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Stress rate dependency and effect of volatile element on seismicity of volcano-tectonic earthquakes

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Even in a quiescent period, magma is charged and discharged intermittently beneath volcanoes, and volcano-tectonic earthquakes often occur with ground inflation that is caused by upward migration of magma. Moreover, an increasing volatile element sometimes leads an increasing seismicity. Therefore, it is well known that the seismicity around a volcano is one of the well-established indicators of volcanic activities. Many evidences show that increasing seismicity is followed by volcanic eruptions or magma intrusions because magma migration makes large stress change. On the other hand, the increasing seismicity does not always result in volcanic eruptions. We need to evaluate seismicity quantitatively and discriminate some kinds of effects that generate earthquakes. At present, research in this field has not been established well. It is partly because we cannot propose the model that express temporal variation of seismicity quantitatively, and we do not have enough observation data except some volcanoes where dense observation networks are installed multi-disciplinary.

We proposed to apply the Rate and State Friction (RSF) law to the seismicity occurring at Izu Oshima volcano where dense GPS network as well as seismic one are installed. At the volcano, stress rate changes are observed every 1 to 2 years because of the intermittent magma charging and discharging processes. We presented in last fall meeting of volcanological and seismological society that a simple RSF law model cannot reproduce the observed seismicity fully. We try to revise the model and get remarkable improvement. Aim of this presentation is to reveal the effect of stress rate as well as the other effect, such as volatile element emitted from magma that affect the seismicity around volcanoes, and demonstrate that the seismicity has large potential to monitor the condition not only in the stress rate but also in the volatile density beneath volcanoes.

In Izu-Oshima volcano, seismicity is well correlated with stress rate caused by magma accumulation except the period after the long-term inflation is weaken in 2011. In several volcanoes, increasing volatile component causes decreasing normal stress at fault plane in seismogenic zone and earthquakes are generated intensely (e.g. Northern Volcanic Rift zone in Iceland, La Fossa volcano in Italy). The weakened inflation means that fresh magma is less supplied and emission of volatile decreases in Izu-Oshima volcano. Therefore, we added the effect of the increasing and decreasing volatile element in the previously proposed RSF law, and revised the model. Finally, we can complete successfully the revised model that realize the observed seismicity for all analyzed period.

In conclusion, temporal variation in seismic activity around volcano is mainly due to changes in stress field generated by the magma accumulation and partly caused by effect of volatile element that affects the confining pressure of the fault surface at seismogenic zone. The effect of the stress field is well modeled by ordinary RSF law, and its parameters can be estimated from the data in quiescent period. If observed seismicity exceeds the level that estimated from the model, the volatile element much emitted from magma and it may be precursor to the volcanic eruptions. Therefore, the difference between observed seismicity and the calculated one based on the RSF law is one of the powerful indicator to forecast volcanic eruptions. We propose that there are two kinds of earthquake generating mechanisms around the volcano. Further study at other volcanoes will be helpful to understand the volcano-tectonic earthquake systematically. In future, we should examine the model from direct observation of volcanic gas at volcanoes.

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Keywords: volcano-tectonic earthquakes, seismicity, stress rate change, ground deformation, volatile element