Viscoelastic behavior of rocks described by scaled Langevin equation and the inversion

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Seismic waveform data provide us with much information on seismogenic zone or other subsurface structures. From a viewpoint of rock rheology, the seismic waveform data is regarded as an output of the linear system of which the input is a dynamical strain (or stress) and the consequent response is viscoelastic behaviour of rocks. In terms of the linear system theory, the mathematical construction of the input-response-output relation enables us to formulate an inversion in order to presume the responding system from the output. However, the relation between the inverse analyses of seismic waveform data and the concrete viscoelastic property of rocks has not been investigated. In this presentation, based on a flow law of rocks (e.g. lherzolite), we theoretically derive an inverse formulation to infer the source field from seismic waveform data.

We first construct a dynamics of a complex system representing viscoelastic behaviour of rocks. One of simple formulations of viscoelastic behavior is described by the generalized Maxwell model. Stress-strain relations of the elements are expressed by a set of the Langevin equations which are equations of thermal motions of particles following fluctuation forces (i.e. the Brownian motions). By introducing a scaling rule on the size and deformation time for the elements, the Langevin equations for the respective elements become conformal equations. Consequently, the set of the scaled Langevin equations produces a temporal power-law behaviour specifying the dynamics of the complex system.

Expressed differentially, the scaled Langevin equation yields a response function (the Green's function) having a temporal fractal property in an input-output relation. When we regard the input and output as a dynamical strain (or stress) and a seismic waveform data, respectively, the response function can describe the viscoelastic property of rocks. Specifically, we have a flow law of rocks (e.g. lherzolite) on a mechanical relaxation following the temporal fractal property. This flow law is generated by the power-law distribution of the relaxation time for the elements of the generalized Maxwell model. The power-law distribution corresponds to the scaling rules in the scaled Langevin equation, and the flow law is applicable to the response function. Thus, we construct the viscoelastic response function based on the flow law of rocks. Moreover, through an inverse transformation on the input and output, we obtain an inverse formulation of the response function which enables us to approach the geophysical source field from seismic waveform data.