Effects of fine-scale laminated heterogeneity on seismic anisotropy from long-period surface waves: Evaluation with two-dimensional waveform modelling

*Xu Yunao[1], Kazunori Yoshizawa[1,2], Takashi Furumura[3]

1. Department of Natural History Sciences, Graduate School of Science, Hokkaido University, Japan , 2. Department of Earth and Planetary Sciences, Faculty of Science, Hokkaido University, Japan, 3. Earthquake Research Institute, The University of Tokyo, Japan

Recent seismic studies using long-period surface waves have revealed lateral variations of radial anisotropy in the lithosphere and asthenosphere (e.g., Nettles & Dziewonski, 2008; Yoshizawa, 2014). Such radial anisotropy estimated from long-period surface waves can be linked partly to the existence of fine-scale laminated structure suggested by recent high-frequency body wave studies (e.g., Kennett et al., 2017).

The aim of this study is to investigate quantitative relationship between such fine-scale laminated heterogeneity and observed radial anisotropy through synthetic experiments with numerical simulations of seismic wavefields. Quantifying the effects of fine-scale heterogeneity on total seismic anisotropy will allow us to estimate the proportions of “apparent anisotropy” (caused by heterogeneity) and “intrinsic anisotropy” (the elastic properties of the medium) that are generally mixed up in observed seismic anisotropy from long-period surface waves.

To investigate the effects of fine-scale laminated heterogeneity on long-period surface waves, we performed a series of 2-D finite-difference method simulations using velocity models with a variety of wavenumber spectrum of random heterogeneity based on von Karman distribution function with varying horizontally-elongated correlation scales. Following the earlier works of Kennett and Furumura (2008, GJI), we considered finely laminated heterogeneities with RMS 2% velocity deviations from PREM in the depth between Moho and 100 km. While the vertical correlation scale is fixed to 0.5 km in 2-D vertical structure along propagation paths, we have changed horizontal correlation scales from 10 km (as suggested by Kennett & Furumura, 2008) to 2000 km (almost equivalent to a 1-D velocity profile).

Using about 100 synthetic seismograms located at the epicentral distances between 2000 and 4000 km for each model, average phase velocities of the fundamental-mode Love and Rayleigh waves are measured using inter-station waveform fitting method (Hamada & Yoshizawa, 2015, GJI). By comparing the average inter-station phase velocities between different models, we investigate the effects of finely-laminated heterogeneity with various horizontal correlation length on the apparent radial anisotropy of surface waves.

Through these numerical experiments, we have found that the horizontal correlation length of laminated random heterogeneity strongly affects the apparent seismic anisotropy; i.e., extending the horizontal correlation length will make the apparent radial anisotropy greater. While the Love wave phase velocities are less affected by such random heterogeneity with any scales, Rayleigh wave phase velocities drop about 0.5-0.6 % slower than the isotropic case in the period range 40-70 s for a relatively long horizontal correlation length (2000 km). Such effects become weaker for a short horizontal scale (10 km), and phase velocity drop of Rayleigh waves is reduced to about 0.1 %. These results indicate that finely laminated heterogeneity with intermediate horizontal scale (several hundred kilometers or greater) may cause non-negligible influence on phase velocity drop of Rayleigh waves, as suggested by observation of scattering and guiding of high-frequncy seismic waves traveling through lithosphere (e.g., Kennett & Furumura, 2015), generating apparent radial anisotropy of S-waves in the upper mantle.

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