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New insight into the relationships between stress, strain and mass change at Mt. Etna during the period between the 1993-94 and 2001 eruptions

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During the time interval between the 1991-93 and 2001 main flank eruptions of Mt. Etna, volcanic activity was confined to the summit vents. Ground deformation and tomography studies suggest that this activity was fed by a magma body located beneath the north-west flank of the volcano, at a depth of around 7 km b.s.l.. Conversely, gravity studies indicate that the most important mass redistributions during the same period took place within an elongated volume centered below the southeastern sector of the volcano, at depths of 2–4 km b.s.l.. The phases of gravity decrease during the 1994-2001 period coincide with phases of higher strain release rate.
The coupling between gravity and seismic data could reflect changes in the rate of micro-fracturing along the NNW–SSE weakness zone that cuts the SE slope of the volcano. This interpretation allows to explain why the main pressure and mass sources active at Etna during the 1994-2001 period do not coincide. The extensional dynamics of the southeastern flank of Etna may represent a second-order effect, triggered by the pressure source below the western flank and accommodated along the NNW–SSE weakness zone.
In order to gain quantitative insight into the relationship between stress, strain and mass changes at Etna during the 1994-2001 period, we use a finite element modeling approach. Relying on recent studies involving stress- and temperature-induced degradation of the mechanical properties of rocks, we hypothesize that the inferred NNW–SSE weakness zone is characterized by an anomalously low Young's modulus (E). Results of our analysis are summarized in the following two points.
(i) The presence of the weakness zone creates a distortion of the displacements field induced by the deeper pressure source, locally resulting in a weak extensional regime. This finding supports the hypothesis of a cause-effect relation between deeper pressurization beneath the western flank and shallower extension across the fracture zone beneath the SE flank of the volcano. However, the bulk extension across the weakness zone which is only due to pressurization of the magma reservoir is not sufficient to induce the observed gravity changes through changes in the rate of microfracturing. We suggest that propagation of pressurized gas, enhanced by the extensional regime across the NNW–SSE weakness zone, may have exerted tensile stresses across it, in turn increasing the bulk extension.
(ii) For a given tensile stress across the fracture zone, the bulk extension increases proportionally as the value of E in the weakness zone decreases, while the ground deformation remains almost the same. This provides an explanation to understand how, during the studied period, the inferred changes in the bulk rate of microfracturing along the NNW-SSE weakness zone could have occurred with an associated small ground deformation. Indeed, we found that, as the value of E in correspondence of the fracture zone decreases, the ratio between deep extension and maximum ground displacement increases and, for values of E equal or less than about 10 GPa, deep extension of 1-2 m can develop with deformation of the surface close to the detection limit of GPS measurements.
Our results highlight the importance of performing gravity studies at at volcanoes where there exists a causal link between medium fracturing and volcanic activity.