Unrest and Eruption at Large Calderas: Campi Flegrei, Southern Italy

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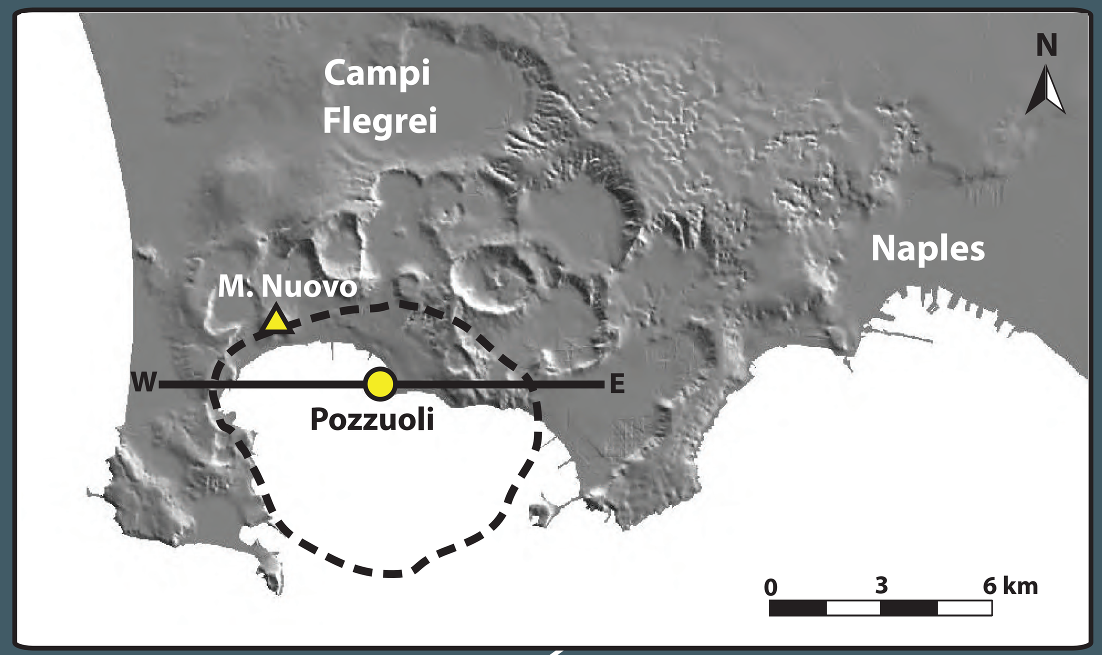
1 Introduction

Campi Flegrei in Southern Italy is one of the most populated calderas on Earth (Fig. 1). After a repose of 400 years, renewed unrest began in 1950, since when it has continued intermittently, uplifting the town of Pozzuoli, at the centre of the caldera, by more than 3 m.

Similar behaviour was observed before Campi Flegrei's only historical eruption, which produced Monte Nuovo in 1538. The eruption occurred after 17 m of ground uplift at Pozzuoli [1]. A crucial goal for emergency management is to determine whether uplift at Pozzuoli must again reach 17 m before an eruption is likely.



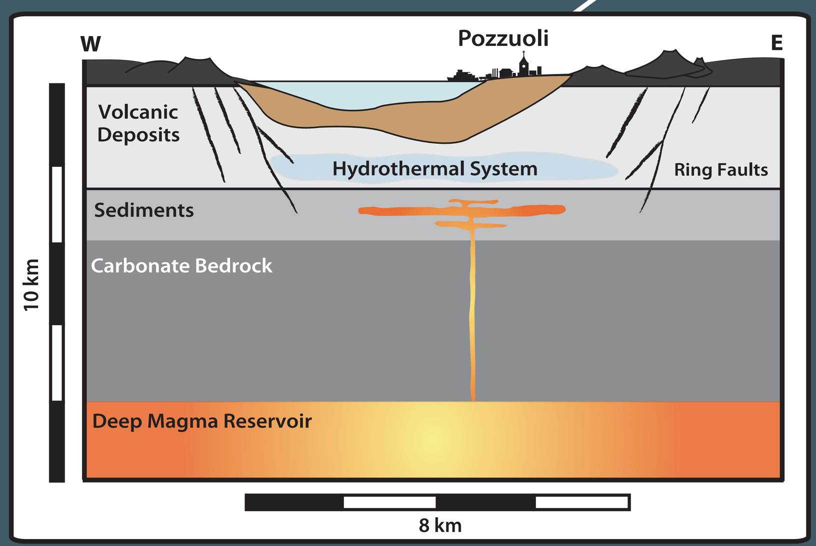


Figure 1. Campi Flegrei caldera. Inset: Campi Flegrei's shallow magmatic system, defined by volcanic deposits (*pale grey*), sediments (*mid grey*) and carbonate bedrock (*dark grey*); volcanic deposits filling the caldera are shown in *brown* [2], and sills in *orange* [3] are fed from a deeper magma reservoir at 7-8 km depth. The ring faults shown were formed during the last caldera forming eruption 15.6 ka BP.

The episodes of recent uplift are consistent with the repeated intrusion of sills at 3 km depth beneath Pozzuoli (Fig. 1) [3]. To investigate conditions for accommodating uplifts of 17 m, we have used the finite-element modelling software COMSOL Multiphysics to simulate the stress fields and displacements generated by a single sill at 3 km depth. The sill is modelled as a uniformly pressurised elliptical cavity in a 2D-axisymmetric domain (Fig. 2). Simulations were run for both a homogeneous and layered elastic-brittle crust [2; 4]. A third set of simulations permitted slip between crustal layers [5].

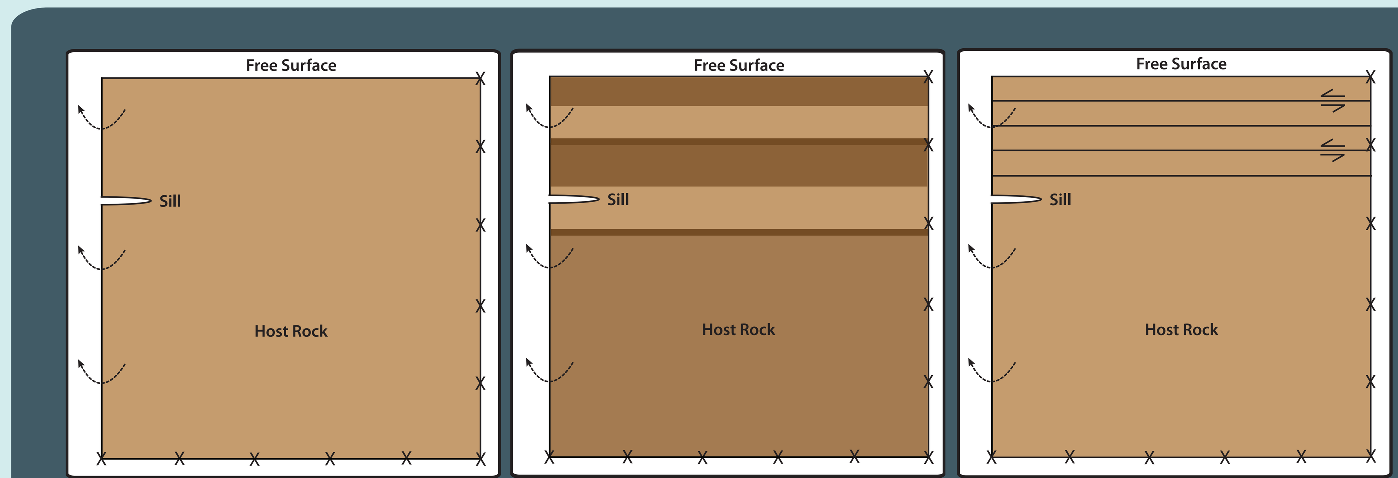


Figure 2. The setup used to benchmark the sill models. Simulations were run for a homogeneous elastic-brittle crust (*left*), and a layered crust with elastic properties derived from a 1D velocity model for Campi Flegrei (*middle*) [2; 4]. Simulations were also run for a homogeneous crust divided into layers that were permitted to slip (*right*) [5]. Frictional resistance between the layers is modelled as the equivalent of a stiffness from 0.1-10 MPa m^{-1}. For all models, boundary conditions are fixed for the lower and lateral margins, and free for the upper margin.

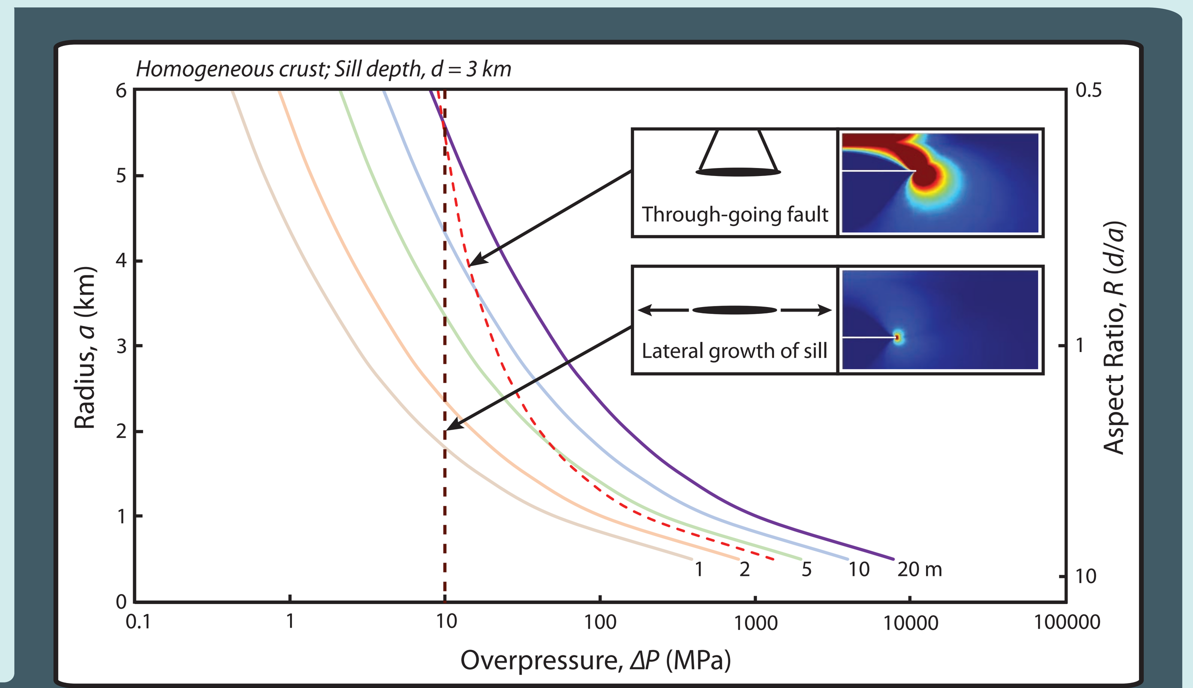
2 Results

In all cases, we have considered two limiting conditions for critical failure before eruption: (1) total failure of the roof, when a new fracture extends between the sill and the surface, and (2) the upward growth of a sill to the surface [6].

Roof-failure triggered eruption

An eruption occurs when a through-going fault connects magma in the sill to the surface [6].

For both the homogeneous and layered elastic-brittle crust, a through-going fault can occur after a minimum uplift of 17 m, provided the sill radius exceeds 5.5 km (Fig. 3).



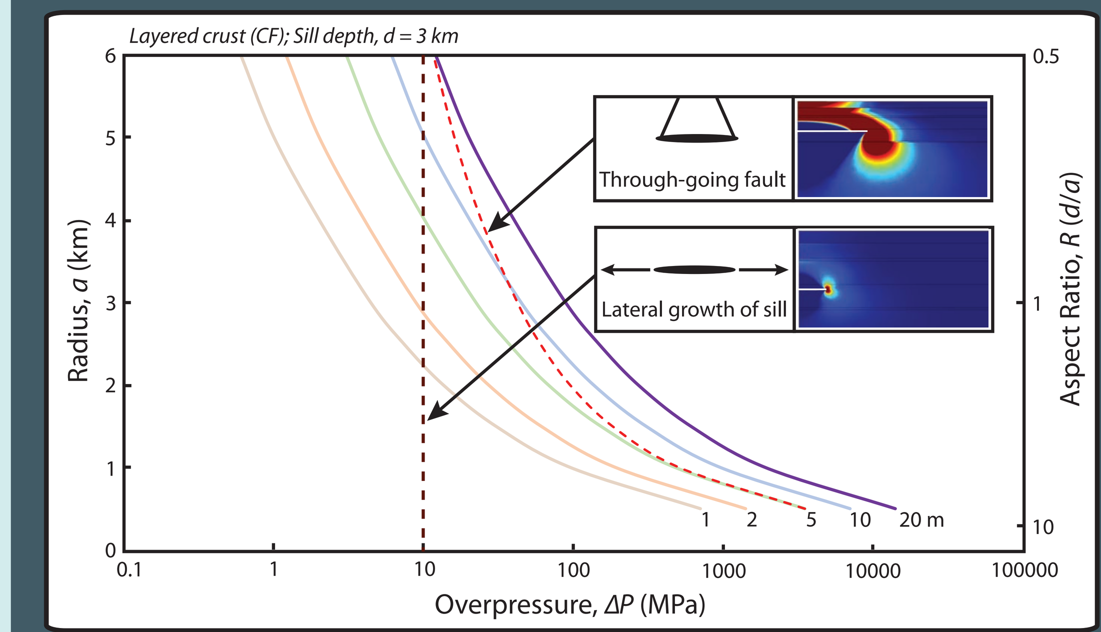
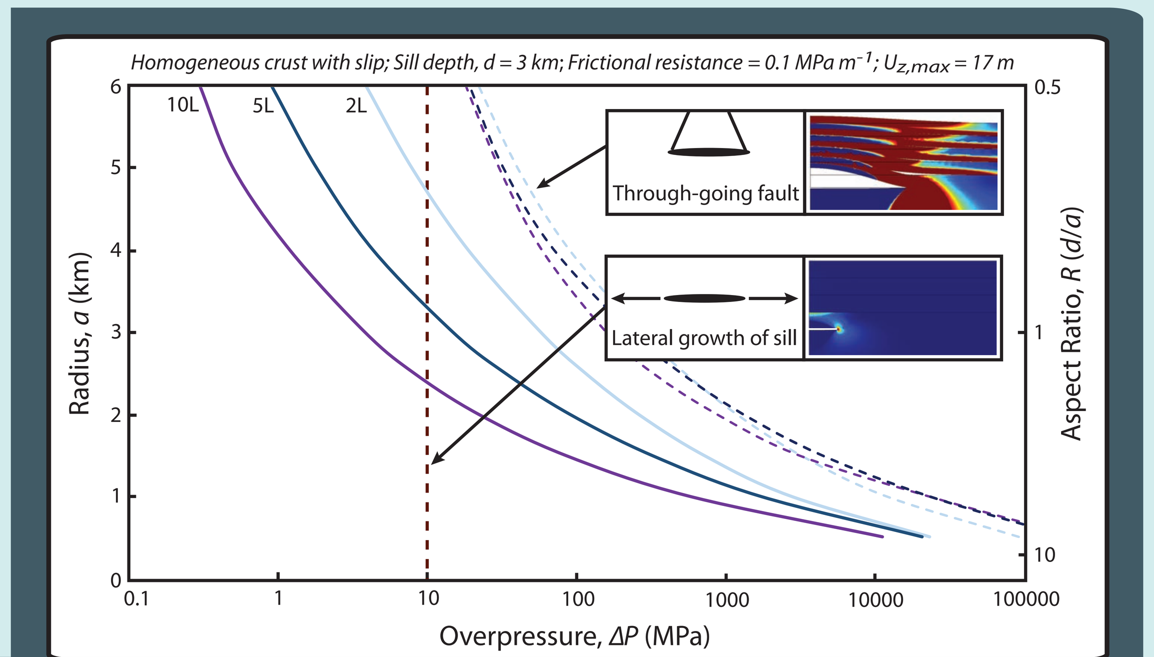


Figure 3. For an uplift of 17 m, a through-going fault (*red dashed line*) in both a homogeneous crust (*above*) and a layered crust (*left*) can only develop when the sill radius $a \geq 5.5$ km. All models are constrained by a maximum overpressure $\Delta P = 10$ MPa (*brown dashed line*), which signifies the loading required to propagate the sill laterally, and a maximum of 9 MPa for the tensile strength of the crust.

Such a sill would have extended beneath the whole of the caldera and have a volume of at least 0.6 km^3, 30 times the volume of the 1538 eruption. Neither condition is consistent with observations.

Slip along sub-horizontal discontinuities allows a greater amount of uplift to be accommodated before total failure of the overburden (Fig. 4).

However, a through-going fault only develops after uplifts significantly greater than 17 m, so that slip would have inhibited a roof-failure triggered eruption for the case of Monte Nuovo.



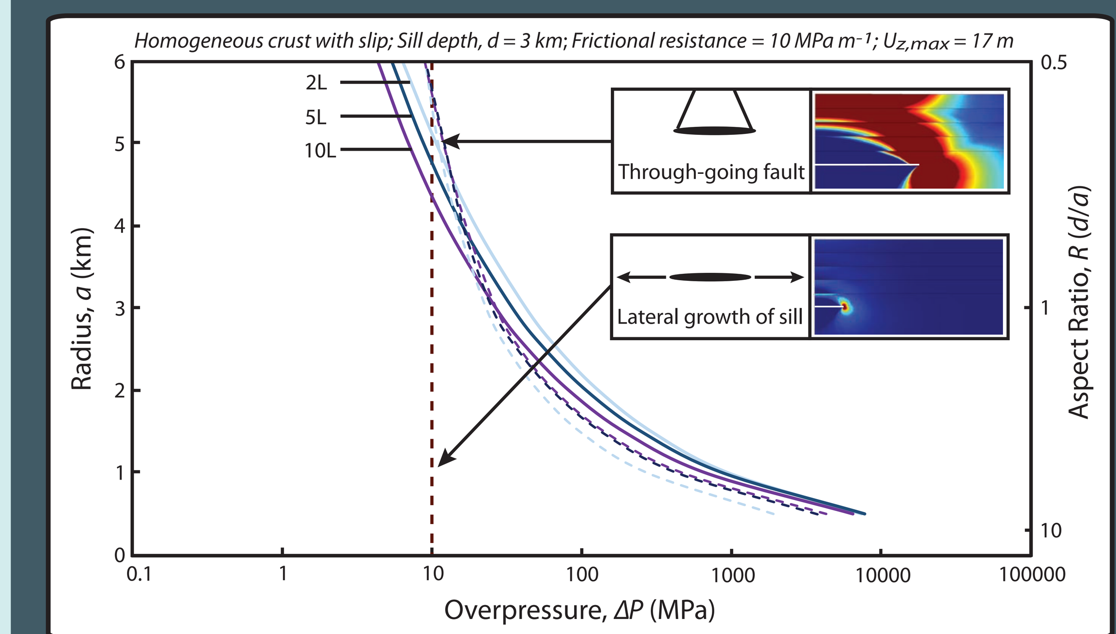


Figure 4. For a crust with sliding layers (*solid coloured lines*), a through-going fault (*dashed coloured lines*) occurs only after an uplift significantly greater than 17 m. Frictional resistance between the layers is modelled as the equivalent of a stiffness of 0.1 MPa m^{-1} (*above*), which represents low frictional resistance *i.e.* conditions close to free-sliding, and 10 MPa m^{-1} (*left*), which represents high frictional resistance *i.e.* strongly bonded layers. Sliding increases the amount of uplift that can be accommodated before total failure of the roof, the amount increasing with a greater number of layers and a lower frictional resistance.

3 More Results

Eruption from the upward growth of a sill to the surface

A sill can propagate to the surface when its radius has exceeded its emplacement depth [7]. In a homogeneous and layered crust, this condition ($d/a \leq 1$) is achieved after uplifts of about 2-4 m. An uplift of 17 m before eruption is possible, but only if the crust is composed of at least 6 layers between which slip can occur (Fig. 5).

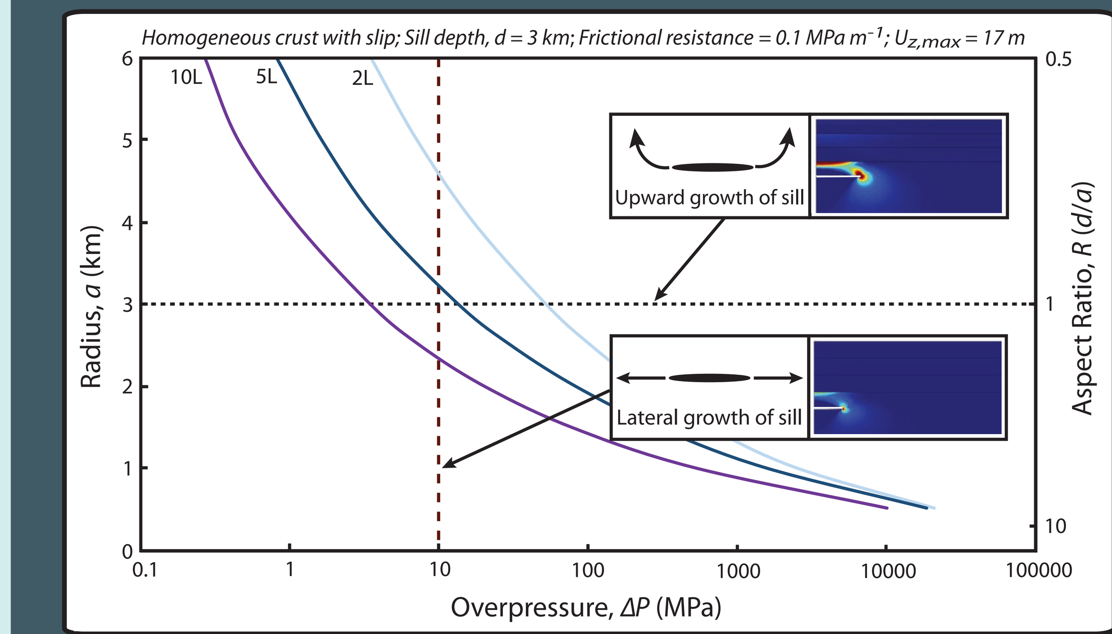
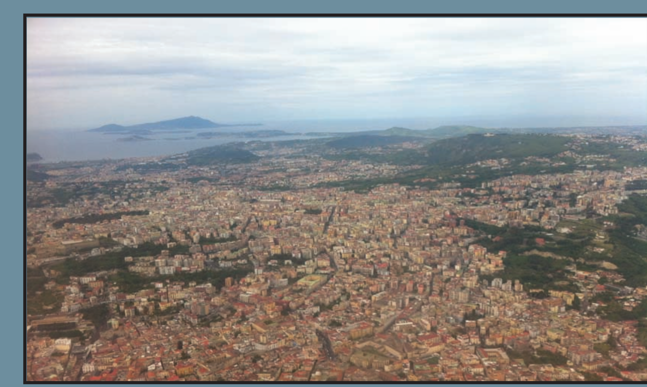


Figure 5. A sill may propagate towards the surface when its radius exceeds its emplacement depth (*black dashed line*). This can occur after uplifts of 17 m only if the crust is able to slip along 6 or more layers. Without crustal slip, a sill may reach the surface after uplifts of 2-4 m.

Looking south-west across Campi Flegrei. The caldera poses a direct threat to its 300,000 inhabitants and the 3.1 million people living in Naples to the East. Recent unrest has raised concern that the volcano is preparing to enter a new phase of eruptive activity (*photo: D. Charlton, 2015*).



4 Conclusions

- An uplift of 17 m before the Monte Nuovo eruption cannot be explained by the growth of a single sill into a homogeneous or layered elastic-brittle crust.

- An eruption after 17 m of uplift may be possible, however, if the crust can slip along sub-horizontal discontinuities.

- An alternative view is that 17 m of uplift requires the intrusion of several sills, each solidifying before a successor is emplaced. The probability of eruption then depends on the probability of an active sill reaching the surface.

- In both cases, an eruption at Campi Flegrei may occur before 17 m of uplift is achieved.

5 References

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More information?

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