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Irreversible thermodynamics and time-scale invariance for viscoelastic behaviour of rocks

Y. Kawada (1), H. Nagahama (1)

(1) Department of Geoenvironmental Sciences, Graduate school of Science, Tohoku University, Sendai 980-8578, Japan (y-kawada@mail.tains.tohoku.ac.jp / Fax: +81 22-795-5786)

We investigate an irreversible thermodynamics representing viscoelastic behaviour of rocks. A general thermodynamics system with n degrees of freedom is defined by n state variables (generalized coordinates). The state variables includes k components of strain conjugate to stress and $n-k$ internal state variables which reflect the states of microstructures such as molecular configuration in polymer, defect in crystals or microcracks and correspond to damage parameter and plastic strain. Then, in the neighbourhood of the equilibrium, a Lagrange equation for the irreversible process with dissipation is derived. The general solution becomes a summation of $n-k$ orthogonal relaxation modes, and a nonlinear viscoelastic constitutive law is derived as an integral form of a stress-strain relation with exponential response. When $n-k$ orthogonal relaxation modes follow a scaling rule for deformation time and relaxation mode and the number of the internal state variables $n-k$ approaches infinity, the response function of the constitutive law becomes a temporal power-law. This constitutive law is applicable to the experimental data of transient and steady-state behaviour of rocks with (or without) damage. Moreover, the cumulative Benioff strain-release for preseismic activations and modified Omori's law of aftershocks are explainable by the constitutive law, and the time-scale invariance of seismicity patterns might be regulated by the fractal property of internal state variables, i.e., the fractal structures of crustal rocks.