Estimation of physical properties of small-scale heterogeneities: Imaging with new parameterization of spectrograms

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Recent studies obtained spatial distributions of small-scale heterogeneities in the crust and/or upper mantle, based on scattering theory (e.g., Nishigami, 2000; Revenaugh, 2000; Taira, 2004). Although the spatial resolution of this type of imaging will be improved rapidly, there are still many insufficient aspects in this research field. One critical factor is that all the previous studies attempted the imaging of scattering coefficients of seismic waves, that is, relative strength of scattering. Taira (2004) recently investigated the scale lengths of those heterogeneities as well as the possibility of fluid, using frequency dependency and the ratio between P-to-P and P-to-S scatterings. In this study, we shall propose two new parameters for observed seismic data to describe the nature of imaged small-scale heterogeneities. As information independent of scattering coefficients, we shall investigate how to relate them with physical properties of heterogeneities.

Following Taira (2004), we corrected source, overall path and site effects on the waveforms recorded by the seismic array deployed around the Nagamachi-Rifu fault area of Northeast Japan. We estimated the temporal decay of coda envelope in a general form and used the normalization method with coda of large lapse time. In addition, we succeeded to obtain time-frequency spectrograms of high resolution by frequency-wavenumber analysis, applying the maximum entropy method. Previous studies have related the maximum of a spectrogram peak to the scattering coefficient to be imaged. We can recognize that peaks are also varied in terms of (1) shape and (2) total area of their spreading. We introduced the following two new parameters defined with the half widths of each peak in spectrogram, dw in frequency, and dt in time: (1) flat rate as (1/dw-dt)/dt, and (2) area as dw x dt. We obtained the spatial distributions of these two parameters, as we did for scattering coefficients. Only from the previous result on scattering coefficients, we could say that scattering is strong in the fault area similar to around the old caldera named Sirasawa. Two parameters in these two areas look very different: flat rate is negative and area is large in the fault area, and vice versa around the caldera.

In their interpretation, we refer numerical simulations of Yomogida et al. (1997). In the case of a cluster of small heterogeneities, they showed the existence of a low-frequency spectral peak of scattering corresponding to the cluster. Its duration in time is also large. As a result, this scattering wave yields a large value of area, compared with an individual isolated heterogeneity. Meanwhile, scattered waves show very different waveforms between low- and high-velocity heterogeneities. Because of a part of incident energy trapped inside a low-velocity heterogeneity, the scattered wave shows long duration in time, that is, nagetive flat rate. Comparing the above observational and numerical results, we can estimate the nature of the imaged heterogeneities in the fault area and around the caldera. The former heterogeneities may be low velocity and composed of small sub-heterogeneities, such as a number of small cracks. In contrast, the latter may be high velocity without any substructures, which suggests a small number of consolidated magma bodies. With more quantitative comparisons, we will quantify physical properties of small-scale heterogeneities imaged with high-frequency seismograms.

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