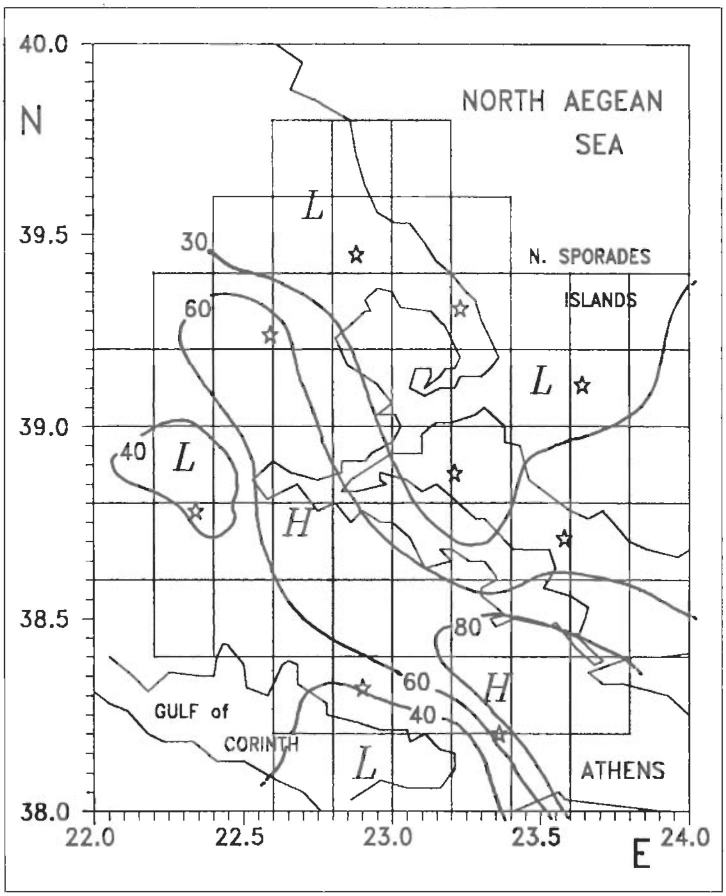

Fig. 3: Spatial distribution of Q_c at 2 Hz and for $1.5t_s$ to $1.5t_s$+10s time window

Figures 3 and 4 show the spatial distribution of Qc at $1.5t_s$ to $1.5t_s$+ 10s lapse time window and at center frequency bands of 2 and 12Hz respectively. Q_c spatial distribution, obtained from the analysis at 1Hz, was omitted since the number of data was significantly less. In figures 2 and 3 the calculated Q_c values at each grid point and equal Q_c values lines can be seen for 2 and 12Hz respectively. In these figures, "L" and "H" indicate the low and high Q_c areas, respectively. Relative low and high spots of Q_c values here were considered the decline from the mean value obtained for the analyzed time window $1.5t_s$ to $1.5t_s$+ 10s and respective frequency band for all stations of the network.

Figure 5 shows the recent shallow seismic activity of the area within 10 years interval around 1984. Data are taken from the catalog of Makropoulos et al., 1989. The comparison of the distribution of relative

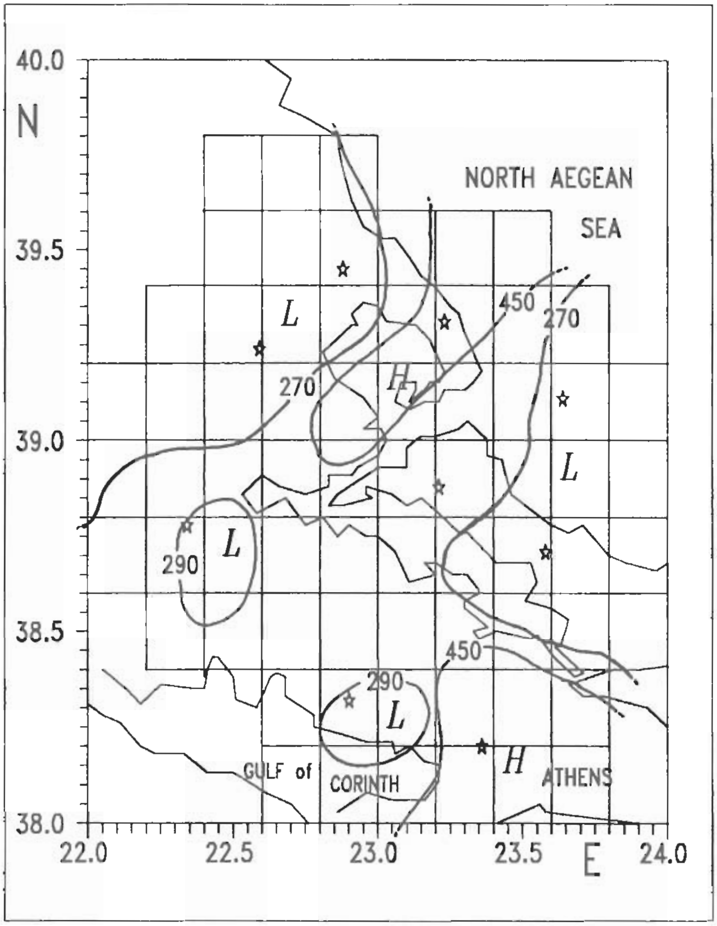

Fig. 4: Spatial distribution of Q_c at 2 Hz and for $1.5t_s$ to $1.5t_s$+10s time window

low Q_c values in Figure 3 with the distribution of epicenters of recent seismic activity shows a remarkable correlation between distribution of low Q_c spots and areas characterized by significant recent and shallow seismic activity. Here we can refer to two well known, very active seismic areas, within the examined area as it can be seen in Figure 5. One is located in the eastern part of the gulf of the Korinth, 100Km west of Athens (38.20N, 22.70E) and the other in the North Sporades Island (39.30N, 23.50E) (Papazachos et al., 1983; Papazachos et. al., 1984; Papazachos, 1990).

Relations between low Q_c values and seismicity were found in different regions of the world, (Singh and Herrmann 1983; Jin et. al., 1985; Jin and Aki 1988; Matsumoto and Hasegawa 1989; Correig et al., 1990). Besides, low Q_c values may be attributed to the tectonically active areas which show high attenuation (Herraiz and Espinosa, 1987). According to Sato's (1984, 1990) model, the scale length of inhomogeneity is large in low frequency range. It seems natural that Q_c for low frequency range is responsible for longer wavelength fluctuation of random inhomogeneity, thus we expect Q_c to depend on the surface scattering structure.

At the higher frequency band, 8-16Hz, the spatial distribution of relative low and high Q_c values is distributed as shown in Figure 3. From the comparison of figures 3 and 4 it seems that there is no direct correlation between low and high Q_c values and active seismic sources. In the SW part of the region two low Q_c spots appear which also shows a tendency to correspond with the seismic source of Alkyonides and a secondary one close to the VPA station. The wide low Q_c area N-NW of VFI and VGL stations may be attributed to different attenuating factors caused by an intensive grade of folding and faulting in old age rocks. High frequency Q_c values, as at 2Hz, show a high Q_c spot around the aseismic area of Attica (Athens) extended in a NW direction. Furthermore, a significant branch of the high, extend from the upper NE corner in a NE-SW direction.

Coda attenuation factor Q_c increases with frequency. Increase of Q_c with frequency is probably caused by the different behavior in the propagation of seismic waves, in different frequencies (Baskoutas and Sato, 1989; Kosuga, 1991; Baskoutas, 1996). The high frequency component of seismic coda can be scattered in the deeper portion of the crust or upper mantle, which is considered to be more fine and homogeneous.

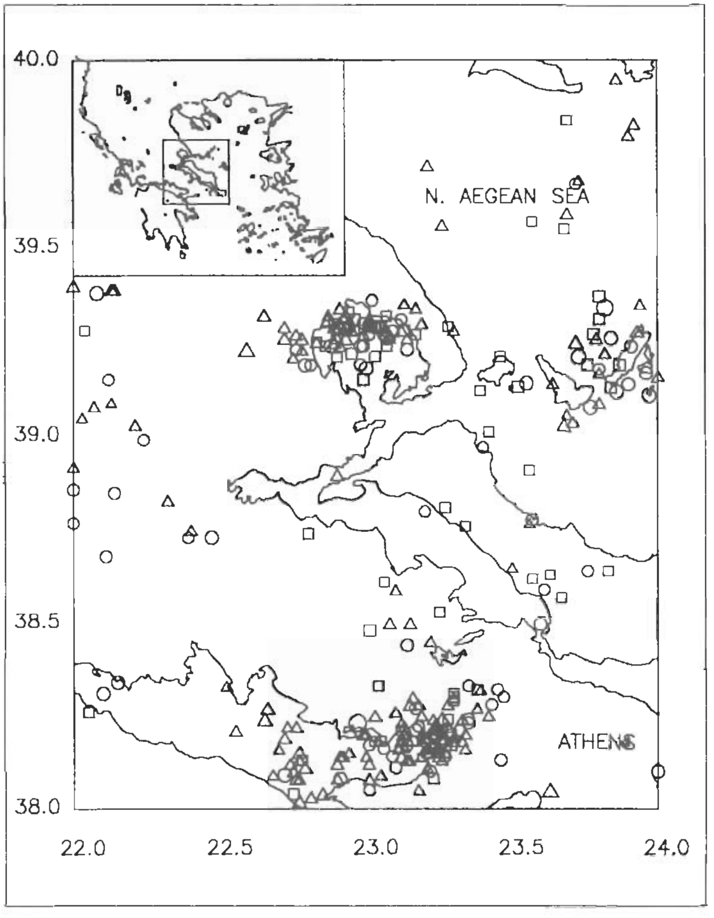

Fig. 5: Distribution of epicenters of the seismic activity of the area under investigation

As a conclusion we can say that seismically active areas affects the distribution of low Q_c value, especially values obtained analyzing data at low frequency band and for very short lapse time. There are several factors which control the real attenuation status in the earth medium. Here it is natural for us to imagine that the opening and reopening of cracks, the presence of liquid in these cracks can be a significant attenuation mechanism. It has been observed by many researchers the temporal change in Q_c associated with the earthquake occurrence (Sato, 1988). Probably it is not possible to detect a very small area with anomalous Q_c value in details. Sato (1988), suggests that the scattering intensity in the crust increase within a radius of about 50km from the main shock.

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