Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SVC46-10 Room:304 Time:May 25 09:30-09:45

Model of phreatic eruptions inferred from the 2014 eruption of Ontake Volcano

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A phreatic eruption (phreatic explosion) happened at Ontake Volcano on September 27, 2014 accompanied by more than 50 casualties including mountain climbers who were caught by volcanic smokes or hit by volcanic bombs. Phreatic eruptions often occur in many active volcanoes but what causes them is less understood compared with magmatic eruptions for some reasons as smaller scales and less influence to people. For that phreatic eruption of Ontake Volcano video images and deformation data that revealed basic natures of the eruption were obtained. Based on these data the present paper proposes a model that may be useful for a better understanding and simulation of eruptive processes.

A video camera at Takigoe Observation Point, Ministry of Land gave an interesting image about initial features of the Ontake eruption that began about 11: 55 a.m. even if the eruption point itself was obscured by clouds. In the summit area with weak fumaroles the eruption suddenly emitted voluminous dark gas, which first flowed down about 3 km long as a pyroclastic flow and then ascended as a plume. The plume reached the height up to 8 km above the sea level according to a radar measurement. Another video image taken from a helicopter about 2:00 p.m. showed that the plume was substantially weakened and split into several separate gas flows.

The gas that was emitted at an early stage of the eruption was very dark and moved down as a pyroclastic flow so that it should have contained abundant solid particles with a higher density than the air. Rich solid particles in the gas explain lots of volcanic bombs and thick ash deposits actually observed near the summit. The gas flow is understood to have turned to a plume when it deposited part of solid particles. It is likely that solid particles were generated by erosion of the permeable layer through which steam migrated to the surface and that resultant high permeability allowed the steam to flow violently out during the eruption.

The tilt data obtained at Tanohara Observation Point, Japan Meteorological Agency gives another important constraint on the eruption process. The data revealed that inflation first took place below the eruption point during about 7 minutes and then contraction followed as soon as the eruption started.

The inflation prior to the eruption was likely caused by increase of vapor in the underground water system. Simple vaporization, however, cannot produce inflation because successive vaporization is suppressed by pressure increase. Inflation often arises in volcanoes when some material ascends under gravity. Here, the process in which steam bubbles generated at the bottom ascend through the ground water is considered. The bubble formation may result from a thermal instability due to heat supply to the bottom consistently with no significant seismicity observed with the inflation.

The above idea gives a model of phreatic eruptions in the system of steam overlying ground water. The equilibrium described by an evaporation curve is assumed to hold at the interface between steam and water. The steam flux generated at the bottom of the ground water is prescribed as a function of time. The steam is assumed to migrate to the surface as a permeable flow and the effect of erosion is represented by the change of permeability whose speed is defined by a prescribed function of steam flux and permeability.

In this model pressure, permeability and gas fluxes are calculated as a function of time from a set of ordinary differential equations derived from conservation laws and thermodynamic relations. The differential equations give the solutions that qualitatively reproduce pre-eruptive underground inflation followed by rapid gas effusion during the eruption if constants and initial values of variables are suitably prescribed..

Keywords: phreatic eruption, phreatic explosion, Ontake Volcano, pyroclastic flow, crustal deformation, computer simulation