Critical phenomena of rock fracturing in groundwater level observation before the 2000 eruption of Usu volcano, Japan

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Fracturing in rock obeys the scaling rule. It is observed at all scales, from the microscale (microcracks) to the continental scale (megafaults)[1]. Some megafaults have their origin in a microscopic organization which can be transferred to larger scale whereas others attain their structure on the macroscopic scale itself. The large-scale fracturing can be derived from accumulations of ruptures of lesser scales. If the concept of the fracturing is true, the mechanism of the fracturing is constrained by critical phenomena and we can approach to earthquake prediction.

We generally know that an acceleration of interactive force near a critical point obeys the log-periodic oscillation superposed on the power law,

$$f(t) = A + B\,(t_c - t)^m\,[1 + C\cos\{\omega \log(t_c - t) + \psi\}],$$

where $f(t)$ represents an arbitrary function (now the residual groundwater level), which addresses interactive forces in the system, t is time, t_c is the critical point which can be accounted for the time of occurrence of earthquake, m and ω are critical exponents, A, B, C and ψ are constants. The log-periodic oscillation results naturally from many-body interactions between the microcracks. The increase of interactions in the rupture accelerates when approaching the critical point.

We report a change in groundwater level observed prior to the 2000 eruption of Usu volcano. The observed data show an oscillation pattern like self-similarity from three months before the eruption, which is accounted for the critical phenomena of the rock rupture. Furthermore, we calculated the Fourier power spectra in the groundwater level, and we obtained linear trend which is yielded by a critical phenomenon. We also estimated fractal dimension in rock fracturing from the change in groundwater level. The obtained fractal dimension is close to that estimated by an experiment of acoustic emission in rock fracturing[2]. Finally, we numerically estimated critical point from different data periods. Then, we can foresee the critical point within 20 days at more than one month prior to the critical point.

The observed fluctuations in groundwater level during volcanic activity of the 2000 eruption of Usu volcano provide rather strong and clear evidence, which answers critical phenomena prior to rock fracturing. The groundwater level exhibits the log-periodic fluctuations and oscillation pattern of self-similarity in the vicinity of the critical point. The observation of the groundwater level can also apply to an area anticipating an earthquake, and will provide a useful forecasting tool for the occurrence of earthquake and eruption of a volcano.

References:

[1] Allègre et al., Scaling rules in rock fracture and possible implications for earthquake prediction, *Nature, 297*, 47-49, 1982.

[2] Hirata et al., Fractal structure of spatial distribution of microfracturing in rock, *Geophys. J. R. Astron Soc., 90*, 369-374, 1987.