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Seismic tomography imaging of inhomogeneous structure in the Earth's interior

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Imaging method of inhomogeneous structure in the Earth's interior is divided into two; stochastic one analyzing coda and scattered waves and deterministic one such as seismic tomography, respectively. The late Prof. Aki is a pioneer of both fields and had made great contributions. In this paper, I give a brief review on development and future improvement in seismic tomography. Seismic tomography using mainly travel times has revealed 3-D structure with several scales in the crust and the mantle, and provided important information for understanding geophysical and geological problems such as the earthquake and volcano activities and mantle convection.

Seismic tomography started with two papers, Aki et al.(1977) and Aki and Lee(1976). The former investigates 3-D structure in the lithosphere beneath seismic arrays using relative travel times from teleseismic events, and the latter determines both the 3-D structure in the crust and the hypocenters simultaneously using travel times of local events. The method was called 3-D inversion of seismic velocity structure. While the studies up to the early 1970s had treated 1-D velocity structure dependent on radius or depth, these papers tried to elucidate also the lateral variation in seismic velocity. I, who was a graduate student, had a chance to read the preprints of these papers to have a hope for novel development in seismology, and tackled a problem of 3-D structure beneath the Japan Islands.

.In 1980s, the data included body waves, surface waves and free oscillation ones, and the investigated region expanded to global mantle tomography. Since the original inverse method based on matrix inversion could not treat the corresponding huge number of unknown parameters, the iterative solving methods in medical tomography had been used. Hence it followed that the method had been called as seismic tomography.

Different from medical tomography, seismic tomography has uneven distributions of stations and events, forcing us to investigate the resolution of the solution in addition to its error bound. Also, fast 3-D ray tracing techniques were developed as well as the methods of model parameterization such as cell, grid and surface harmonic expansion. See the details on the methods and initial results for the books edited by Nolet (1987) and Iyer and Hirahara (1993).

There have been recent developments in seismic tomography. First one is double-difference (DD) tomography (Zhang and Thurber, 2003), which enhances the resolution of the fine structure in the region with high-density of events. Second is finite-frequency tomography which uses banana- doughnut kernel taking the finite-frequency effects (Dahlen et al., 2000), and has advanced ray-theoretical travel time tomography. Finally, the noise-correlation method for retrieving Green's function between two seismic stations has been proposed and the far more data of surface group or phase velocities than before have been obtained for surface wave tomography (e,g., Nishida et al., 2005). This correlation method has been applied to investigate the structure in volcanic areas, and has revealed time variation in structure (e.g, Snieder and Hagerty,2004), and hence 4-D tomography might be possible in future. Such a 4-D seismic tomography is a direction which Prof. Aki aimed at in his original work.

Finally, I add the problem of velocity discontinuities. Seismic tomography had assumed a smooth variation of velocities. Zhao et al. (1992) firstly introduced the velocity discontinuities in seismic tomography. The discontinuity surface has, however, not been improved in their seismic tomography, while only velocity has been estimated. The estimation of 3-D velocity structure including velocity discontinuities requires the waveform tomography such as receiver function analyses including several later converted phases.