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TIME DISTRIBUTION OF CODA Q VALUES IN THE MYGDONIA GRABEN, NORTHERN GREECE

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ABSTRACT

The temporal variation of coda Q^{-1} is examined in the present study, for the area of the Mygdonia graben, in northern Greece. The single scattering model has been applied for the es timation of coda Q^{-1} values for local earthquakes that occurred during the period 1983-1989 and recorded by the telemetered net work of the Geophysical Laboratory of the University of Thessaloniki. Coda Q estimations were made for four frequency bands centered at 1.5 Hz, 3.0 Hz, 6.0 Hz and 12.0 Hz and for the lapse time windows 10-20 sec, 15-30 sec, 20-45 sec, 30-60 sec and 50-100 sec. The coda Q-1 values show a characteristic stability in time over the period 1983-1989 in good agreement with the present period of seismic quiescence after the 1978 Thessaloniki earthquake. The values of coda Q^{-1} estimated in this time interval should be considered as the average representative values of the area in order to detect any anomalous changes in the future.

ΣΥΝΟΨΗ

Στην παρούσα εργασία μελετάται η χρονική κατανομή των τιμών του παράγοντα ποιότητας Qc που υπολογίστηκε από τα κύματα ουράς στην περιοχή της Μυγδονίας λεκάνης. Χρησιμοποιήθηκαν δεδομένα τοπικών σεισμών της περιόδου 1983-1989 που καταγράφηκαν από το τηλεμετρικό σεισμολογικό δίκτυο του Εργαστηρίου Γεωφυσικής του Πανεπιστημίου Θεσσαλονίκης. Με την εφαρμογή του μοντέλου της απλής οπισθοδιασποράς που προτάθηκε για τη γένεση των κυμάτων ουράς υπολογίστηκε ο παράγοντας ποιότητας Q_c, για συχνότητες 1.5 Hz, 3.0 Hz, 6.0 Hz και 12.0 Hz και για χρονικά παράθυρα 10-20 sec, 15-30 sec, 20-45 sec, 30-60 sec και 50-100 sec από το χρόνο γένεσης του σεισμού. Βρέθηκε ότι οι τιμές Q_c^{-1} για όλες τις συχνότητες είναι σταθερές με το χρόνο, γεγονός που βρίσκεται σε εξαιρετική συμφωνία με την περίοδο σεισμικής ησυχίας στην οποία βρίσκεται η περιοχή μετά τη σεισμική έξαρση του 1978. Οι τιμές Q_c^{-1} που υπολογίστηκαν για τη χρονική περίοδο 1983-1989 μπορούν, επομένως, να θεωρηθούν σαν οι αντιπροσωπευτικές τιμές για την περιοχή και οποιαδήποτε μεταβολή μελλοντικά να θεωρηθεί σαν πρόδρομο φαινόμενο ενός επικείμενου σεισμού.

ΕΙΣΑΓΩΓΗ - INTRODUCTION

The coda waves of local earthquakes were modeled by Aki (1969), Aki and Chouet (1975) and Sato (1977) as backscattered S waves whose amplitude at a given time depend on the source, site and path properties. The coda amplitude decay rate is characterized by coda Q^{-1} , (Q_c^{-1}), is a stable parameter for all earthquake-station pairs within a given region and reflects the average

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attenuation properties of the area containing the sources and the receivers (Aki, 1980a,b; Roecker et al., 1982; Sato, 1977, 1990).

Recently, observations of temporal variations of the coda Q values of small local earthquakes preceding major earthquakes have been reported in various areas of the world, suggesting that the temporal variations of coda Q can be one of the most promis- ing precursory phennomena.

Jin (1981) discovered that S coda durations for earthquakes of the same magnitude, at stations close to the aftershock area, were anomalously shorter than usual in a three year period preceding the Tangshan earthquake (M=7.8) of 1976 in China. She also found a similar temporal variation in the relation between S coda duration and magnitude for the Songman earthquake (M=7.2) of 1976. In a more detailed study Jin and Aki (1986) found that Q_c^{-1} in the close vicinity of the main shock in a three year period preceding the Tangshan earthquake was about 3 times larger than before or after that period. A 30% increase in Q_c^{-1} has been observed before the 1975 Hawaii M=7.2 earthquake (Wyss, 1985), before three large earthquakes (M=8.0) in the Kuril- Kamchatka area (Gusev and Lemzikov, 1985) and before the Petatlan earthquake (M=7.6) in Mexico (Novelo-Casanova et al., 1985). Sato (1986) found that the attenuation intensity in the vicinity of a M=6.0 earthquake in Kanto-Tokai region in Japan was higher than that after the main shock and similar results were also obtained for the Nagano earthquake (M=6.8) of 1984 in central Japan (Sato,1987).

Peng et al., (1987) found precursory changes in coda Q that varied in a complicated manner with distance from the site of the 1984 Round Valley California earthquake with M=5.7. Tsukuda (1988) observed that 3 years before the Misasa 1983 erthquake in Japan with M=6.2 the Q_c^{-1} measured at 5 Hz increased about 20% compared with the mean of other time periods and then decreased immediately after the earthquake. The source of this anomalous change was localized near the epicentral region of the earthquake. A temporal and spatial change of Q_c^{-1} was associated with the occurrence of the North Palm Springs earthquake of 1986 (Su and Aki, 1990). Q_c^{-1} of earthquakes which occurred before the mainshock was significantly higher than that of the aftershocks in the mainshock area, while the Q_c^{-1} for the surrounding area remained almost constant.

Anomalous changes of Q_c^{-1} have been also associated with volcanic eruptions. Fehler et al., (1988) based on data of earthquakes at Mount St. Helens recorded before during and after the eruption of September 1981 that found that Q_c^{-1} was 20-30% higher before than after the eruption.

The scope of the present paper is to study the temporal distribution of Qc-1 values which were estimated from local earthquakes in the region of the Mygdonia Graben, northern Greece during the period 1983-1989 (Hatzidimitriou, 1993a). Stable in time Q_c^{-1} values can be the base in order any premonitory changes due to a probable major earthquake to be detected.

ΠΕΡΙΟΧΗ ΜΕΛΕΤΗΣ - AREA STUDIED

The area which is studied in the present paper is shown in a rectangle in the map of figure (1). This map shows the distribution of the epicenters of all earthquakes with magnitudes M > 5.4 which occurred between 1901 and 1978 in northern Greece and the surrounding area (Papazachos et al., 1979). In the same figure the main geological zones (Rodope, Serbomacedonian, Axios-Vardar) are also shown (Mercier, 1968; Kockel et al., 1971). The Axios-Vardar zone consists mainly of deformed mesozoic metasediments and the Serbomacedonian and the Rhodope massif of premesozoic crystalline rocks and schists.

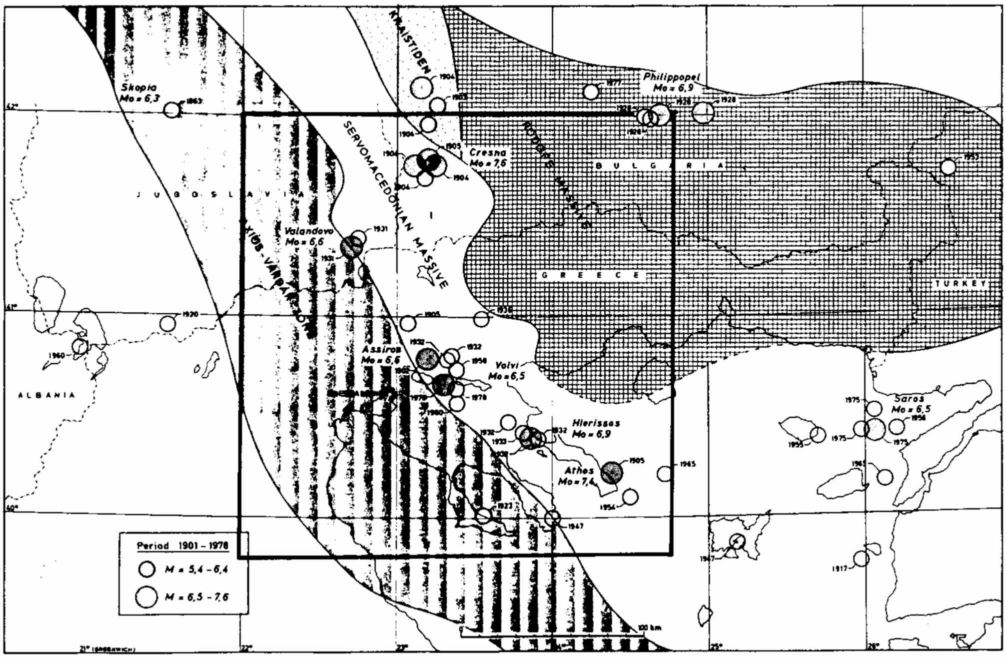

Fig. 1: The seismic activity (Ms≥5.4) in northern Greece and the surounding area during the present century (Papazachos et al. 1979). The area studied in the present paper is shown in the rectangle.

Σχ. 1: Σεισμική δραστηριότητα (Ms≥5.4) στη βόρεια Ελλάδα και τις γύρω περιοχές κατά τη διάρκεια του παρόντα αιώνα (Papazachos et al. 1979). Η περιοχή που μελετάται περιλαμβάνεται στο τετράγωνο.

As it can be seen from this figure, the epicenters of the largest shocks which occurred in the area during the present century are located within the Serbomacedonian massif forming a well defined seismic zone trending NW-SE. The whole zone is dominated by a N-S extensional stress field and the large destructive earthquakes were caused by normal faults striking E-W, while the low b value of the frequency-magnitude relation equal to 0.6 found for that region depicts the high seismicity in large magnitude earthquakes (Papazachos, 1990).

The seismic activity of this zone has been very high during the present century. The last earthquake sequence occurred during the spring and summer of 1978 with three earthquakes of magnitudes 5.8 , 6.5 and 5.5 at a distance of about 25 Km NE from the city of Thessaloniki causing severe damage to the city.

Many studies have been made, especially after the 1978 earthquakes, concerning the seismicity (Carver and Bollinger, 1978; Papazachos et al., 1979; Scordilis, 1985; Hatzfeld et al., 1986) and the tectonics (Mercier et al., 1983; Psilovikos, 1984, Pavlides and Kilias, 1987) of the area. The Neotectonic and Landsat images have shown that three main groups of faults can be distinguished: faults striking NE-SW, probably inherited from tectonic episodes occurred before the Neogene, faults striking NW-SE and faults striking E-W. On these three groups of faults three different tectonic episodes have been recognized, the last one being a very intensive Quaternary N-S extension (Mercier et al., 1983).

ΔΕΔΟΜΕΝΑ ΚΑΙ ΜΕΘΟΔΟΣ ΑΝΑΛΥΣΗΣ - DATA AND METHOD OF ANALYSIS

The data used in the present study come from local earthquakes recorded by the telemetered network which is operated by the Geophysical Laboratory of the University of Thessaloniki during the period 1983-1989. 405 events were finally selected for further analysis and in Figure 2 we show the epicenters of these earthquakes (circles) and the seismological stations (black triangles). The local magnitudes of these events are between 1.0 to 4.5, while the focal depths are all less than 20 km.

For the estimation of the coda Q values the single S to S backscattering model of Aki and Chouet (1975) has beem applied. According to this model the power spectrum P(ω/t) of the coda waves at time t after 2ts, where ts is the travel time of the S waves (Rautian and Khalturin, 1978) is expressed by

$$P(\omega/t) = c(\omega)t^{-2}\exp(-\omega Q_c^{-1}t) \qquad (1)$$

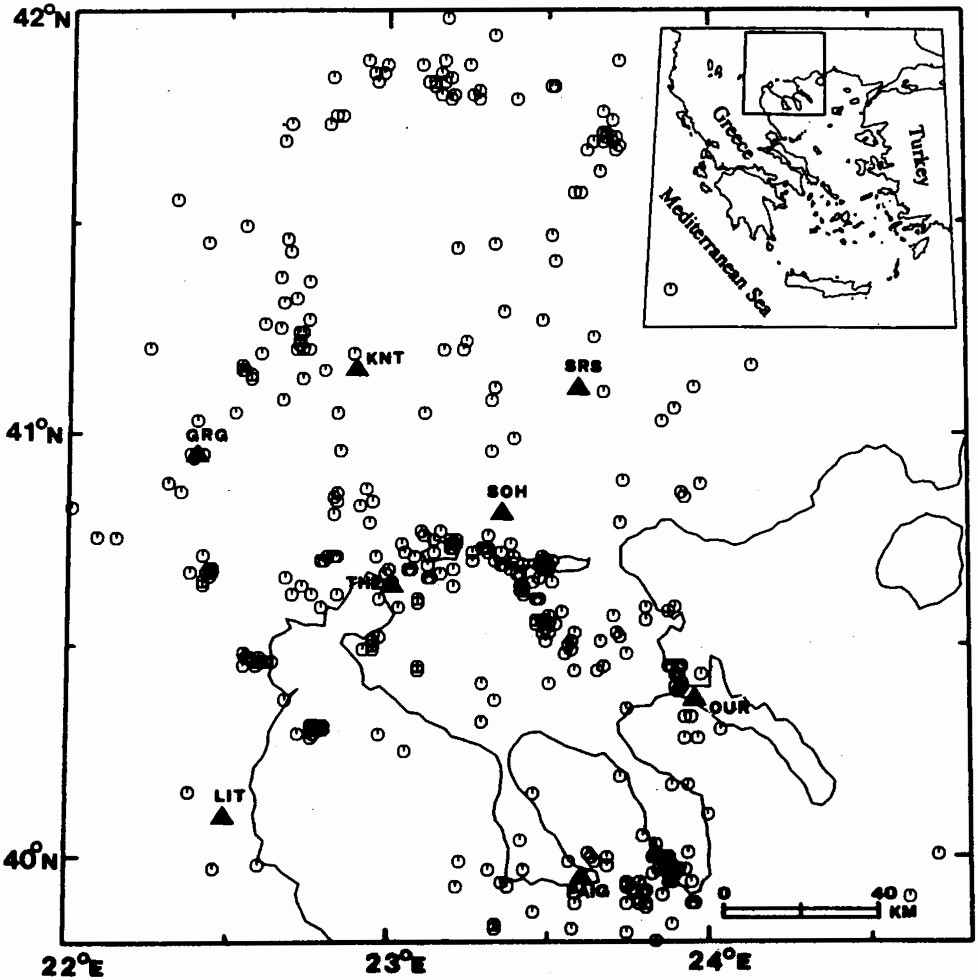

Fig. 2: Map showing the stations (black triangles) and the events (open circles) used for coda wave analysis.

Σχ. 2: Χάρτης των σταθμών (μαύρα τρίγωνα) και των επικέντρων των σεισμών τα δεδομένα των οποίων χρησιμοποιήθηκαν για την ανάλυση των κυμάτων ουράς.

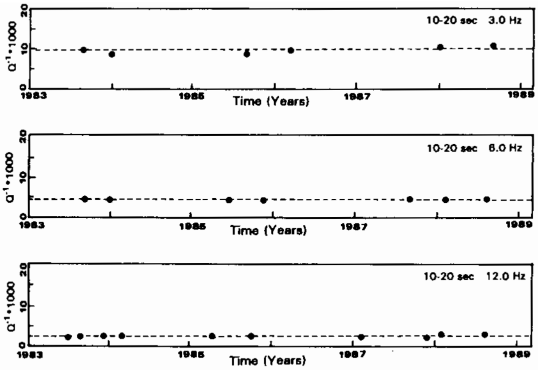

Fig. 3: Plot of Q_c^{-1} values versus time, for the lapse time window of 10 - 20 sec for frequencies 3.0, 6.0 and 12.0 Hz. Each point represents the mean of 20 measurements of Q_c^{-1} with 10 values overlapping. The straight broken lines for each frequency show the average values of Qc-1 of the whole time period given in Table 1.

Σχ. 3: Χαρτογράφηση των τιμών Q_c^{-1} για συχνότητες 3.0, 6.0 και 12.0 Hz και χρόνο 10-20sec, σε συνάρτηση με το χρόνο. Κάθε σημείο αντιπροσωπεύει το μέσο όρο 20 μετρήσεων με επικάλυψη 10 τιμών. Οι ευθείες διακεκομένες γραμμές δείχνουν το μέσο όρο του Q_c^{-1} για όλη την περίοδο, όπως δίνεται στον Πίνακα 1.

where ω is the circular frequency and t is the lapse time measured from the earthquake origin time. c(ω) depends on the source, the recording site and the scattering coeficients of the medium and Qc is the quality factor including both scattering and intrinsic attenuation. Rewriting (1) as

$$\ln[P(\omega/t)t^2]=\ln[c(\omega)]-\omega Q_c^{-1}t \qquad (2)$$

we can calculate Qc from the linear regression of $\ln[P(\omega/t)t^2]$ versus t.

Following Phillips and Aki (1986) and Su and Aki (1990), the power spectrum was estimated from the discrete Fourier Transform calculated for successive overlapping time windows centered at time ti, and then it was corrected for instrument gain and noise and averaged over octave frequency bands centered at 1.5 , 3.0 , 6.0 and 12.0 Hz. Linear regression was applied according to relation (2) and the coda Q values were calculated for each frequency band and for five specified lapse time windows, which are 10 - 20 sec, 15 - 30 sec, 20 - 45 sec, 30 - 60 sec and 50 - 100 sec. More detailes on the data processing is given by Hatzidimitriou, (1993a).

Table 1: Average coda Q-1*1000 values and their standard deviation of the mean for different frequencies and lapse time windows. No is the number of observations used for the calculation of the mean Q values.

Lapse time	Frequency			
Window	1.5 Hz	3.0 Hz	6.0 Hz	12.0 Hz
10 - 20 sec	21.28+4.34	10.22+2.71	4.53+1.00	2.70+0.65
No	23	48	47	88
15 - 30 sec	12.19+4.01	6.89+1.62	4.07+0.74	2.34+0.49
No	64	126	145	190
20 - 45 sec	8.42+1.91	5.00+1.75	3.21+0.64	1.87+0.37
No	149	227	223	261
30 - 60 sec	7.49+1.89	4.71+1.05	2.62+0.44	1.51+0.24
No	227	223	219	234
50 - 100sec	5.63+1.33	3.60+0.80	2.02+0.37	1.23+0.21
No	171	169	167	173

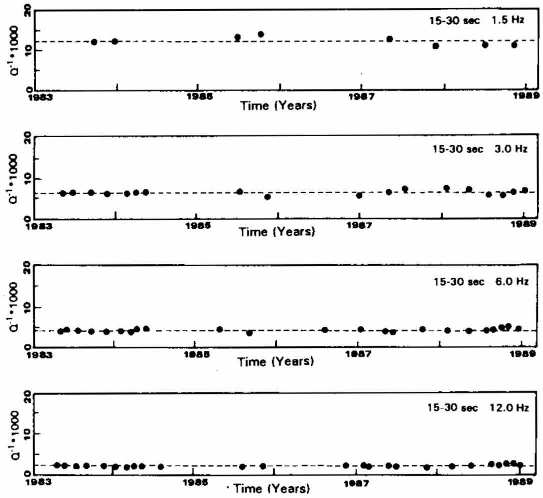

Fig. 4: Plot of Q_c^{-1} values versus time, for the lapse time window of 15 - 30 sec, for frequencies 1.5, 3.0, 6.0 and 12.0 Hz. (The other are the same as in Fig. 3)

Σχ. 4: Χαρτογράφηση των τιμών Q_c^{-1} για συχνότητες 1.5, 3.0 , 6.0 και 12.0 Hz και χρόνο 15-30 sec, σε συνάρτηση με το χρόνο. (Τα υπόλοιπα όπως στο Σχήμα 3.)

ΑΠΟΤΕΛΕΣΜΑΤΑ - RESULTS AND DISCUSSION

Mean Qc values were calculated for each station for the five lapse time windows and the four frequency bands. However, there were not any differences in the mean values between stations and this was expected because all the stations are located on hard bedrock and the earthquakes show an even spatial distribution. A study on the site effects of the seismological stations of the network (Hatzidimitriou, 1993b) using the coda wave method (Philips and Aki, 1986) showed that there are no significant site amplifications for the frequency range between 1.5 and 12.0 Hz.

This is especially important in the study of the spatial and temporal variations of coda Q because some of the reported changes considered as precursory anomalies can be due to the effects of the local site conditions (Sato, 1988).

Average Q_c^{-1} values were calculated using all the stations and all events for each lapse time window and each frequency. These mean values and the number of observations from which they were estimated are given in Table 1. Q_c^{-1} values show a significant decrease both with frequency and with lapse time window. For this reason, in order to see if there are any temporal variations data from the same lapse time window must be used. In Figure 3 we show the plot of Q_c^{-1} values versus time, for the lapse time window of 10 - 20 sec for frequencies 3.0, 6.0 and 12.0 Hz. Each point represents the mean of 20 measurements of Q_c^{-1} with 10 values overlapping. The mean values shown in Figure 3 are not equally spaced in time because we did not have recordings covering evenly the period 1983-1989. Also, Q_c^{-1} values at 1.5 Hz for this time window were not enough in order to study their temporal variation. The straight broken lines show the average values of Q_c^{-1} over the whole time period given in Table 1. In Figures 4 and 5 we show the same plots as in Figure 3 for the time windows of 15-30 sec and 30-60 sec. As we can see from these figures there is a remarcable stability in time of the Q_c^{-1} values for all lapse time windows. This is a very interesting result, especially for the window of 10 to 20 sec because at these early lapse times coda waves sample a small volume around each station and are more sensitive to the local geology and to trapped surface waves (Steck et al. 1989; Mayeda et al., 1991). The same stability in time of Qc-1 was also observed for the

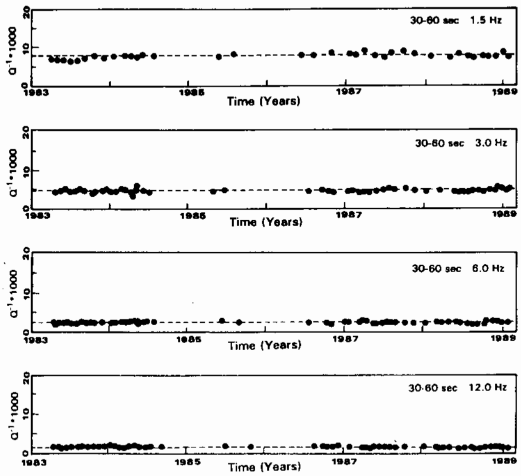

Fig. 5: Plot of Q_c^{-1} values versus time, for the lapse time window of 30 - 60 sec, for frequencies 1.5, 3.0, 6.0 and 12.0 Hz. (The other are the same as in Fig. 3).

Σχ. 5: Χαρτογράφηση των τιμών Q_c^{-1} για συχνότητες 1.5, 3.0 , 6.0 και 12.0 Hz και χρόνο 30-60 sec, σε συνάρτηση με το χρόνο. (Τα υπόλοιπα όπως στο Σχήμα 3.)

time windows of 20-45sec and 50-100sec. This is in very good agreement with the results of Karakaisis et al., (1991) who found that the post-shock activity does not last more than 6.0 years, in average, for the area of Greece. In the area of the present study the last big earthquake occured in 1978 and now we are in the time interval which follows the postshock activity and therefore the Q_c^{-1} values given in Table 1 represent the average of the quiescent period.

Recent studies (Peng et al., 1987; Sato, 1988; Su and Aki, 1990) have shown that the Q_c^{-1} precursory changes have complicated patterns and that special care must be taken in difining the lapse time window used for the estimation of Q_c^{-1}. The dependence of Qc-1 on the lapse time window is attributed to the different volumes that coda waves sample at different times (Rautian and Khalturin, 1978; Roecker et al., 1982). According to the single scattering model, assuming an S wave velocity of 3.5 Km/sec, at lapse times of 20, 30 and 60sec, coda waves sample a volume with radius approximately 35 Km, 52 Km and 105 Km, respectively (Pulli, 1984). Therefore the Q_c^{-1} values shown in Figures 3, 4 and 5 represent the average attenuation properties for a volume with radius of 35 Km, 52 Km and 105 Km around each station, respectively. When using Q_c^{-1} calculated from later lapse times, eg. 50 to 100 sec the sampled volume of coda waves has a radius of about 175 Km and therefore any precursory change in Q_c^{-1} is difficult to show up, unless the seismogenic volume of the forthcoming earthquake is very large.

A typical precursory change of Q_c^{-1} is to increase to a pick and then to decrease before an earthquake (Sato, 1986; Jin and Aki, 1989). This is explained as due to the formation of new cracks, reopening of existing closed cracks and water movement through cracked media which directly increase the attenuation intensity deduced from the coda waves while the Q_c^{-1} may decrease before the earthquake because of closure of creep fractures outside the seismogenic volume. The big advantage of measuring the temporal change of Q_c^{-1} is that coda waves respond to elastic properties in all parts of a volume around the source-receiver pair and are therfore more sensitive to changes in the elastic properties than the direct waves (Sato, 1987) .

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