Geophysical Research Abstracts
Vol. 17, EGU2015-9309, 2015
EGU General Assembly 2015

Numerical Stress Field Modelling: from geophysical observations toward volcano hazard assessment

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We propose numerical approaches to evaluate ground deformation caused by hydrothermal fluid circulation and pressurization of magma chambers. Our aims are focused on the developing of advanced numerical models for interpreting the observed ground deformation and evaluating the conditions leading to volcano unrest. Deformation of volcano edifice is traditionally interpreted as being induced by pressure change within a finite source, though it has also been suggested that hydrothermal fluid circulations may play an important role. To investigate both processes, numerical procedures are implemented to estimate the expected changes in stress and strain fields generated by magmatic overpressure and hydrothermal activity.

Firstly, we conduct a stress-strain analysis in an inelastic medium, to determine the favorable conditions for magma chamber failure in different source geometries, reference stress states, failure criteria, rock rheologies and topographic profiles. The numerical results allow us to pinpoint the conditions promoting seismicity, ground deformation and flank instability. The stress-strain analysis provides hints about the favourable conditions which lead to magma chamber wall rupture and the onset of magma migration toward the surface.

Secondly, we implemented a thermo-poroelastic model to evaluate ground deformation, caused by hydrothermal fluid circulation. The numerical model is fully coupled with TOUGH2, a commercial software simulating multi-phase and multi-component fluid flow and heat transfer. The two-way coupling is performed through: (i) the concept of effective stress, which is controlled by pore pressure and thermal expansion, and (ii) empirical expressions for porosity, permeability, and capillary pressure, which are dependent on the effective stress. Based on poroelasticity theory and the definition of failure criteria, stress and strain fields are evaluated to define the regions of the volcano edifice more likely to fail and displace. Numerical results show the contribution of groundwater head gradients associated with topographically induced flow and pore-pressure changes, providing a quantitative estimate for deformation and failure of volcano edifice.

The comparison between the predictions of the model and the observations can provide valuable insights about the stress state of the volcano and, hence, about the likelihood of an impending eruption. This innovative approach opens up new perspectives in geodetic inverse modelling and poses the basis for future development in a volcano hazard assessment based on a critical combination of geophysical observations and numerical modelling.