Imaging of crustal heterogeneity around the Nagamachi-Rifu fault in northeastern Japan with the effect of scattering mode

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In this study, we estimated small-scale heterogeneities around the Nagamachi-Rifu fault in northeastern Japan by multiple three-component seismic array observation. We identified scattering mode (i.e., P-to-P and P-to-S) using f-k and polarization analyses quantitatively, and mapped f-k power spectra into P-to-P and P-to-S scattering coefficients after the correction for source, station, and propagation effects.

As one of our important results, only P-to-S scatterers are localized near the surface trace of the Nagamachi-Rifu fault. In a depth range of 2 - 3 km, the scatterer distributions at 8 and 16 Hz do not show any specific anomalies near the surface trace, while scatterers at 4 Hz are linearly distributed with the same direction as the surface trace. In contrast, coefficients at 8 and 16 Hz are large in the northwest region of the surface trace in a depth range of 4 - 5 km. These clear frequency dependencies suggest different distributions of heterogeneities with different sizes around the fault area. This area of large scattering coefficients shows some correlations with the microseismic activity in this region. Localized small-scale heterogeneities near the surface trace of the Nagamachi-Rifu fault in the two depth ranges of 2 - 3 and 4 - 5 km are estimated to be about 0.3 and 0.07 km (i.e., the corresponding wavelength of 4 and 16 Hz), respectively. Although we cannot estimate and/or discuss the size of small-scale heterogeneities smaller than 0.07 km because we analyzed the seismograms lower than 20 Hz, the above results suggest that the scattering is strong around the Nagamachi-Rifu fault at 4 - 5 km depth, probably due to the abundance of fractures of the size around 0.07 km, attributing to the high activity of microearthquakes there.

Another area of large relative scattering coefficient is found in the northwest of the Nagamachi-Rifu fault at depth shallower than 10 km, where an old caldera is supposed to exist. The distribution of relative scattering coefficients does not show any significant frequency dependency in this region. As depth increases, the dominant seismic scattering seems to change from P-to-P to P-to-S. The above feature of scattering implies that the materials composed of seismic scatterers may show spatial variations in depth from dry cracks to fluid-fill cracks because P-to-S scattering becomes relatively effective in the case of fluid-fill cracks.

In order to estimate more detail and reliable quantification of small-scale heterogeneities, we next introduce two new parameters: \`flat rate\` and \`area\` in the f-k spectrogram. Flat rate and area may provide the nature of the waveform of each scattered wave and the simplicity of scattering process, respectively. Flat rate distinguishes an impulse-like scattered phase for its large value from a wavepacket of long duration for its small value. On the other hand, area is small if a scattering process is composed of a simple one while the summation of many processes or multiple process of scattering yields a large value of area.

We revealed that two regions in the studied area show different characteristics of seismic scatterers from the newly introduced parameters. A sallow part of the Nagamachi-Rifu fault may be composed of many seismic scatterers with the characteristics size of 0.3 km, and these seismic scatterers generate sinusoidal-like waves with the conversion of P-to-S because flat rate is relatively small (0.02 - 0.04) and area is large (larger than 0.9) in this region. On the other hand, the caldera region in the west of the Nagamachi-Rifu fault seems to contain high-frequency seismic scatterers, and all of the scatterers are characterized by relatively simple scattering process, for example, several isolated heterogeneities, because of small values of area (0.2 - 0.5) there.