The possibility of rapid and huge magma accumulation in the crust from dynamical point of view

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As much as 100s-1000s km^3 magma eruption in a single event (Machida & Arai, 1992) proves huge magma accumulation in the crust before eruption. Moreover, Takada (1999) indicates several times as much as erupted magma may accumulate in the crust from ratio of erupted volume to accumulated volume. Although the magma accumulation rate for caldera eruption can be calculated to be 0.001-0.01 km^3/year on average (Salisbury et al, 2011), its accumulation process has not clearly understood yet (Jellinek & DePaolo, 2003).
Druitt et al. (2012) examined composition of some plagioclases from Santorini volcano which emitted 40-60 km^3 of magma and concluded that a few km^3 magma were added to a magma chamber in about 100 years. This rapid magma accumulation rate is about 0.01-0.1 km^3/year, ten times as large as foregoing one. This result can be crucial for volcanic eruption prediction because the accumulation may cause large scale crustal deformation. However, this petrological result has not been examined whether it also meets the dynamic constraint or not. In order to clarify this point, our study intends to estimate the maximum magma volume that the crust can accumulate in short time by using FEM (Marc Mentat). The crust is assumed as an elastic body since about 100 years is relatively short time compared with Maxwell relaxation time of the crust.
In our analysis, we inflate the magma chamber by pressuring chamber wall and compared the resulted strain around it with the ultimate strain of the crust 10^{-4}-10^{-5} (Rikitake, 1975). Our hypothesis is that two of the influential parameters involving large magma accumulation may be magma chamber shape and a magma chamber volume that has already existed before a new magma is added (hereinafter called, “primary volume”). Therefore, the calculation was carried out for spherical magma chamber and spheroid-shaped sill which have 100-2000 km^3 of primary volume, respectively. The upper depth of magma chambers are fixed at 5 km depth (Yasuda et al., 2015); that is, the central depth of these chamber are different between models. We assumed that the surface of the Earth to be free surface, the crust to be isotropic and homogeneous, $\lambda = \mu = 40$ GPa (Mogi, 1957), and ignored the gravitational effect. In addition to this numerical calculation, we also computed two analytical formulae as a reference, Mogi model (Mogi,1958) for spherical chamber and tensile fault model (Okada,1992) for sill, under the same condition. Note that these models are only applicable on the condition that primary chamber volume are very small.
As a result, maximum shear strain exponentially decreased as primary volumes increase in both types of chambers, and the maximum value was obtained at the analytical solution. Fig.a.b shows the maximum shear strain on the surface caused by an expansion of magma chamber which has 2000 km^3 of primary volume. For both models, volume increment was proportional to the maximum shear strain, while sill had smaller intercept for same volume increment. This result means that sill-shaped magma chamber has larger potential for magma accumulation than spherical chamber when same volume of magma accumulates. However, even the primary volume is as large as 2000 km^3, the strain derived from more than 1 km^3 volume increment exceeds the ultimate strain of the crust. Generally, when a strain is bigger than the ultimate strain, the crust cannot be dealt as an elastic body because the crust around magma chamber yields or causes brittle fracture; that is, we think that the discussion which considered plastic deformation or brittle fracture is necessary when we illustrate the crustal deformation in case that a few km^3 of magma accumulate in about 100 year which Druitt et

al. 2012 proposed, regardless of the difference of magma chamber shape or variety of primary volume.

Keywords: large volcanic eruption, magma accumulation, crust, strain, stress, caldera

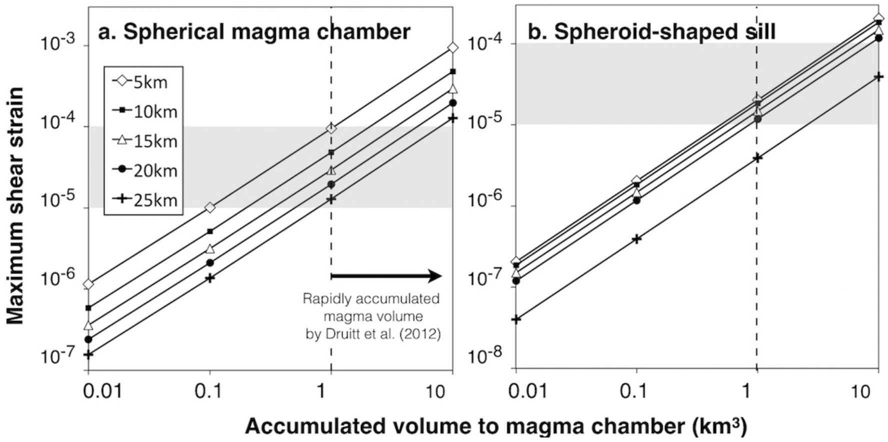

fig. a, b

The maximum shear strain in the surface versus volume increment for **a. Spherical magma chamber** (radius 7.8 km·central depth 12.8 km·upper depth 5 km) and **b. Spheroid-shaped sill** (aspect ratio 10 : 10 : 1· major radius 16.8 km·minor radius 1.68 km·central depth 6.68 km·upper depth 5 km). Primary volume is 2000 km^3, respectively. The distance starts and radially directed from immediately above the chamber in the surface. The shaded region shows the probable range of the ultimate strain of the crust and the region to the right of the dash line indicates the rapid magma accumulation volume by Druitt et al. (2012).