Geophysical Research Abstracts, Vol. 7, 00262, 2005
SRef-ID: 1607-7962/gra/EGU05-A-00262

Potential earthquake source formation: an analogy with second-order phase transition

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A potential earthquake source is associated with a region where the process of faulting self-organization initiated by the interaction of fractures takes place. It is supposed that, with a certain spatial–temporal averaging, the main general features of the system behavior associated with the interaction of fractures can be taken into account through introducing, in addition to the standard thermodynamic parameters, generalized variables α characterizing the damage of material and φ characterizing the amount of the effect of interaction between fractures on the faulting process. The self-organization of fracturing (formation of a potential earthquake source) begins when the fracture parameter α exceeds a critical value α_{cr}, generally depending on current parameters of the state of the medium, the stress rate, etc. Formally, this is described by the condition that the equilibrium value φ_0 of the parameter φ is nonzero only at $\alpha > \alpha_{cr}$. Mathematically, the model is based on the expression for the free energy

$$F(\varepsilon_{ij}, \alpha, \varphi) = F_e(\varepsilon_{ij}, \alpha) + F_i(\varepsilon_{ij}, \alpha, \varphi) \qquad (1)$$

Here

$F_e = F_0 + \frac{1}{\rho}(\frac{\lambda(\alpha)}{2} I_1^2 + \mu(\alpha) I_2 - \gamma(\alpha) I_1 \sqrt{I_2})$ where $I_1 = \sum_i \varepsilon_{ii}$, $I_2 = \sum_{ij} \varepsilon_{ij}\varepsilon_{ij}$ are the first and second invariants of the strain tensor; ρ is the density; $\lambda(\alpha) = \lambda_0 - \alpha\lambda_r$, $\mu(\alpha) = \mu_0 - \alpha\mu_r$, $\gamma(\alpha) = \alpha\gamma_r$; λ_0 and μ_0 are the elastic moduli of intact material; the constants λ_r, μ_r and γ_r are parameters characterizing the contributions of structural disturbances to elastic properties (Lyakhovsky, Ben-Zion, and Agnon, 1997).

$F_i(\varepsilon_{ij}, \alpha, \varphi) = A(\varepsilon_{ij}, \alpha)\varphi^2 + B(\varepsilon_{ij}, \alpha)\varphi^3 + C(\varepsilon_{ij}, \alpha)\varphi^4$ where $A(\varepsilon_{ij}, \alpha) = \tilde{a}(I_1, I_2)(\alpha_{cr} - \alpha)$, $\tilde{a}(I_1, I_2) > 0$; $B(\varepsilon_{ij}, \alpha) = \tilde{b}(I_1, I_2) \geq 0$; $C(\varepsilon_{ij}, \alpha) = \tilde{c}(I_1, I_2) > 0$ for $\alpha \sim \alpha_{cr}$

The expression of $F_i(\varepsilon_{ij}, \alpha, \varphi)$ is based on a formal analogy with the phenomenological theory of second-order phase transitions. With the fracture interaction taken into account, the system is shown to lose stability primarily in the region where $\varphi_0 \neq 0$, justifying the use of the term “potential earthquake source.” It is also shown that the incorporation of the fracture interaction into the model leads to a significant reorganization favoring an acceleration of the fracture process in the potential earthquake source region in comparison with the surrounding medium. The spatial heterogeneity of the medium associated with the presence of a potential source is accounted for through the incorporation of term containing spatial derivatives of the generalized variableφ into the functional of free energy. Such a generalization of the model is shown to include the effect of internal stresses in the region of a potential earthquake source and takes into account the fact that the origination of a potential source changes the stress state in its vicinity. This work was funded by Russian Basic Research Foundation (grant 03-05-64016a)