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Stress evolution during caldera collapse: a Distinct Element Method perspective

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The dynamics of caldera collapse are subject of long-running debate. Still unresolved questions concern the relationships between: (1) the depletion of the magma reservoir, (2) the state and evolution of stress in the reservoir roof, and (3) the timing and mode of fractures that mark the roof's failure and accommodate its collapse. By means of two-dimensional numerical models based on the Distinct Element Method (DEM), we characterise the evolution of stress states within a mass of rock above a depleting sub-surface magma body, from onset of subsidence through to failure and collapse. We report on relationships between the onset of roof failure, reservoir 'volume' depletion and reservoir 'under-pressure' for varying mechanical and geometric conditions in the roof. We identify four end-member stress paths taken by the roof material on the way to failure and fracture formation. Each stress path corresponds to a particular location within the roof. Fractures associated with ultimate roof failure initiate as shear fractures, rather than opening-mode fractures as was suggested by some past studies. The models also illustrate how changes in the geometry of principal stress trajectories during progressive deformation leads to a transition from initial reverse faulting to later normal faulting. Finally, the models show how the residual friction of faults that bound the down-going roof after failure will, without fluid-derived counter-effects, act to prevent a return to the initial pre-collapse pressure in the magma reservoir.