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Gravity-driven deformation of Olympus Mons volcano, Mars: plate flexure and volcanic spreading studied with finite element models

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Olympus Mons on Mars is an exceptional volcano, not only for its enormous size, but also for its structural inventory that includes faulting and mass movements. It is a basaltic shield volcano with a height of 22 km, a diameter of about 600 km, and an average flank slope of 5°. Its characteristics include a summit caldera complex, upper- to mid-flank terraces, a basal circumferential scarp of up to 8 km height, and widespread lobate deposits that extend several hundred kilometers from the basal scarp into the surrounding plains.

The formation of these major structural elements and association to gravity tectonics remained unclear, however. This study investigated the combined effects of lithospheric flexure and volcanic spreading in the evolution of Olympus Mons. For this purpose, the deformation of an elastoplastic volcanic cone under Martian gravity was simulated with axisymmetric finite element models. To reproduce observed structural complexities, these models were combined with a viscoelastic mantle and a variable coupling-decoupling behaviour at the interface between volcano and underlying lithosphere.

We found that the combination of lithospheric flexure and volcanic spreading is able to account for Olympus Mons upper-flank terraces and basal overthrusting. Terraces are explained with radial compression, with an extent and expression that is related to both lithospheric flexure and the nature of a basal detachment surface. As coupling along the basal detachment decreases, and spreading increases, the zone of flank terracing migrates toward the summit area.

The presence of faults on the shield depends on the edifice cohesion and the time of volcano growth relative to mantle relaxation. To produce surface faults, a high edifice cohesion has to be combined with quasi instantaneous volcano emplacement. When edifice cohesion is an order of magnitude lower, however, an instantaneous volcano emplacement is unnecessary to produce surface faults. For a load growing in equilibrium with a deforming mantle, modelled by allowing for viscous relaxation of the mantle between loading steps, faults can be produced on every incrementally-formed volcano surface. For a large shield volcano made of basaltic rock mass, a growth time of up to millions of years and a low cohesion value are more realistic assumptions in the end.

Therefore, to understand the structural configuration of Olympus Mons, interfingered processes of deformation need to be considered. Flexure, spreading, and other factors may display complexities that significantly alter the position and expression of surface faults, such as those associated with unstable flanks, circumferential scarps and thrust belts, or terraces.