



# The role of pre-existing tectonic structures and magma chamber shape on the geometry of resurgent blocks: Analogue models



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## ARTICLE INFO

### Article history:

Received 6 September 2013

Accepted 24 December 2013

Available online 3 January 2014

### Keywords:

Analogue model

Collapse caldera

Resurgence

Magma chamber

Extensional tectonics

## ABSTRACT

A set of analogue models has been carried out to understand the role of an asymmetric magma chamber on the resurgence-related deformation of a previously deformed crustal sector. The results are then compared with those of similar experiments, previously performed using a symmetric magma chamber. Two lines of experiments were performed to simulate resurgence in an area with a simple graben-like structure and resurgence in a caldera that collapsed within the previously generated graben-like structure. On the basis of commonly accepted scaling laws, we used dry-quartz sand to simulate the brittle behaviour of the crust and Newtonian silicone to simulate the ductile behaviour of the intruding magma. An asymmetric shape of the magma chamber was simulated by moulding the upper surface of the silicone. The resulting empty space was then filled with sand. The results of the asymmetric-resurgence experiments are similar to those obtained with symmetrically shaped silicone. In the sample with a simple graben-like structure, resurgence occurs through the formation of a discrete number of differentially displaced blocks. The most uplifted portion of the deformed depression floor is affected by newly formed, high-angle, inward-dipping reverse ring-faults. The least uplifted portion of the caldera is affected by normal faults with similar orientation, either newly formed or resulting from reactivation of the pre-existing graben faults. This asymmetric block resurgence is also observed in experiments performed with a previous caldera collapse. In this case, the caldera-collapse-related reverse ring-fault is completely erased along the shortened side, and enhances the effect of the extensional faults on the opposite side, so facilitating the intrusion of the silicone. The most uplifted sector, due to an asymmetrically shaped intrusion, is always in correspondence of the thickest overburden. These results suggest that the stress field induced by resurgence is likely dictated by the geometry of the intruding magma body, and the related deformation is partially controlled by pre-existing tectonic and/or volcano-tectonic structures.

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## 1. Introduction

Caldera collapse and resurgence are quite common phenomena, recognized worldwide and usually interpreted as generated by regional tumescence, major eruption, caldera collapse and intracaldera resurgent doming, which is commonly related to inflation–deflation processes in magma reservoirs (Smith and Bailey, 1968; Henry and Price, 1984; Lipman, 1984, 1997; Newhall and Dzurisin, 1988; Orsi et al., 1996, 1999a; Di Vito et al., 1999).

In the past few decades, analogue modelling has been carried out by many authors, using variable methods, to investigate caldera collapse and resurgence mechanisms and structures (Withjack and Scheiner, 1982; Komuro et al., 1984; Komuro, 1987; Marti et al., 1994; Merle and Vendeville, 1995; Roman-Berdiel et al., 1995; Benn et al., 1998; Kennedy et al., 1999; Acocella et al., 2000a, 2001; Roche et al., 2000; Walter and Troll, 2001; Troll et al., 2002). However, after the pioneering work of Withjack and Scheiner (1982), almost all these authors only

modelled the effects of the near-field stress induced by the intrusion, and did not consider the possible role of a far-field (i.e. regional) stress, in terms of pre-existing regional structures (inherited strain), which may influence the propagation of the stresses or also be reactivated during collapse and resurgence, or in terms of direct control (simultaneous stress) on the geometry of collapse calderas and resurgence. Although most calderas are located in extensional tectonic settings, more recent experiments tried to simulate collapse and resurgence in a crustal sector with both an inherited extensional or compressional strain, responsible for the pre-existence of regional structures (Acocella et al., 2004; Holohan et al., 2005). A very few analogue models have been performed in order to investigate the role of magma chamber geometry on the structure of collapse calderas (Acocella et al., 2004; Holohan et al., 2008).

The most relevant results of these studies suggest that high-angle reverse faults border calderas and resurgent areas, whereas normal faults form subsequently as a result of gravitational readjustment (Acocella et al., 2000a, and references therein). Resurgence is the uplifting of a portion of a caldera floor, due to the injection of new magma into the system. It may form asymmetric resurgent blocks

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(Orsi et al., 1991; Acocella and Funiciello, 1999) or domes (Smith and Bailey, 1968; Bailey et al., 1976; Lipman, 1984; Self et al., 1986) depending on the thickness/width ( $T/W$ ) ratio of the crust overlying the magma chamber: resurgent blocks form for  $T/W \sim 1$ , whereas domes form for  $T/W \sim 0.4$  (Acocella et al., 2001). The elliptical shape of calderas and resurgent blocks may develop even with circular magma chamber, and is the result of the interplay between newly formed structures and partial or total reactivation of pre-existing faults. Moreover, the presence of previously formed extensional structures, strongly influences the geometry of the resurgent block and the kinematics of resurgence, which occurs through the formation of a discrete number of differentially displaced blocks, the most uplifted of which is bordered, along one side, by inward dipping reverse faults. Normal faults with similar orientations form on the opposite side together with the reactivation of one or more pre-existing faults (Acocella et al., 2004).

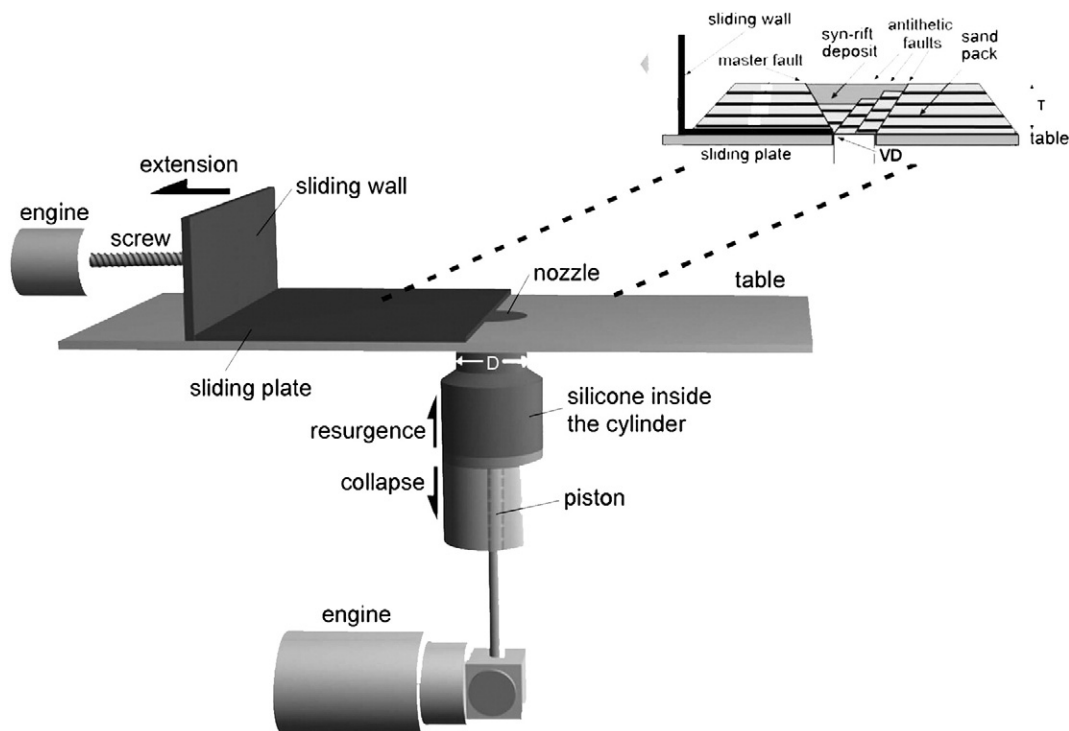
Here we report the results of a new set of analogue models that ideally represent the continuation of the experiments performed by Acocella et al. (2004). This modelling has been carried out in order to simulate resurgence in an extensional setting, with different configurations of the magma chamber top surface, aimed at better understanding the effects of different magma chamber geometries on the structure of the resurgent block. This is the first attempt to reproduce the local stress field induced by the asymmetric intrusion of magma at shallow depth in a strongly fractured crustal sector (both affected or not by previous caldera collapse), which ultimately can account for the differential displacement of blocks in the resurgent portion of a caldera and the distribution of volcanic vents at surface (e.g. Ischia, Pantelleria and Campi Flegrei calderas in Italy; Orsi et al., 1991, 1996, 1999a; Di Vito et al., 1999; de Vita et al., 2010).

According to scaling laws (Appendix A), dry-quartz sand and Newtonian silicone putty have been used as analogue materials to simulate the brittle behaviour of the Earth's crust and the ductile behaviour of magma, respectively (Acocella et al., 2000a, 2001, 2004). We compared our results with those obtained (using the same materials and similar methods) by previous experiments performed to simulate caldera resurgence in a non-deformed crustal sector with both symmetric (Acocella et al., 2000a) and asymmetric (Acocella et al., 2001) intruding magma body, and in a previously deformed crustal sector with a symmetric intruding magma body (Acocella et al., 2004). Moreover, we compared our experimental results with available data on natural resurgent calderas.

## 2. Experimental equipment and procedure

Following Acocella et al. (2004), the experimental equipment includes two superimposed machines used to simulate extension and collapse or resurgence in a stratified sand-pack. Extension is controlled by a mobile plate that slides at a constant velocity along the table surface. Collapse or resurgence are generated by the downward or upward movement of a piston accommodated inside a silicone-filled cylinder (Fig. 1).

The upper surface of the silicone in the cylinder was hand moulded to simulate an asymmetric intrusion starting from one side of the magma chamber (Fig. 2a). The resulting empty space above the silicone was filled with sand up to the table surface (Fig. 2b). Two different sets of experiments were performed, starting from two different geometrical configurations of the magma chamber, which generated an asymmetric strain field in the overlying sand-pack. In the first configuration



**Fig. 1.** Sketch of the experimental equipment. The first component (Acocella et al., 2000b and references therein), includes a few mm-thick plate that slides at a constant speed upon the surface of a table, in which a hole connects to the second part. The sliding plate is fixed to a vertical wall, which is in turn connected to an engine through an endless screw. This plate has been suitably placed upon the second component of the equipment, used for simulating collapse and/or resurgence (Acocella et al., 2000a, 2001), which consists of a piston, accommodated inside a silicone-filled cylinder, whose nozzle lies underneath the hole in the Table. A constant diameter  $D = 5$  cm of the nozzle has been imposed in our experiments. The piston is connected to a second engine, which can be pulled down to simulate collapse, or pushed up to simulate resurgence. A sand model simulating the brittle crust, was built partly on the sliding plate and partly on the table. The thickness of the sand-pack ( $T$ ) was fixed at 5 cm for all the experiments on the basis of the results of previous experiments (Acocella et al., 2000a, 2001, 2004). These experiments showed that the deformation pattern induced by collapse and/or resurgence in a previously deformed sand-pack, with a  $T$  value between 3 and 7 cm, is unrelated to the overburden thickness but depends on both the amount of extension and position of the extensional faults, relative to the caldera and/or resurgence faults.  $D$  = nozzle diameter;  $T$  = sand-pack thickness;  $VD$  = velocity discontinuity.

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