Quantitative Imaging of Small-Scale Heterogeneities around Active Fault System as Seismic Wave Scatterers

（活断層系周辺における地震波散乱体としての
微細不均質構造の定量的イメージング）

学位論文内容の要旨

While large-scale heterogeneities on the earth have been intensively studied by seismic tomography with travel-time data, small-scale heterogeneities of less than several kilometers are not fully investigated yet because of extremely complexity of seismograms at higher than 1 Hz. We propose a new imaging method in a deterministic manner, using a f-k and polarization analysis, based on an autoregressive model. We estimated the 3-D spatial distribution of small-scale heterogeneities (i.e., scattering coefficients) around the Nagamachi-Rifu fault in a frequency ranges of 2 - 20 Hz. In order to overcome high complex nature of observed high-frequency seismograms, we used seismograms by dense (i.e., 50 m) three-component seismic arrays developed in this region for several explosion sources.

Small-scale heterogeneities are characterized by using f-k power level as a kind of scales of scattering strength such as scattering coefficient. In order to obtain a reliable distribution of scattering coefficient, we followed the six major steps; (1) estimating and/or removing propagation effects with Akaike Information Criteria, (2) obtaining the f-k power spectra in the time-frequency domain of high resolution, (3) conducting polarization analysis with correlation matrices of three-component seismogram and determining the scattering mode (i.e., P or S wave arrival) from the slowness vector and the maximum direction of polarization, (5) correcting source and station effects using the coda-normalization method, (6) mapping f-k power spectra as a function of lapse time into each small block in the model space with relative scattering coefficient.

We found several systematic spatial variations of scattering coefficients, revealing highly non-uniform distribution of small-scale heterogeneities in this area. As one of our important results, there are concentrations only for P-to-S scatterers but not P-to-P scatterers near the surface trace of the Nagamachi-Rifu fault. The distributions at both 8 and 16 Hz in a depth range of 2 - 3 km do not show any specific anomalies, while P-to-S scatterers at 4 Hz are localized in the same direction as that of the surface trace of the fault, implying the possibility of strong heterogeneities with a representative scale of 0.3 km (corresponding to the wavelength of 4 Hz) there. Another anomaly with large relative scattering coefficient is found in

the northwest of the Nagamachi-Rifu fault at the depth shallower than 10 km. As depth increases, seismic scatterers seem to convert from *P*-to-*P* to *P*-to-*S* relative scattering coefficients. This feature implies that the materials composed of seismic scatterers may show spatial variations from dry cracks to fluid-fill cracks with depth.

Next, we also introduced new two parameters called flat rate and area of each seismic scatterer that is responsible for scattered wave. Flat rate and area may provide the nature of waveform of each scattered wave and the simplicity of scattering process, respectively. Flat rate distinguishes an impulse-like scattered phase for large value from wavepackets of long duration for small value. Area is small if a scattering process is composed of a simple one while the summation of many processes or multiple process yield a large value of area. As a result, scattered waves may contain impulse-like waves caused by simple scattering process in the Shira-sawa caldera region while they are composed of the summation of many sinusoidal-like phases near the surface trace of the Nagamachi-Rifu fault. We revealed the existence localized two kinds of seismic scatterers around the Nagamachi-Rifu fault from the spatial variation of both flat rate and area even though the distribution of intensity or scattering coefficient is rather constant.

Further studies including more complex phenomena, such as non-isotropic and multiple scattering, will reveal more physical insight to these small-scale hetero-geneities, utilizing multiple arrays fully, together with more advanced scattering models.

学位論文審査の要旨

主 査　教 授　小 山 順 二

副 査　教 授　蓬 田　　清

副 査　助教授　森 谷 武 男

副 査　助教授　笹 谷　　努

学 位 論 文 題 名

Quantitative Imaging of Small-Scale Heterogeneities around Active Fault System as Seismic Wave Scatterers

（活断層系周辺における地震波散乱体としての
微細不均質構造の定量的イメージング）

　高周波地震波形記録を用いた微細不均質性構造の研究は，高密度な観測と計算手法の開発により近年急速な発展がある．高密度な地震観測がなされる度に微細構造のイメージングが行われている．この論文では地震観測アレイデータの利点を生かしつつ、空間・周波数分解能を向上させる新しい工夫がある。そして，これまで確率論的にしか扱えなかった高周波地震波形に対して，高分解能の時間－周波数解析を適用することにより，決定論的に地球内部の微細不均質構造を定量的に推定する手法を開発した．また、3成分観測による地震波動の振動方向解析から，P波からP波 と P波からS波への変換を区別してイメージングした．このような詳細な解析は本研究が初めてである．さらに，散乱強度ばかりでなく、スペクトルの特徴から散乱体について新しい2パラメータを導入し、その本質（物性や物質）に定量的に迫ろうという、今までにない試みもある．

　宮城県長町－利府断層系で展開された高密度地震アレイ観測に対してこの手法を適用し，不均質媒質の強度とその周波数依存性から既存の断層の深部延長と付近で発生する地震の破壊域に関して物理的性質を空間的に高分解能で評価した．本研究成果により，内陸の地震発生場に関して新たな知見を得ることができた．

　よって著者は北海道大学博士（理学）の学位を授与される資格あるものと認める．