Pioneering research on the lithospheric heterogeneity by using coda waves

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Coda study is very unique and original among many research subjects of late Dr. Keiiti Aki. He was attracted by the beautiful shape of coda waves having fruitful information about medium heterogeneity. Even in his young days as in 1956 (JPE), he put a focus on the independence of coda spectra of local earthquakes from epicentral distances. He proposed a new interpretation of coda as scattered waves by distributed lithospheric heterogeneity in 1969 (JGR). He offered a paradigm of coda analysis with Chouet in 1975 (JGR), in which he proposed to measure the scattering coefficient as a scattering power per unit volume of the lithosphere, which can be related with the power spectrum of random inhomogeneity. Their model predicts that the coda power is proportional to the source energy, scattering coefficient and the inverse square of lapse time, where a phenomenological parameter, coda attenuation was introduced. The scattering coefficient of S-waves was estimated to be of the order of 0.01kmˆ-1 for 1-30Hz in the world. Coda attenuation was estimated to be of the order of 0.01 at 1Hz and decreases to 0.001 at 20Hz. This paper offered a guiding principle of short-period seismology since it showed the effectiveness of stochastic approach for treating seismic wave propagation through the heterogeneous Earth. In 1980 (PEPI, JGR), he proposed a coda normalization method for the estimation of site amplification factor, source spectra, and attenuation of S-waves per travel distance on the basis that coda amplitude is a function of lapse time independent of hypocentral distance. This method is now widely used in the world. In 1986 (JGR), he reported with Jin that the coda attenuation changed associated with the occurrence of the Tangshan earthquake in China. Since then he put more focus on the temporal change in coda attenuation. In the paper of 1989 (JGR) with Jin, he reported that coda attenuation is variable with time having a correlation with the b-value from the analysis of California data as long as 57 years. They interpreted that the temporal change in coda attenuation reflects the number density of small cracks in the ductile part of the crust. In his last paper of 2004 (EPS), he proposed to monitor the temporal change in coda attenuation with the number of earthquakes of a characteristic size for detecting the stress accumulation in the crust before an earthquake occurrence.

Stimulated by Aki's work, studies on seismic wave scattering and envelopes were developed in the world. Tsujiura carefully examined band pass filtered traces, Sato developed scattering models for the synthesis of coda envelopes, Yomogida and Benites numerically simulated coda in a heterogeneous medium, Hoshiba and Fehler developed a method to separate scattering loss from intrinsic absorption. Envelope broadening modeling of Sato and Obara is also included in the framework of stochastic approach. Nishigami and Matsumoto proposed an inversion scheme for the spatial distribution scattering coefficient from the coda analysis. Jin's coda Q map revealed from Hi-net data detected the Niigata-Kobe tectonic zone as a low Q zone. These works deepened our understanding of lithospheric heterogeneity and seismic wave scattering.

The acceptance of coda waves in the data set is needed for the acceptance of small-scale seismic heterogeneity of the lithosphere. For the study of short-period seismic-wave propagation in such media, stochastic approach is inevitable for describing both media and waves. Seismic waves are able to detect medium heterogeneity which varies with time. These are the message of late Dr. Keiiti Aki through his life-long commitment to coda studies. Stochastic characterization and deterministic imaging of the lithosphere are complementary to each other for making a more fruitful image of the solid Earth.