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Crustal structure in and around the Onikobe geothermal area, northeastern Honshu, Japan, inferred from the spatial variation of coda decay

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ABSTRACT

The Onikobe area is an active geothermal area situated in the Ou backbone range of northeastern Honshu, Japan. It is home to calderas from the Tertiary to Quaternary eras and active volcanoes. A systematic spatial variation of Q_c has been found in this area: Q_c values are lower at stations in and around calderas than at other stations. The amplitude of coda waves with high Q_cs decreases more slowly after a lapse time of around 7–10 s than that with low Q_cs. In the present study, to determine causes for these coda decay variations, coda envelopes were synthesized in a structure model in which high attenuation zones existed beneath the Onikobe and Sanzugawa calderas and where scattering coefficients were higher in the lower crust than in the upper crust. Using hypocenters shallower than 10 km, envelopes were calculated for 256 station-hypocenter pairs with epicentral distances of less than 10 km. It was assumed that the coda waves were composed of S–S scattered waves, and that the scattering was single and isotropic. The observed features of the Q_c distribution were reproduced in the synthesis, and synthesized envelopes were found to mostly coincide with observed decay curves. The top of high attenuation zones was thus estimated as being deeper than 7.5 km. The structure assumed for the synthesis was consistent with that of previous studies. We consider that the structure model used was appropriate, and that high attenuation zones beneath calderas and the reflective lower crust caused the spatial variation of the Q_c and decay curves in the Onikobe area. We also consider that studies using coda decay would be beneficial in detecting high attenuation zones and the reflective lower crust.

1. Introduction

Seismic waves arriving after a direct S-wave create a coda (tail) of wave trains that are composed of scattered waves related to inhomogeneity within the crust and mantle (Aki, 1969; Aki and Chouet, 1975). Aki and Chouet (1975) derived a formula for the coda amplitude as a function of lapse time (time measured from the source origin time) based on the single back scattering model and the diffusion model. In addition, Sato (1977) obtained an equation for the space–time distribution of coda energy for a single isotropic scattering model. The equations derived from these studies show that the Q value in the region, as sampled by the scattered waves, can be estimated from the temporal decay of coda amplitudes. The Q value thus obtained is termed coda-Q or Q_c.

Miura et al. (2003) estimated the Q_c values in the Onikobe area (northeastern Honshu, Japan) based on the single back scattering model. The models of Aki and Chouet (1975) and Sato (1977) suggest that if regions that are sampled by coda waves overlap, then the Q_c estimated for different station-hypocenter pairs should be almost the same. However, Miura et al. (2003) found that the values obtained showed variations between close stations. They suggested that Q_c variation could be produced in places where the lower crust effectively returned seismic wave energy and where strong attenuation zones existed beneath calderas.

The existence of strong attenuation zones, or low-Q zones has been detected by analyzing the amplitude of P- and S-waves in volcanic regions (e.g. Matumoto, 1971; Horiuchi et al., 1997). Since

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the 1980s, the inversion method has been used to delineate low-Q zones (e.g. Young and Ward, 1980; De Siena et al., 2010), but in some regions it is not possible to employ this method as it requires a sufficient number of rays passing through the low-Q zone. However, if the effects of a low-Q zone can be noted in relation to coda decay, as implied by Miura et al. (2003), coda decay could also be used as a method for detecting low-Q zones.

This present study uses the information presented in Miura et al. (2003), and validates their structure model. Coda envelopes are synthesized for station-hypocenter pairs with observed waveforms, and are then compared with results from observations.

2. Study area and previous studies

The Onikobe area is an active geothermal area situated in the Ou backbone range, and is home to Tertiary to Quaternary calderas and active volcanoes (see Fig. 1). On August 11, 1996, a series of earthquakes of magnitudes larger than 5 occurred near the Onikobe caldera. A number of aftershocks followed these earthquakes, and from 1996 to 1997 a dense seismographic network was set up for aftershock observations (Onodera et al., 1998; Umino et al., 1998). In 1997 and 1998, joint seismic observations were then carried out in the central part of northeastern Japan (Hasegawa and Hirata, 1999) and as a part of this observation project temporary stations were densely installed throughout the Onikobe area.

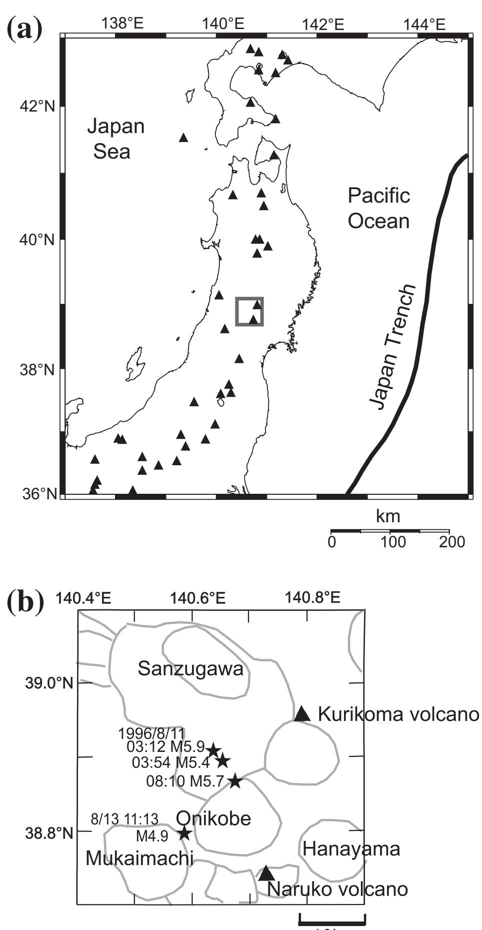

Fig. 1. (a) Map of northeastern Honshu. Solid triangles denote locations of active volcanoes, and the rectangle indicates the study area. (b) Map of studied area. Stars are epicenters of earthquakes with magnitudes of around 5 or larger that occurred in August 1996. Active volcanoes are represented by triangles. Calderas delineated by Yoshida (2001) are shown by gray lines.

Using the data obtained from both the aftershock observations and the joint observation project, the hypocenter distribution, focal mechanisms, seismic velocity, attenuation structures, and the Q_c were investigated. These studies revealed an inhomogeneous structure around the Onikobe area. Based on the aftershock distribution, geological features and a seismic attenuation structure, Umino et al. (1998) estimated the characteristic length of heterogeneity to be 10 km. Onodera et al. (1998) and Nakajima and Hasegawa (2003) obtained detailed three dimensional P- and S-wave velocity structures, and Nakajima and Hasegawa (2003) found low-Vp (P-wave velocity) and low-Vs (S-wave velocity) anomalies at depths greater than 10 km beneath the Sanzugawa and Onikobe calderas. Onodera et al. (1998) detected a high seismic attenuation zone close to the Sanzugawa caldera, based on highly attenuated amplitude of waves that passed beneath the Sanzugawa caldera. The location of this high attenuation zone agreed with the zone identified by a low velocity anomaly. Taking the results of Onodera et al. (1998) and Miura et al. (2003) into account, Nakajima and Hasegawa (2003) suggested the existence of fluids within low velocity zones.

As this present study succeeds that of Miura et al. (2003), the results of their study are summarized here. Their study calculated the Q_c in and around the Onikobe area based on the single scattering model by Aki and Chouet (1975). Seismograms were analyzed after applying 4–8 Hz, 8–16 Hz, and 16–32 Hz band-pass filters, and the end of the time window for analysis was set so that the waves that scattered within the crust were contained. Results showed that the Q_c values obtained were lower at stations in and around calderas than at other stations. The amplitude of coda waves with high Q_cs decreases more slowly after a lapse time of around 7–10 s compared than that with low Q_cs. These features were almost common among U-D, N-S, and E-W component seismograms. Based on these observational facts, Miura et al. (2003) concluded that the lower crust returned large seismic wave energy, which caused the slow coda decay after a lapse time of around 7–10 s. Close to a caldera, a considerable part of the seismic wave energy from the lower crust was attenuated in a high attenuation zone beneath the caldera, so that the decay rate did not reach such a slow rate within the lapse time. In order to check the validity of this conclusion, they synthesized coda envelopes for a simplified, schematic structure model in which the scattering was very large in the lower crust and a small and strong attenuation zone was embedded in the upper crust (Fig. 2a). The results showed that such a structure could explain the overall features of the observed Q_c values and decay curves (Fig. 2b). Fig. 2c shows the model geometry used for synthesis. This model geometry was used in the present study, and will be explained in Section 4.

3. Data

We collected records from the data source that Miura et al. (2003) used to select their data. The data were obtained at 15 stations during aftershock observations in 1996 and 1997 and the joint seismic observation in 1997 and 1998 (Table 1 and Fig. 3). These waveforms were recorded using L22D (2.2 Hz) and JC-V200 (0.05 Hz) sensors with a 100 Hz sampling interval. We collected waveforms from events shallower than 10 km, as recorded within a 10 km epicentral distance. Waveforms were checked visually, and those that contained large noise or another event were removed. The decay rates of coda waves were very similar among all the three components, as observed by Miura et al. (2003), and we used only N-S component ones in this study. When the N-S component was missing, either E-W or U-D component was used.