論文内容の要旨

論文題目: A methodology for inversion of seismic waveforms for elastic and anelastic structure and its preliminary application to the mantle transition zone benath the Northwestern Pacific

（波形インバージョンによる弾性・非弾性パラメータの
同時推定手法および
その北西太平洋のマントル遷移層への試験的応用）

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We develop a quantitative and objective methodology for inversion of body-wave waveform data for elastic and anelastic structure and apply it to the upper mantle and mantle transition zone (MTZ) beneath the Northwestern Pacific, using PREM as the starting model. We derive the Jacobian for elastic and anelastic perturbations to the initial model in order to efficiently calculate the partial derivatives. Fig. 1 shows a schematic explanation of the inversion process.

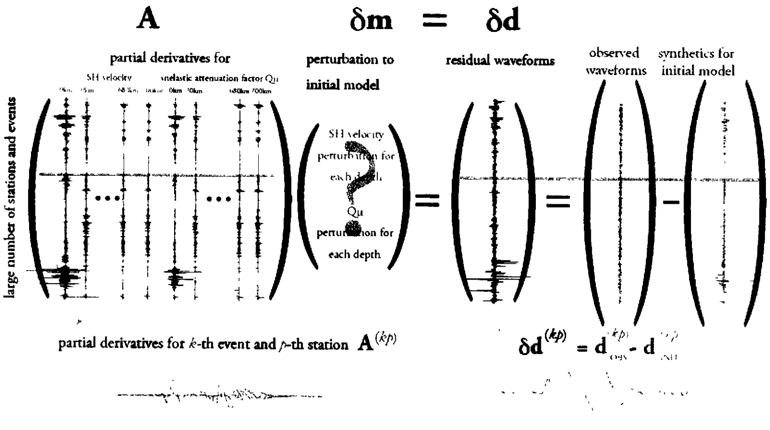

Fig. 1: Schematic interpretation of the inverse problem. The residuals and partial derivatives for the various events are gathered in a single vector and a single matrix, respectively. We then perform a simultaneous inversion for the perturbation to the model parameters.

This study has three aims: (1) to present techniques for automated inversion of broad-band body-wave waveform data for elastic and anelastic Earth structure; (2) to apply these techniques to invert for seismic structure for various sub-regions of the upper mantle and the MTZ; (3) to estimate the uncertainty and study the robustness of the results. This study is the first attempt to invert broad-band body-wave waveforms to estimate the radial dependence of regional anelastic structure.

We use the singular value decomposition (SVD) as the basis for our inversion and use Akaike's Information Criterion (AIC) to evaluate the statistical significance of the models and determine the appropriate size of the basis. Waveform inversion has often been thought to be a "black-box-like" procedure, but we explicitly show that the model obtained by the inversion is the projection of the data onto the model space using orthogonal vectors. Models are examined using several statistical tests. Because the SVD inversion uses an orthogonal basis (and the covariance matrix is thus diagonal), we develop methodologies for evaluating the data distribution and results in the model space, in data space, and in the intermediate orthogonal space (SVD space) to show the reliability and robustness of the obtained models.

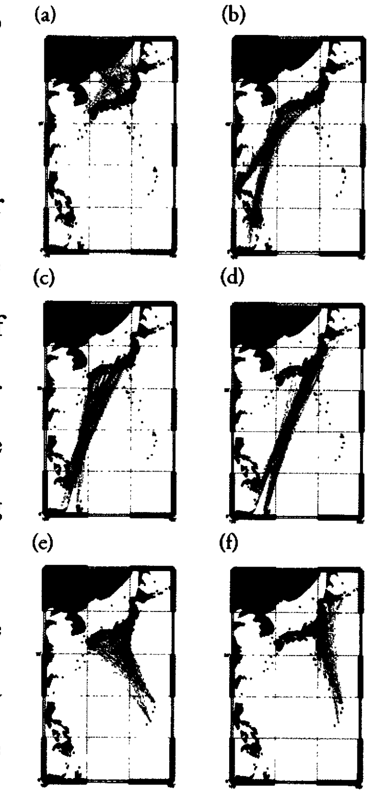

Fig. 2: The six subregions for this study, namely, (a) Japan Sea, (b) Philippines Sea West, (c) Philippines Sea Middle, (d) Philippines Sea East, (e) Pacific West, (f) Pacific East.

As we observe a large difference between the variance reductions computed based on the Born approximation and re-computed without linear approximation, we perform one iterative inversion as an example. The second iteration produces only a small change in the model space. This is due to the fact that the data themselves have a large degree of noise due to scattering although the inversion process is non-linear. Thus we do not perform iterative inversion.

We also confirm the results by comparison to models obtained using the conjugate gradient (CG) method. Because the CG inversion also utilizes an orthogonal basis systems we can evaluate statistical parameters as we do in the SVD inversion.

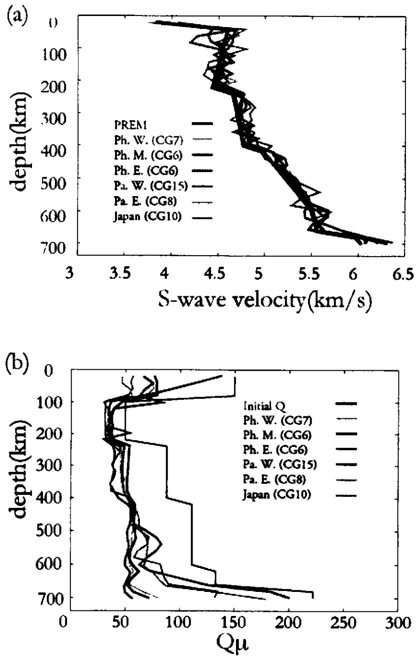

Fig. 3: The models obtained for the six subregions: (a) S-wave velocity and (b) Qμ. Sky-blue, blue, purple curves are for the Philippines Sea Regions.

We select the upper mantle and MTZ beneath the Northwestern Pacific as the target for this study. In this thesis, we invert for the datasets for six subregions (Fig. 2) and obtain 1-D elastic and anelastic models (e.g., Fig. 3).

We obtain an average positive S-wave velocity anomaly in the MTZ beneath the Philippine Sea Plate and the Japan Sea, which is consistent with other long-period wave tomographic models. The magnitude of the positive anomaly is stronger beneath the Philippines Sea than the Pacific.

For anelastic structure, our inversions obtained a lower Q_μ (50-100), as compared to PREM, for all of the subregions. There are two possible reasons for caution about these low Q_μ values: (1) the fact that we assumed the source time function is a δ-function; (2) the fact that we ignored the effects of 3-D elastic structure, which could also lessen the amplitude of the waveforms due to scattering and de-focusing effects, which are likely to occur during travel along a slab. Thus $Q_\mu = 50$ is probably a lower limit for the average value in the MTZ beneath these region. For comparison, previous studies using long-period surface waveforms (e.g., Romanowicz, 1998) suggest a Q_μ of around 100-200 for the upper mantle or the MTZ, but they also found lower Q_μ for this region than other regions. A weak sub-regional dependence of Q_μ structure was found, despite the large uncertainty about absolute values of Q_μ. Beneath the Philippines Sea region, we find the $Q_\mu \sim 50$ throughout the MTZ down to 660 km, while we find an increasing Q_μ in the deep part (500-660 km) beneath the Pacific. This may reflect the water rich content beneath the mantle wedge driven down to the lowermost part of MTZ in the Philippines Sea, which is consistent with a scenario where water depleted into the deep mantle beneath the mantle wedge (Karato, in press; Maruyama et al., 2009).