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Q_c, Q_β, Q_i and Q_s attenuation parameters in the Umbria–Marche (Italy) region

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ABSTRACT

The attenuation of coda and S waves has been inferred for the Umbria–Marche region (central Italy) using seismic waveforms collected during the 1997 seismic crisis. The selected dataset is composed of 343 small magnitude ($1.4 < M_L < 4.2$) earthquakes recorded at a temporary array composed of 23 seismic stations. The Sato (1977) method, based on the assumption of single isotropic scattering has been used to infer Q_c, considering three different lapse times (20, 30 and 40 s). The coda normalization method (Aki, 1980) has been used to infer Q_β. Both Q_c and Q_β show a clear frequency dependence with a different frequency dependent parameter. The frequency dependence of Q_c is comparable with that previously found in the same area and around it. Using the method of Wennerberg (1993), intrinsic and scattering attenuation have been separated. Intrinsic attenuation is found to be close to coda attenuation and dominates over scattering dissipation. Coda Q increases with increasing lapse time but at a rate smaller than that observed in other areas of the Earth. Coda and intrinsic attenuation in the Umbria–Marche region are very high compared to other seismic active regions of the Earth. The retrieved high values of intrinsic attenuation may be explained in terms of the previously hypothesized fluid-pressurized regime of the crust in the central Apennines (Miller et al., 2004).

1. Introduction

Attenuation is one of the fundamental properties of seismic waves from which the material and physical conditions in the Earth's interior can be inferred (Aki, 1980). Moreover attenuation is considered as a key observable in defining the tectonic regime of the crust (Mitchell and Romanowicz, 1998).

The study of attenuation is often carried out by analyzing the decay rate of the coda of a seismogram, i.e. that portion of a seismic recording that follows the first S wave arrival. Many theoretical and experimental investigations (see Sato and Fehler, 2008 for a thorough review) have led to advanced methods to extract information on seismic attenuation from coda waves. It has been recognized that the coda of a seismogram is substantially composed of many incoherent arrivals from elastic discontinuities in the Earth's interior; our ability in reproducing the average properties of the coda is related to our ability to simulate scattering from heterogeneities at different wave-lengths inside the Earth (e.g. Zeng et al., 1991). Single scattering models are usually considered in the analysis of the early part of the coda (e.g. Aki, 1969; Aki and Chouet, 1975; Sato, 1977), whereas multiple scattering models have been developed to simulate the whole coda (Gao et al., 1983; Hoshiba, 1991; Zeng, 1991; Yoshimoto, 2000).

The coda attenuation is usually quantified through the inverse of an averaged frequency dependent parameter, known as coda Q (Q_c). As discussed in many papers (e.g. Del Pezzo, 2008), this parameter in principle represents the combined effect of intrinsic and scattering attenuation, even though in many observational studies (see Sato and Fehler, 2008 and references therein), confirmed by some lab measurements (Matsunami, 1991), the measurements show that Q_i^{-1} approaches Q_c^{-1}. On the other hand, this is not the case of earth media characterized by high heterogeneity, like volcanoes, where scattering attenuation prevails over intrinsic dissipation. The intrinsic attenuation Q_i^{-1} describes the absorption of the energy transported by seismic waves, due to defects in elasticity. Intrinsic attenuation is the seismological parameter most sensitive to the physical state of the rocks (e.g. Sato and Sacks, 1989 and references therein). The scattering coefficient Q_s^{-1} is related to the redistribution of seismic energy in the medium caused by elastic scattering of seismic radiation. Q_s^{-1} is related to the mean free path of seismic radiation (e.g. Dainty, 1981) and therefore quantifies the degree of heterogeneity of the lithosphere. Both Q_s and Q_i are closely related on the seismic observations and affect the observed decay rate of coda, described by Q_c^{-1}. If the attenuation of shear waves is known the effect of inelasticity can

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be separated by that due to scattering using the method due to Wennerberg (1993). Another method, known as "Multiple Lapse Time Window Analysis" (MLTWA) (Fehler et al., 1992) can also be used to this aim. The MLTWA compares the integral of the signal energy calculated in three successive time windows along the coda of local earthquakes, with the corresponding values, theoretically evaluated on the basis of the radiative transfer theory applied to elastic waves (Sato and Fehler, 1998).

In the present paper we show the attenuation properties of coda and shear waves in the Umbria–Marche (Central Italy) region, using seismic data collected at a temporary array during the 1997 seismic crisis. We separate intrinsic and scattering attenuation using the method of Wennerberg (1993). Previous attenuation studies, based on different datasets or using different techniques, have been carried out in the same area considering a frequency dependent Q (Del Pezzo and Zollo, 1984; Del Pezzo and Scarcella, 1986; Malagnini et al., 2000; Castro et al., 2002) or a constant Q (de Lorenzo and Zollo, 2003; Filippucci et al., 2006; de Lorenzo et al., 2010). The results obtained in the present study will be then compared with those previously obtained by several authors, in order to acquire further insights on the attenuating properties of the crust in Central Italy.

2. Seismological and tectonic setting of the area

The seismic activity in the Umbria–Marche region is related to the tectonic activity of central Apennines and is well documented in the Italian historical earthquake catalogue (Boschi et al., 2000).

The central and northern Apennines consist of a NE verging thrust-fold belt formed as the result of the collision between the European continental margin (Sardinia–Corsica block) and the Adriatic lithosphere (Pauselli et al., 2006). From the Oligocene to the present-day, the area has experienced an early compression with eastward directed thrusting and a later phase of extension (Pauselli et al., 2006). This activity generated a complex fault system. The present day seismicity is mainly associated to active faults striking in the Apennine direction and antithetic to a regional low-angle apenninic horizon, named Alto-Tiberina fault, whose seismic activity is still in debate (Boncio and Lavecchia, 2000).

The 1997 seismic crisis was characterized by nine strong shocks, with magnitude higher than $Mw = 5$, and more than 2000 aftershocks (Amato et al., 1998). During the crisis, the seismicity migrated from north towards south in the Apennine direction and the activity was concentrated on an area elongated in the NW–SE direction, mainly shallower than 9 km. A high fraction of the energy radiated during the unusually long Umbria–Marche 1997 seismic sequence was released by the aftershocks, with a total extent of the aftershock zone of about 40 km (Amato et al., 1998). Many recent studies have concerned the properties of the crust in the region. V_p and V_s 3D tomographic studies (e.g. Chiarabba and Amato, 2003 and references therein) revealed the existence of lithological discontinuities in the upper crust due to lateral variations of material properties along the faults that controlled the evolution of the rupture.

3. Dataset

During the seismic crisis a temporary array of 23 three-component seismic stations was installed in the area. The network included 15 temporary and eight permanent stations. Ten temporary stations (dark triangles in Fig. 1) consist of MarsLite data loggers recording on 230 Mbyte optical disks, in continuous mode at 125 samples per second (blue triangles in Fig. 1); four of them equipped with Lennartz LE-3D/5s (flat velocity response between 0.2 and 40 Hz) and six with Lennartz LE-3D/1s (flat velocity response between 1 and 40 Hz). Five temporary stations (red triangles in Fig. 1) consist of RefTek 72-A07 data loggers equipped with Mark-L22-3D 1s (flat velocity response between 2 and 40 Hz). Permanent stations were managed by the RSM (Osservatorio Geofisico Sperimentale di Macerata) and RESIL (Regione Umbria) and recorded in continuous mode at 62.5 samples per second. These stations consist of MARS88/FD data loggers equipped with Mark L4C-3D seismometers (flat response between 1 and 40 Hz).

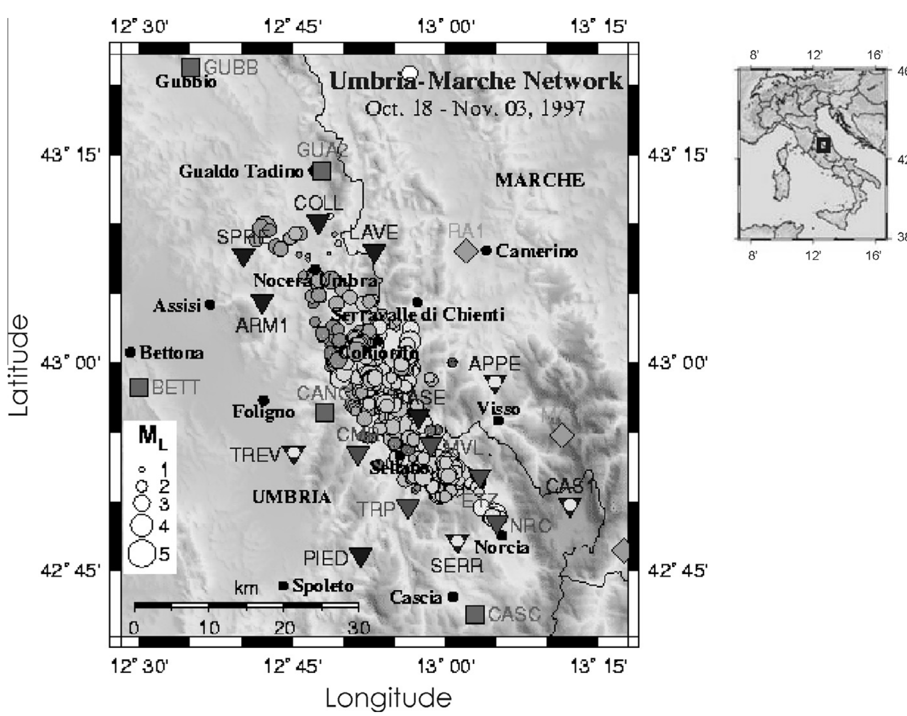

Fig. 1. Map of the 621 epicenters (circles) and the 23 seismic stations of the temporary array located in the Umbria–Marche region during the 1997 seismic crisis.