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Modelling of Outflow Activity near the Volcano Hadriaca Patera on Mars

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Introduction

Deep depressions (cavi and chaos) have been identified as source regions for channels (valles) in the vicinity of the volcano Hadriaca Patera, north-east of Hellas Planitia (Fig. 1). Their morphology indicates fracturing and outflow. Moreover, the cavi and the Dao head area seem to be arranged concentrically around Hadriaca Patera. Using finite-element modelling, we want to better understand the formation of these features. We test the idea that flexure of an elastic plate by volcanic loading [1] may induce extension and fracturing in the surrounding of the volcano and allow outflow from a subsurface aquifer (Fig. 2).

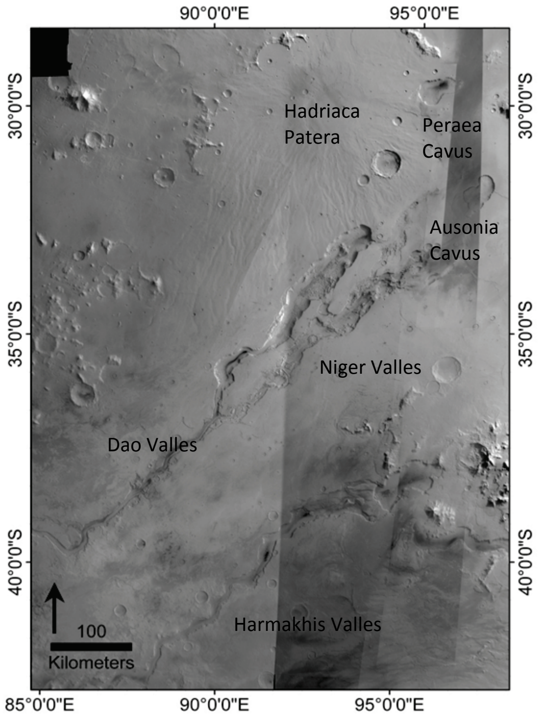

Figure 1: Depressions and channels around the volcano Hadriaca Patera

Modelling

We set up a 2D-axisymmetric model of the Martian crust. A coupled pore-fluid flow and stress analysis is conducted. Long-term fluid behaviour of the mantle underlying the plate loading is modeled using elastic springs. The time-dependent model is divided into several steps: The first step is to verify that the geostatic stress field due to gravitational loading (without volcanic loading) is in equilibrium with applied loads and boundary conditions. Further 3 steps represent different episodes of volcanic activity 3.9, 3.7 and 3.5 Ga ago [2]. Another step simulates the crustal fracture and outflow activity.

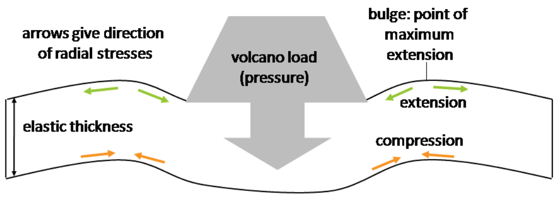

Figure 2: Sketch showing the flexure and subsequent stress field of an elastic plate due to volcanic loading

Parameters

For the example shown here and according to the age of the volcano (Noachian to Hesperian) we choose an elastic thickness of the crust of 20 km as found by [3]. The thickness of near-surface frozen ground at that time is ~1 km [4]. The final topography of the volcano has a 1 km height and a 150 km radius. The degree of confinement at the base of the permafrost layer is not well constrained, therefore we assume an initial hydrostatic gradient. In the last step, fracture and outflow are simulated by applying a zero pore pressure on a vertical line of nodes down to 5 km depth, where stresses are maximum tensile at 226 km distance from the axis of symmetry. The initial porosity is taken as 0.1 up

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to a depth of 20 km. Due to gravitational loading or compaction in the first step, the porosity decreases along depth. The permeability is $1x10^{-15}$ m^2, parameters used in [5]. Crustal density is 3000 kg/m^3, mantle density is 3500 kg/m^3, Young's modulus 100 GPa and Poisson's ratio 0.25.

Results

The gravitational loading alone leads to a 55 km downward displacement of the whole plate. This is due to the numerical set-up that uses elastic springs at the base of the crust to simulate the fluid mantle. This has no effect on the stress field, because we get a zero stress value at far distance from the volcano or axis of symmetry. Subtracting this initial displacement after volcano emplacement, we find a bulge surrounding the volcano and positive extensional stresses sufficient to fracture the plate.

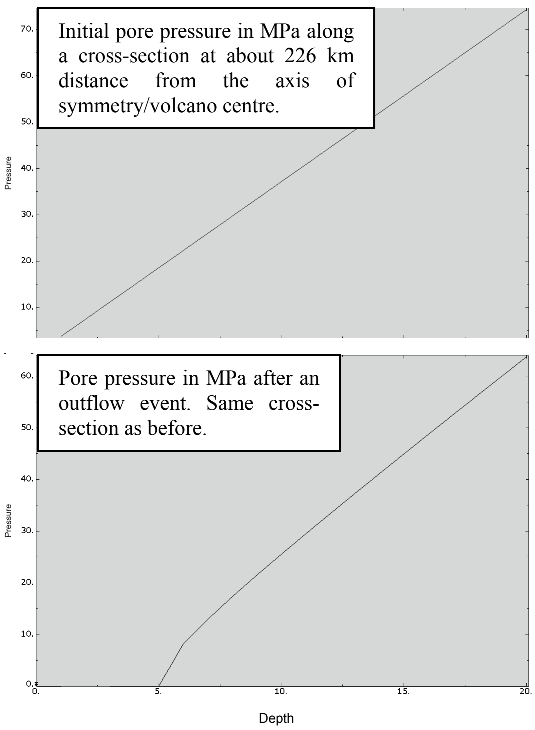

Figure 3: Vertical section of pore pressure in the aquifer below 1 km of frozen ground up to a depth of 20 km at the beginning (top), and after the outflow event (bottom).

Figure 3 shows the evolution of pore pressure with depth at about 226 km distance from the axis of symmetry where the fracture is implemented. In this model we find an outflow volume of 565 km^3.

Outlook

Further works include an investigation of the effects of used parameters and the implementation of dashpots at the base of the plate to simulate viscous response of the mantle due to short-time lava unit emplacement and outflow event and inviscid response due to long-time volcano loading.

References

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