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Collapse caldera shape caused by a single sphere magma chamber in anisotropic homogeneous regional stress field

Shigekazu Kusumoto[1*], Toshiyasu Nagao[2]

[1]Grad. Sch. Sci. and Eng. Univ. Toyama, [2]EPRC, Inst. Ocean. Res. Dev. Tokai Univ.

We derived a fundamental solution giving caldera shape caused by a single magma chamber in an isotropic or anisotropic homogeneous regional stress field of which stress ratio between horizontal maximum and minimum principal stresses is constant.

In nature, many calderas are elliptical in shape and lie in extensional and compressive regional tectonic settings (e.g., Taupo, Taal, Valles, Long Valley, Campi Flegrei). As reasons which calderas have elliptical, we can cite (1) horizontally elongated magma body due to regional stresses in the crust, (2) the effects of far-field stresses, and (3) overlap of several collapse structures, each of which is related to an individual collapse event and possibly also associated with a discrete magma chamber. In this study, we attempted to investigate the effects of far-field stresses in caldera formation by analytical method. In order to simplify mathematical treatment of the problems, we assumed that the magma chamber is a small sphere, and approximated the collapse of the chamber to contraction (volume change).

The fundamental solution giving caldera shape caused by a single magma chamber in regional stress field was derived by evaluating the surface stress field due to volume change of magma chamber and the regional stress field by the Coulomb failure criteria. We estimated the shape of caldera by solving the derived equation numerically, because it was difficult to solve the equation algebraically.

We first estimated the shape of caldera without any regional stress field. As a result, caldera was formed as circular shape. This supports the existing results given by many analogue experiments and numerical simulations (e.g., Komuro et al., 1984; Komuro, 1987; Marti et al., 1994; Gudmundsson et al., 1997; Acocella et al., 2000; Roche et al., 2000; Kusumoto and Takemura, 2003). Under the condition that the regional stress field was isotropic compression, caldera was formed as circular shape, but its radius is smaller than radius of caldera without the regional stress field. On the other hand, under the anisotropic compressive stress field, caldera was formed as elliptical shape elongating to the direction of the maximum compressive stress axis. Under the anisotropic extension stress field, caldera was formed as elliptical shape elongating to the direction of the maximum extension stress axis. This supports the results given in analogue experiments by Holohan et al. (2005).

Not only elastic and strength constants of the crust but depth and volume change of the magma chamber and information (stress ratio and magnitude of the horizontal maximum principal stress regional stress field) on regional stress fields were included explicitly in the fundamental equation. We evaluated effects that these factors would give the shape of caldera, and it was found that the stress ratio and the magnitude of the horizontal maximum principal stress would play an important role in determination of caldera shape in the anisotropic homogeneous regional stress field.

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[References]

Acocella et al., 2000, JVGR; Gudmundsson et al., 1997, GRL; Holohan et al. 2005, JVGR; Komuro et al., 1984, BV; Komuro, 1987, JVGR; Kusumoto and Takemura, 2003, GRL; Marti et al., 1994, JGS; Roche et al., 2000, JGR.