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Preseismic change in atmospheric radon concentration and crustal damage process

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Prior to large earthquakes (e.g., 1995 Hyogo-ken Nambu earthquake, Japan), an increase in the atmospheric radon concentration was observed, and the increase in the rate follows a power-law of the time-to-earthquake (time-to-failure). This preseismic phenomenon corresponds to the increase in the radon migration in crust and the exhalation into atmosphere. We investigate this phenomenon in terms of the irreversible thermodynamics. In this theory, the Helmholtz free energy is prescribed by the macroscopic stress-strain relation, chemical potential (i.e., radon concentration in crust), volume fluid content advecting radon and internal state variables (generalized coordinates). The dynamics of the internal state variables represent the damage evolution such as microcracking or local plastic straining. A huge number of internal states have each characteristic relaxation time, while the collective dynamics of internal states shows temporal power-law behavior. This condition corresponds to mechanical behavior of crustal rocks following the stress power-law of strain-rate associated with time-scale invariant evolution of microscopic damage. On the other hand, in a linear irreversible process, the Helmholtz free energy and mass balance equations for radon and advecting fluid generate the Fick's law ([radon flux] = [diffusion constant] ∗[gradient of radon concentration]) and Darcy's law ([fluid volume flux] = [hydraulic conductivity (or permeability)] ∗[gradient of fluid pressure]). Moreover, in the Helmholtz free energy, the Maxwell's relations can be defined between the radon concentration and internal state variables, and between the volume fluid content and internal state variables, respectively. These relations explain that the time-scale invariant evolution of crustal damage promotes an increase in the permeability (hydraulic conductivity), gradient of fluid pressure, and the gradient of radon concentration within the crustal rocks, all of which affect the time-scale invariant increase in the flux of radon into the atmosphere and hence the atmospheric radon concentration. We point out that the concentration of atmospheric radon can be used as a proxy for the seismic precursory processes associated with crustal dynamics.