Triggering and driving mechanisms of earthquake swarm

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Earthquake swarms usually occur in volcanic areas, geothermal fields and oceanic ridges. Detailed seismological observations suggest that swarm activity is driven by the flow of fluid, at least, at an initial stage of activity (e.g.,Yukutake et al., 2011). Hence, it is believed that high-pressure fluids are involved in the generation of earthquake swarm. However, recent geodetic observations suggest a possibility that aseismically evolving fault drives earthquake swarm activity (e.g., Takada and Furuya, 2010). Aseismic slip is, however, known to be induced by the injection of high-pressure fluid (e.g., Scotti and Cornet, 1994), so that aseismic slip evolution may be related to the existence of high-pressure fluid. It will therefore be indispensable to assume high-pressure fluid in the modeling of earthquake swarm. We may be able to consider the following two contrasting models (models 1 and 2) for the triggering and driving of earthquake swarm if the medium is saturated with fluid. Substantial local pressurization of pore fluid is assumed in model 1. If the crustal stress is near a critical level, ruptures triggered by the fluid pressurization will soon begin unstable growth according to linear fracture mechanics. Such ruptures will be regarded as ordinary earthquakes. Hence, we will have to assume highly under-stressed media and long-sustained supply of high-pressure fluid in model 1. However, model 1 has a weakness that how aseismic slip evolution is coupled with swarm activity is not clear. Although we do not assume local pressurization of fluid or highly under-stressed media in model 2, the fault zone is assumed to be permeated with high-pressure fluid. In such model, we will have to introduce some mechanism to suppress the accelerated rupture growth. One of the mechanisms that have strong compatibility with the existence of high-pressure fluid will be slip-induced dilatancy coupled with fluid flow, which is introduced in model 2. If the slip-induced dilatancy plays a dominant role, we do not necessarily require the local pressurization of fluid to trigger earthquake swarm. What is required for the triggering is the occurrence of small-size seed event. Fluid pressure lowers suddenly in the slip zone concurrently with the occurrence of the seed event if the degree of slip-induced dilatancy is large enough. Since the decrease in the fluid pressure raises the friction, the seed crack does not begin the growth soon after the nucleation. However, the dilatancy induces the fluid inflow from the surrounding medium, which gradually elevates the fluid pressure in the slip zone. This can trigger and drive the aseismic extension of slip zone if the stress state is near a critical level. The rate of aseismic extension depends on the balance between the fluid inflow rate and degree of slip-induced dilatancy. Spatial heterogeneity in the degree of slip-induced dilatancy or fracture strength gives rise to small-scale dynamic events, which will be a model for seismic swarm activity. We theoretically study the generation mechanism of earthquake swarm, assuming model 2, in this study. We analyze quasi-static extension of 2D crack in a linear poroelastic medium saturated with fluid. The dilatancy is assumed to increase with the slip evolution. We assume near-critical stress state, Coulomb's friction coupled with the effective normal stress and Darcy's law for the fluid flow. Our calculation shows that the moment evolution is proportional to t**1/2 for any values of the model parameters, which contrasts with the classical solution for dynamic crack growth, which is proportional to t**2 (Kostrov, 1964), where t is time. The expansion rates of aseismic slip zone are larger for higher diffusivities and lower degree of dilatancy. If the slip-induced dilatancy is locally negligible, small-scale dynamic slip is triggered at the advancing edge of aseismic slip zone, which is regarded as the occurrence of seismic event.

Keywords: earthquake swarm, fluid, dilatancy