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# Spatial variation of coda wave attenuation in the AL Hoceima region (Earthquakes of 24 Frebruary 2004), Morocco

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**Abstract.** On 24th February 2004 a significant earthquake (Md = 6.4) occurred in the north of Morocco causing great damage in the vicinity of Al Hoceima region. This area is characterized by a complex faulting system as a result of compressional tectonic forces. Three short period stations are set in this area of interest and recordings from these stations were used in this study. In order to complete our knowledge of attenuation, 60 local earthquakes are recorded a few days after the great earthquake with magnitude Ml 2.6-5.0 to estimate seismic attenuation. For this purpose, we applied the single backscattering model of Aki & Chouet 1975 in the frequency range for 1 to 4 Hz. The study of coda waves was limited to a relatively short lapse time (10 Seconds) in order to sample the earth's crust only .The values of $Q_c$ estimated for all the three stations show a strong frequency dependent relationship of the form $Q_c=Q_0f^n$, where $Q_0$ is $Q_c$ at 1Hz , and n represents the degree of frequency dependence , and reflect the level of crustal heterogeneities to varying degrees. The average frequency dependent attenuation relationship has been obtained which indicates that the attenuation is high in this region. Finally to conclude our work, the values of $Q_0$ suggest that Al Hoceima area is highly heterogeneous and the n parameter indicates a meaning frequency dependence of $Q_c$.

## INTRODUCTION

Al Hoceima is located among the most active seismic zones in Morocco between the African and Eurasian plates [4] . During the last 10 years , Al Hoceima has been affected by two strong earthquakes [5,4 ], the first on May 26th , 1996 (Mw=6.0) and the later on February 24th ,2004 (Mw=6.4). That's why , the study of its seismicity is very important in order to establish the seismic hazard assessment for this important area. Although this is a very active seismic zone , little is known about the seismic attenuation

Attenuation, inverse of quality factor, is one of the most fundamental proprieties of seismic waves from which a lot of information about the earth can be deduced [6] . The attenuation can be described as the decay of the seismic waves amplitude [3].The single backscattering model given by of Aki and Chouet [3] , has been used in this study . This method is widely applied to studies in the crustal structures in different parts of the world ([1,6,8,10,11,12,13]) .

In the present study , the seismic attenuation was investigated in Al Hoceima region by analyzing a large number of short period local seismograms and comparing it with other regions of the world [10] . The results of this study are discussed and compared with previous results and correlate with tectonic structures. These results may be helpful for seismic risk and earthquake engineering purposes .

## TECTONIC SETTING OF THE STUDIED AREA

The study area is located in the northern seismotectonic part of Rif chain . The seismotectonic framework of the region is characterized by generally diffuse seismicity, with clusters of important earthquakes. This area has experienced several destructive earthquakes such as the 26th May, 1994 and 24th February 2004 shockes .The latter produced several massive damage (about 600 deaths and more than 2500 buildings destroyed ) in Al Hoceima and the surrounding areas .

Four geomorphologic units can be distinguished [5] within this system (Fig. 2) :

- Bokkoya regions, containing nappe of Palaeozoic terranes and covering with Mesozoic-Cenozoic
- The Ketama metamorphic unit, which consist of Cretaceous flysch and lime- stones
- The middle Miocene Ras-Tarf andesites , which consists of Volcanic rocks
- The Tiziren unit,comprising Middle Jurassic to. Early Cretaceous

The study area is exploded by faults such as the Nekor fault [5] , which is the major transverse structure and The Imzouren (NNW-SSE) and Trougout (N-S) normal faults and The Jbel Hammam fault system (NNW-SSE) .

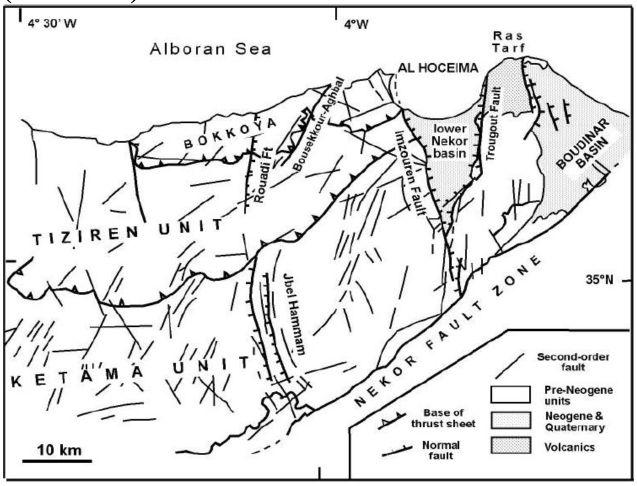


Fig 1. Structural map of the Al Hoceima area and main faults [5]

## DATA SET AND METHODS

For the estimation of the Coda waves quality factor , a group of 60 earthquakes recorded in are used , with magnitudes ranging from 2,6 to 5 .These events were recorded during the period from 6 to 8 March 2004 around the Al Hoceima Area by a three station network operating in the study area .Data were recorded digitally at 20 samples /sec. The details of these events are plotted in **Figure 2** together. The depths of these events are generally lower than 14 Km .The seismograms having the signal to noise ratio below 3 were discarded for obtaining reliable of quality factor values . For this study only the vertical components of the seismograms have been used.

Recordings of Al Hoceima earthquakes have been used to determine the attenuation of coda wave , from the rate of coda amplitude decay .

In the present study, $Q_c$ is estimated following single scattering model of Aki and Chouet (1975) .From this model the coda amplitude will take the following :

$$A(f,t)=c(f).t^{-1}.\exp(-f.t.\pi/Q) \quad (1)$$

where c(f) represent the coda source factor , Q the quality factor

Taking the logarithm of (1) gives

$$\ln[A(f,t).t] = \ln c - b.t \quad (2)$$

The quality factor is then determined by a least square fit of $\ln[A(f,t).t]$ versus t for (eq.2) .

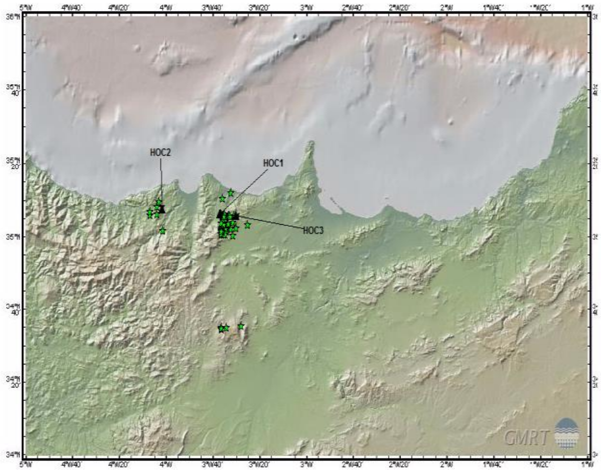


Fig 2: Location map of earthquakes and stations used for this study [14]

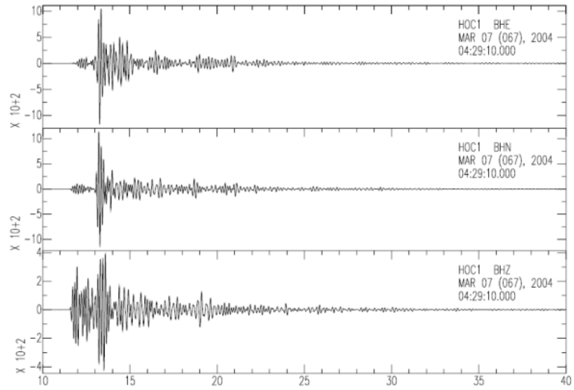


Fig. 3 :Example of seismograms recorded by the network for the event of 07 October 2004, 04:29 hr. Units of velocity are cm/sec. BHZ, vertical component; BHN, north-south component; BHE, east-west component.

## RESULTS AND DISCUSSION

The quality factor values are estimated filtering the coda waves of 60 local earthquakes in frequency band centered at 1, 1.5, 1.75, 3 and 4 for lapse time window length of 10 seconds.

The $Q_c$ measurements estimated from 10 sec coda window length are about 31 at frequency 1Hz and 126 at 4Hz. The distributions of $Q_c$ values with frequency are shown in Figure 4.

It is observed from the general trend (Figure 5) that $Q_c$ values follow a power law of the from $Q_c=Q_0f^n$, where $Q_0$ is the quality factor at 1Hz and n is the frequency dependent coefficient.

The frequency dependence of Q relationship for the Al Hoceima area : $Q_c$ =40.85.f0.9 with n=0.905±0.208 and $\log(Q_0)$=3.371±0.172

The graph of log(Q) against ln(f) is plotted and the following calculations are made .This is shown in the figure 5 .

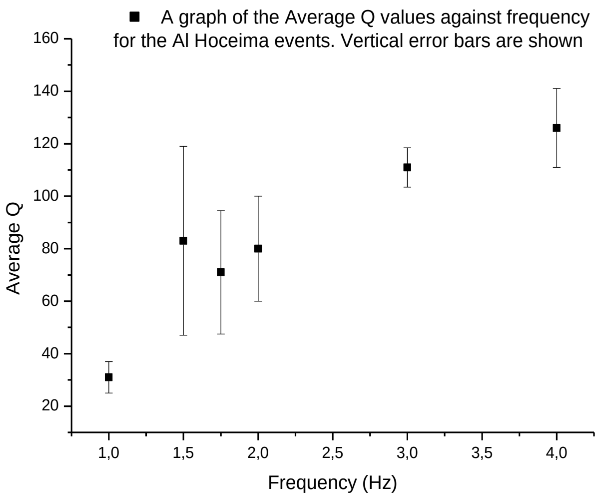


Fig. 4. Shows the distributions of Qc values with frequency for coda window lengths 10 seconds

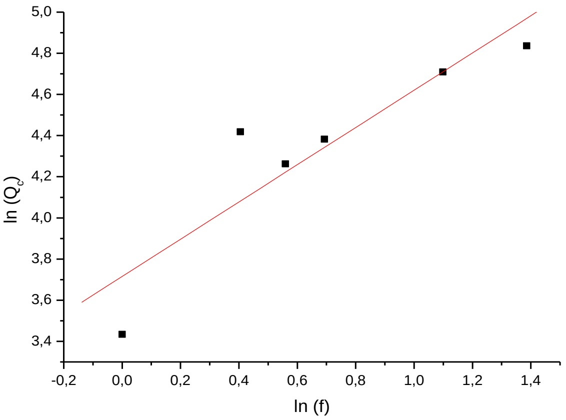


Fig 5. A graph of log(Q) against ln(f) for the AL Hoceima events .

From the above results , it is observed that $Q_c$ values obtained for the seismograms are high frequency dependent. Both $Q_c$ values and frequency increase simultaneously. The high frequency dependent characteristics of the $Q_c$ values may be due to different heterogeneity present in the propagating media [7] . This study shows the lowest values of $Q_0$ and the highest n components in 10 s lapse time. Most studies show that the value of quality factor on 1 Hz , $Q_0$ , is less than 200 for tectonically and seismically active regions [10] such as Yunnan, China , Washington State, whereas larger have been observed for inactive or stable regions such as New England, , South India and , North Iberia .Thus our area is tectonically and seismically active regions such as Yunnan and China [6,10,11] . Low coda values for this area ($Q_0$ =40.85 ) seem to be associated with tectonically and seismically active regions .

| Places | $Q_0$ | n | Sources |
|---|---|---|---|
| Active regions | | | |
| Aleutian | 200 | 1.05 | Scherbaum and Kisslinger (1985) |
| Washington State | 63 | 0.97 | Havskov *et al.* (1989) |
| South Spain | 155 | 0.89 | Ibanez *et al.* (1990) |
| West Anatolia, Turkey | 183 | 0.76 | Akinci *et al.* (1994) |
| Parkfield | 79 | 0.74 | Hellweg *et al.* (1995) |
| Koyna, India | 169 | 0.77 | Mandal and Rastogi (1998) |
| Bhuj, India | 102 | 0.98 | Mandal *et al.* (2004) |
| Stable regions | | | |
| Norway | 120 | 1.09 | Kavamme and Havskov (1989) |
| South Carolina | 190 | 0.94 | Rhea (1984) |
| South India | 460 | 0.83 | Ramakrishna Rao *et al.* (1997) |
| New England | 460 | 0.40 | Pulli (1984) |
| Eastern North America | 680 | 0.36 | Atkinson and Boore (1995) |
| North Iberia | 600 | 0.45 | Pujades *et al.* (1997) |
| B: From $L_g$ spectral Amplitude method | | | |
| Active regions | | | |
| Western U.S. | 150 | 0.4 | Singh and Herrmann (1983) |
| NW U.S. | 300 | 0.3 | Singh and Herrmann (1983) |
| Stable regions | | | |
| Indian Shield | 800 | 0.42 | Singh *et al.* (2004) |
| NE U.S. | 900 | 0.35 | Singh and Herrmann (1983) |
| Central U.S. | 1000 | 0.20 | Singh and Herrmann (1983) |
| Canadian Shield | 900 | 0.20 | Hasegawa (1985) |

Fig. 5 : A detailed comparison of coda-Q studies for different regions of the World [11]

## CONCLUSIONS

In this study, the coda quality factor was analyzed along the Al Hoceima using a single backscattering method 1975 in the frequency range for 1 to 4 Hz..This work suggests that the quality factor values are frequency dependent in the Al Hoceima area and the value of frequency dependencies is about n =0.95(□ 1), which indicate a high degree of heterogeneity .The comparison of the low of quality factor on Al Hoceima region indicates that the attenuation is higher than other regions of the world .

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