A MODEL OF PORE-FLUID FLOW APPLIED TO THE FORMATION OF OUTFLOW CHANNELS IN THE NORTH-EASTERN HELLAS REGION ON MARS. S. Musiol, B. Cailleau and G. Neukum, Dept. of Planetary Sciences and Remote Sensing, Institute of Geosciences, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany (stefanie.musiol@fu-berlin.de)

Introduction: The release of water from a confined aquifer proposed by [1] could be an effective mechanism to form outflow channels on Mars. However, water breakout needs a trigger to overcome the lithostatic pressure. We want to test the hypothesis that a volcanic load initialises a stress field capable of mobilising pore fluid and fracturing the lithosphere.

Study Area: Unlike the Chryse region where a direct spatial connection of volcanoes and outflow channels cannot be observed, the volcanoes Tyrrhena and Hadriaca Patera in the north-eastern Hellas region are well correlated with the outflow channels Dao, Niger and Harmakhis Valles (see fig. 1), which follow the local gradient from the southern highlands down to the Hellas basin. We choose this area because it has been investigated for a long time [2,3,4,5] and with different methods, among them gravimetry [6] and magnetometry [7]. Together with detailed geological mapping [8,9,10] and age determination [11,12] this provides an indication of the parameters for modelling.

Method: For our calculations we use the finite-elements software ABAQUS, version 6.7-EF. A coupled pore-fluid flow and stress analysis is conducted in a 2D axisymmetric model representing the Martian crust with the volcano Hadriaca Patera as a load in the centre. The model geometry is an elastic plate 1000 km long with an underlying mantle modelled as elastic foundation (see fig. 1, white box). The elastic thickness of 20 km is adapted from the values for Hellas south and west rim at the time of formation as given by [13]. A fixed boundary is set at the far end of the model which cannot move in the vertical and horizontal directions.

Elements used are quadratic, 6-node modified axisymmetric stress/displacement and pore pressure elements (CAX6M and CAX6MP) for the impermeable and permeable crust, respectively. The element shape is triangular.

In a first step, consisting of a soil-consolidation analysis, the volcano growth and subsequent plate flexure is simulated. The volcanic load is composed of the observed topography and the hidden part filling the moat of the flexed elastic plate. The topography is entered as pressure on the surface. The chosen maximum dimensions of the volcano are 150 km radius and 1 km height. The hidden part is unknown at the beginning of the numerical simulation and is entered as Winkler foundation (e.g. [14]). From crater counts [12] we know that the oldest activity at Hadriaca Patera occurred 3.9 Ga ago. The Ausonia Cavus depression (see fig. 1) has a maximum age of 3.7 Ga [11]. Thus we can assume a 200 Ma period of volcano-growth and pressurisation of the aquifer.

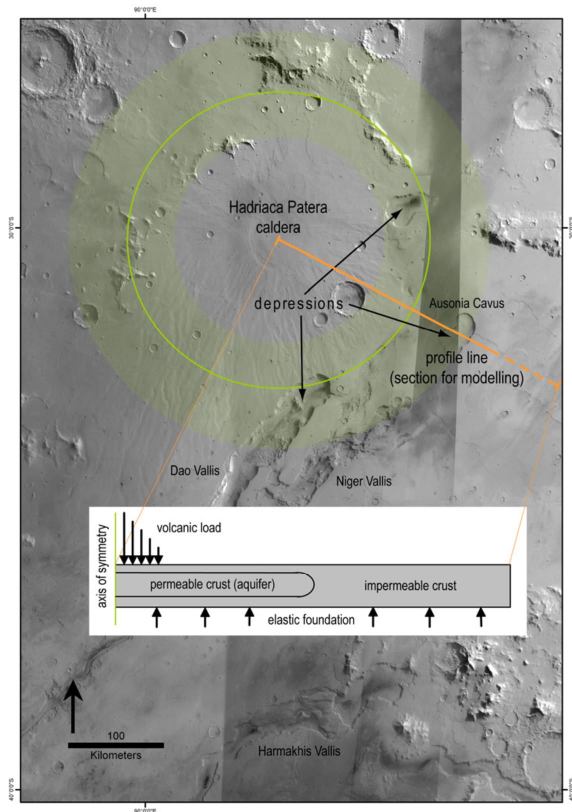

Figure 1: High Resolution Stereo Camera (HRSC) mosaic of the study area (ESA/DLR/FU Berlin) with superimposed example section and corresponding model geometry. The green circle corresponds to the modelled volcano circumference. Note that the depressions are all situated in a concentric pattern around Hadriaca Patera (in light green).

After that, a second soil-consolidation step with an arbitrary duration of 100 years is inserted during which the amount of water flowing out of the depressions is studied. We assume that the depressions (see fig. 1), being source regions for the channels, resulted from fractures in the crust and were subsequently filled by water from the pressurised aquifer beneath. Therefore we simulate them as a zero pore pressure boundary condition (in this example at the location of Ausonia Cavus at a radial distance of 200-230 km from the volcano-centre).

The following table summarises the parameters used in the model described above.

elastic thickness of the crust	20 km
Young's modulus	1×10^{11} Pa
Poisson's ratio	0.25
horizontal extent of aquifer	600 km
vertical extent of aquifer	15 km
crustal thickness above aquifer	1 km
density of crust	3000 kg/m³
density of mantle	3500 kg/m³
density of volcano	2400 kg/m³
hydraulic conductivity	3.7×10^{-6} m/s
porosity	10 %

Preliminary results: With our modelling we have two main aims: first to derive the stress field and location of possible ruptures and second to investigate the maximum possible outflow from the aquifer for the observed depression geometry.

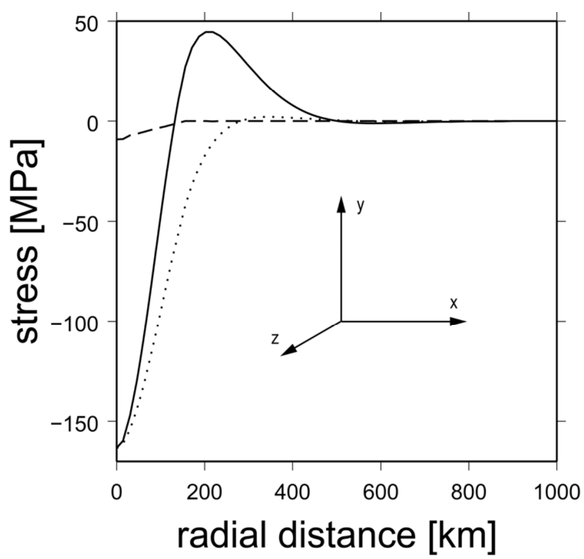

Figure 2: Stresses resulting from elastic flexure of the lithosphere after 200 Ma of volcano growth. Radial distance is measured from the volcano-centre. Continuous line: radial stress (along x-axis), dashed line: vertical stress (along y-axis), dotted line: hoop stress (along z-axis). Positive stress denotes region of extension, negative stress denotes region of compression.

For the model introduced here we get a maximum pore pressure of 1.2×10^5 Pa due to aquifer compaction after 200 Ma of volcano growth. The vertical downward displacement of the crust due to volcanic load has a maximum value of 1.7 km. This value is found directly below the volcano-centre and corresponds to maximum compressive stresses (see fig. 2). The maximum upward displacement of 26 m is observed at a bulge surrounding the base of the volcano in a radial distance between 400 and 450 km from the volcano-centre. Here the stresses become mostly tensile and may lead to rupture of the crust (see fig. 2). For the fracture simulation in the second step (see fig. 3) we get a total volume of 14 km³ of water flowing out of the aquifer in 100 years. Of course this is far too little to explain the observed erosion structures, so further models should be investigated.

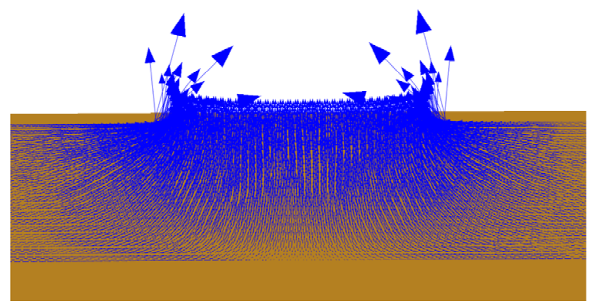

Figure 3: Illustration of simulated volumetric flow rate (effective velocity) of the pore fluid at the location of Ausonia Cavus 9.5 days after initiation of the zero pore pressure boundary condition. The arrows appear at the integration points and show the magnitude and direction of the flow.

Future work: The introduced example is one of the models we have made to understand the behaviour of the poroelastic Martian crust under loading. Our plan for the future is to study the effect of varying properties and geometry of the poroelastic plate and aquifer on the simulation.

By examining the stresses using fracture criteria we can predict probability and location of crustal ruptures. Moreover we want to compare the outflow volumes with missing rock volumes of the depressions we calculated before, using Digital Terrain Models derived from HRSC images.

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